ASSESSING THE CAUSES OF LOW FLOWS IN THE LINGONI RIVER, MPOSA AREA, MACHINGA DISTRICT

MSc. (GEOGRAPHY AND EARTH SCIENCES) THESIS

By

DANIEL HUSSEIN

B.Ed Honours (Islamic University in Uganda)

Submitted in the Department of Geography and Earth Sciences, Faculty of Science, in fulfillment of the requirements for the Degree of Master of Science (Geography)

UNIVERSITY OF MALAWI

CHANCELLOR COLLEGE

MAY, 2013

DECLARATION

I, the undersigned, hereby declare that this dissertation is my own original work which has not been submitted to any other institution for a similar purpose. Where other people's works have been used, acknowledgments have been made.

DANIEL FIVE NAKAPU HUSSEIN

Full Legal Name

____

Signature

____

Date

CERTIFICATE OF APPROVAL

The undersigned, certify that this thesis represents the student's own work and effort and has been submitted with our approval.

Signatures:

____ _____________________

Geoffrey Chavula, PhD (Senior Lecturer) Date

Main Supervisor

____ _____________________

James Chimphamba, MSc (Senior Lecturer) Date

Supervisor

____ _____________________

Cosmo S. Ngongondo, PhD (Associate Professor) Date

Supervisor

DEDICATION

This thesis is dedicated to my parents, Mr. Daniel Huwala Madi Hussein and Mrs. Annie Kazembe Hussein. Because of your love and support, I have advanced this far with my education. I also dedicate this thesis to my wife Chrissie, and my two daughters Wema and Waqeera for their patience. During the years of this research work, I gave them little attention as I worked under pressure in order to complete the work within the required time frame.

ACKNOWLEDGEMENTS

First of all, sincere thanks go to the Almighty God for making this thesis a success. My particular gratitude goes to my supervisory team: Dr. G. Chavula, Mr. J. Chimphamba, and Dr. C. Ngongondo for wisely guiding me throughout the work. Indeed, this project would not have been possible without their help. I also feel great pleasure to express my special gratitude to Dr. M.A. Makumanya (Uganda) for his invaluable guidance and insightful comments from which I benefited much. Without his professional assistance the task would have been very difficult. I also pay tribute to Messrs. G.B. Ndengu and T.Tandwe for helping me with statistical concepts and providing me with literature, all lecturers in the Department of Geography and Earth Sciences, Chancellor College, for their encouragement, Mrs. M. Chirwa, the Departmental Secretary for all the communications and Mr. J. Gwaligwali for producing the maps.

I would also like to express my deepest gratitude and appreciation to Messrs J. Chitete and F. Mpherembe, Irrigation Officers at Zomba Residential Training Centre, a Mr. Boyce of National Meteorological Services for the rainfall data, and Mr. A. Salubeni of the National Herbarium, Zomba for all their technical support rendered to me during my field work, Mr. L. Chiwere, for assisting me in carrying out the hard work of primary data collection successfully, and Mr. A. Makwinja, Machinga District Water Officer for his enlightening ideas. I sincerely recognize rice farmers' hospitality during my frequent visits to the Lingoni Rice Irrigation Scheme and their cooperation and patience to answer my long and tiresome research questions. I have deep appreciation to Group Village Headman Mbando and Mr. J. Labana, Lingoni Irrigation Committee Treasurer for their useful contributions in providing useful information during informal discussions.

Finally, I extend my sincere thanks to the Ministry of Education, Science, and Technology and my dear wife Chrissie for the endless moral and financial support starting from the time of joining of this postgraduate program up to completion. I also wish to thank the Humanitarian Development Association (HDA) for the scholarship.

ABBREVIATIONS

AWMS	Agricultural Water Management Systems
BLADD	Blantyre Agricultural Development Division
ECHAM	European Centre Hamburg Model
FAO	Food and Agricultural Organization
GOM	Government of Malawi
IGPWP	Income Generating Public Works Programme
INZ	Irrigation New Zealand
IPCC	Inter-governmental Policy on Climate Change
IPTRID	International Programme for Technology and Research in Irrigation and Drainage
IWMI	International Water Management Institute
KRADD	Karonga Agricultural Development Division
LADD	Lilongwe Agricultural Development Division
LRIS	Lingoni Rice Irrigation Scheme
MADD	Machinga Agricultural Development Division
MBERU	Molecular Biological and Environmental Research Unit
MDA	Machinga District Assembly
MDG	Millennium Development Goal
MOIWD	Ministry of Irrigation and Water Development
NEAP	National Environmental Action Plan
NEP	National Environmental Programme
NIPDS	National Irrigation Policy and Development Strategy
NSO	National Statistical Office
NWDP	National Water Development Project
NWP	National Water Policy
ODA	Overseas Development Administration
Ppm	parts per million

QREM	Quarterly Review of Environmental Management
RDP	Rural Development Programme
SFF	Small Form Factor
SLADD	Salima Agricultural Development Division
SOER	State of the Environment Report
UNEP	United Nations Environmental Programme
UNCED	United Nations Conference on Environment and Development
UNO	United Nations Organisation
WRMPS	Water Resources Management Policy and Strategies
ZRB	Zambezi River Basin

ABSTRACT

This study investigated the causes of low flows in the Lingoni River, Mposa area in Machinga district. A total of 60 rice farmers, 25 (42%) males and 35 (58%) females were randomly sampled for interviews. In addition, irrigation aspects like water conveyance efficiency, water application efficiency, scheme irrigation efficiency, water distribution efficiency, irrigation time and water use efficiency were also established during the data collection period. Rainfall data for Mposa area was collected from the Department of Meteorological Services in Blantyre and was already processed for errors.

The data was then analysed using both exploratory and inferential statistical tools. Rice farmers' socio-economic activities data was analysed using Microsoft Excel from which charts and tables were generated to illustrate trends in water resources availability, use and management. Irrigation efficiencies were analysed using Paleontological Statistical Package (PAST) software while vegetation species diversity were analysed using Ecosim 7.0. The non-parametric Mann-Kendall statistical test was used for the analysis of rainfall data.

The study found out that some water resources management practices being applied in the rice scheme were affecting water flows in Lingoni River. Such practices included water application duration and irrigation scheduling. In addition, the overall general scheme or project efficiency was established to be 21%, a figure that was below the 50% efficiency established by the Malawi Government. Further than this, the Sen.'s slope estimator on long term rainfall trend in Lingoni catchment showed a negative decline of -1.610 mm/ per year.

Considering the huge volume of water in the Lingoni River, such a figure is likely to have a significant impact on water flows. It is hence, recommended that all water resources planning activities in the catchment should consider proper utilisation of the river banks and also variations and trends in rainfall pattern. The introduction of water demand management measures may assist people in adjusting to the projected water stress.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE: INTRODUCTION

1.0. Background to the study

River basin analysis provides a framework for water and ecosystem management, currently the best option for the conservation and management of natural resources (Barkhordari, 2003). For sometime, Malawi has been experiencing increased depletion and degradation of the water resources mainly due to pressure caused by droughts, the ever increasing population and water abstractions for water supply and irrigation agriculture (GOM, 1998). Thus, for some years there has been an increase in water resources degradation in many river catchments, including the Lingoni catchment, a sub-catchment of the Lake Chilwa Basin. Low peak flows and reduced base flows, especially during the dry season (July to November) are some of the manifestations of hydrological changes associated with water resources depletion in catchment areas (Barkhordari, 2003). Reductions in flows in rivers may be attributed to factors such as land use and land cover change or climate change and variability (GOM, 1998).

Most of the land under irrigated agriculture in Malawi is located along river banks (GOM, 1998). This implies that the catchments of some of these streams are under intensive cultivation, often without consideration to land and water conservation measures. Research has shown that smallholder irrigation development in the country has quadrupled over the past four decades in terms of land area brought under irrigation (GOM, 2000). This means that water abstraction has increased by approximately the same magnitude. Therefore, similar trends should be expected in the case of irrigation on estates and commercial farms for which data was not available.

According to The World Bank (2010), Malawi's irrigation development can be divided into four categories. The first and largest category is the private-sector estates developed on public land largely with private capital and expertise, such as growing sugar cane. The second is private estates on freehold or leasehold land, producing mainly tea, coffee, macadamia and tobacco. The third is government-owned settlement schemes on public land on which rice is the principal crop grown and the fourth category is "self-help" schemes on customary land, generally producing rice and vegetables.

Irrigated agricultural production is the largest user of fresh water resources in many river basins around the world, and in many places, these resources are being overused (Lamm, 2002; Watts, 2000). Irrigation water consumption varies considerably from year to year, however, depending upon water availability, rainfall and other climatic conditions. Irrigation presently uses about 2.5% of the mean annual natural run-off of the Zambezi River Basin (The World Bank, 2010), of which Malawi is one of the riparian countries.

The Zambezi riparian countries have major plans to continue to develop their irrigation sectors (The World Bank, 2010). In the short term, the development of identified irrigation projects could raise the use of run-off to 7%. In the long-term, given the existing development plans for high-level of irrigation, abstractions could increase to 25% of the mean annual natural run-off in the basin. However, Stockle (2010) and van der Zaag (2002) note that often water use for irrigation accounts for at least 70% of the total water use in a water resources system.

Therefore, rivers warrant geographical study because of their existence in the physical landscape and their significance for producing fluvial landforms, their importance indirectly in relation to many other geomorphological processes in fluvial landscapes and their significance for human use (Gregory and Walling, 1973). River water in many regions of the world has become so vital to the economic and social systems of humans that maintaining and controlling the flow of it, assuring the usable quality of it, and seeing to an equitable allocation of it have become first-order preoccupations of public authorities. In both developing and developed countries of the regions of the world, millions of people are subsistence users of rivers (King, 2002).

However, as Shams (2011) has rightly said, for millions of people living mostly in the rural areas of the developing regions of our planet, access to a safe, convenient and affordable water supply is still not guaranteed. Considerable effort and resources have been dedicated to the water sector over the last decades and although the situation has improved, progress is still frustratingly slow. The Joint Monitoring Programme of the UNO estimates that in 2015, even if the MDG 7 to "*reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015*" has been achieved, there will still be an estimated 672 million people waiting for improvements (WHO and UNICEF, 2010 in Shams 2011).

In the early 1990s, the African Development Bank predicted that by 2000 Malawi would experience absolute water scarcity and that by 2025 the country will be living beyond its water barrier (African Development Bank, 1993). By 2025, based on data on renewable supplies and demographics, it is envisaged that Malawi and South Africa will face water scarcity (availability of 1,000 cubic metres of freshwater/person/year or less) and Lesotho, Mauritius, Tanzania and Zimbabwe will be water stressed (availability of 1.000-1.700 cubic metres of freshwater/person/year or less), (Mafuta, 2003).

Ohlsson (1995 in Mulwafu 2002), also predicted that along with South Africa, Malawi would face absolute water scarcity in 2025. Although Malawi has not yet experienced absolute water scarcity or lived beyond its water barrier, the prospect of either happening in future is real (Mulwafu, 2000). The Millennium development Goals set a 75% target in safe water access by 2015, but Malawi is currently at 74.2% (Mpaka, 2009).

Svendsen and Rosegrant (1994, in Wolff and Hubner 1999) state that irrigation, especially of rice, will be subject to increasing pressure in order to reduce its consumption, release supplies for competing uses and pay the economic scarcity cost for water, rather than the current highly subsidized prices. Moreover the world is facing severe and growing challenges in maintaining water quality and meeting the rapidly growing demands for water resources (Amin, Rowshon and Masumoto, 2006).

A study in the USA on water management for rice indicates that water use for the crop is considerably greater than for other agricultural crops (Teare and Peet, 1983). Rice needs permanently flooded conditions of water of between 450-700 mm per growing period of 130 days or four months for optimal growth (Singh 2005; FAO, 2001). Hence, timely prediction of available water resources along with proper allocation and distribution is an essential prerequisite for the successful operation and management of a rice irrigation system (Amin *et al*, 2006).

Hammett (1990), determined a statistically significant decline in annual mean discharge for the Peace River (Canada) at three gauging stations of Bartow, Zolfo Springs, and the Arcadia from the 1930s to 1984. Lewelling, Tihansky and Kindinger (1998), updated this work by including the subsequent 10-year period and found the same declining trend from the 1930s to 1994.

Previous studies attribute this flow decline primarily to anthropogenic factors, mainly through loss of base flow contribution due to groundwater withdrawals for irrigation (Hammett, 1990; Lewelling *et al*, 1998).

While there is little doubt that anthropogenic factors have contributed to flow reductions, the role of long-term, multi-decadal variation in rainfall towards stream flow changes has received little attention until very recently (Basso and Schultz, 2003). However, it is only during the past 30 years that impact of climate change on water resources has received much attention globally (Mbano and Ngongondo, 2007). With global warming, rainfall in many parts of the world has been either increasing or decreasing. But for sub Saharan Africa, many general circulation models show a decreasing trend in rainfall amounts (Hulme, 1992).

Since the beginning of the Industrial Revolution in 1750, global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased markedly as a consequence of human activities (IPCC, 2007a). That increase in green-house gases brings about warming of the earth's temperature, leading to a change in global climate. The IPCC has stated that mean surface temperatures may rise from 0.3–0.6 ^{0}C per decade in the 21st century (IPCC, 2001 in Wang, McGrath, Semmler, Sweeney and Nolan 2006) as a result of anthropogenic influences. This is currently supported by several evidences, which the IPCC (2001), developed under the form of different indicators. The table below displays observed changes attributable to human actions for different evidence indicators.

Table 1: IPCC climate change evidence indicators

Indicator	**Observed changes**
Atmospheric concentration of CO_2	280 parts per million for the period 1.000-1.750 to 368 parts per million in year 2000
Global mean surface temperature	Increased by 0.6+0.2 ^{0}C over the 20th Century
El Nino events	Became more frequent, persistent and intense during the last twenty to thirty years compared to the previous 100 years

Source: Adapted from IPCC (2001, in Lorenzo, 2007)

GOM (2000) asserts that data from several stations indicate that for the past 40 years, fluctuations in rainfall, temperature, sunshine, evapotranspiration, and other parameters have been a common phenomenon in the Lake Chilwa area where Lingoni River is located. This report further states that it is not clear whether climate is actually changing significantly, although rainfall data from several weather stations show a slightly declining trend. Similarly, it is also not clear, how long this trend will continue.

Rainfall is a critical water resources quantity indicator whose variations and trends may indicate the degree of the response of water resources to climate variation and change (Ngongondo, 2003). Ngongondo (2003) analyzed long-term rainfall variability, trend and water availability in Mulunguzi catchment and noted that long term rainfall variability and trend in Mulunguzi catchment area suggested 15% decline between 1953/54 and 1997/98.

In view of the above observations, the present study foregrounds the importance of assessing the water management practices in the Lingoni Rice Irrigation Scheme and climate change and variability in the Lingoni catchment. This is because Lingoni River provides for a number of uses, both within the catchment and in the surrounding areas. The river supplies significant volumes of domestic water to communities living in the basin. River water is also important for the survival of riverine plants such as reeds that stabilize the riverbanks. People within the river basin use these reeds for making different types of products such as mats and baskets used in homes and for sale. Lingoni River basin provides good grazing environment for both livestock and wild animals. This river is therefore of great importance for the communities in Mposa area.

1.1. Problem statement

The water resources of Machinga district exist in form of groundwater and surface water (GOM, 2004). However, this report states that over the past twenty years, a combination of decreasing rainfall reliability, land resources degradation and human activities in the Lingoni catchment area has been observed to be having an adverse effect on the quantity and quality of water resources of Machinga district. It is argued that the Lingoni river which used to be perennial in the past now runs dry during the period from August to October every year since 2005 (GOM, 2004).

The river only shows peak flows during the wet season, from November to March, with flows decreasing over the summer period. In addition, the sediment load of the river has increased tremendously making water turbid and unfit for human consumption, and also aggravating siltation of the channel. As a result of siltation, the capacity of the river has been drastically reduced, rendering the river banks vulnerable to flooding.

In the light of the above, it is absolutely necessary to investigate whether the reduced flows observed downstream of Lingoni Rice Irrigation Scheme are a direct evidence of the increased abstraction of water from Lingoni River to meet the ever growing demand for crop water requirements at the irrigation scheme or a direct result of climate change on the hydrological regime of the catchment.

1.2. Study objectives

The main objective of this study was to investigate the main causes of low flows observed in the Lingoni River, downstream of the irrigation scheme in Mposa area.

The specific objectives were as follows:

1. to assess the existing water resources management practices in the Lingoni Rice Irrigation Scheme,
2. to assess the impact of climate change on the hydrological regime of the Lingoni catchment.

1.3. Justification for the study

Freshwater from rivers is vital for irrigation, manufacturing, transportation and fishing, in addition to the provision of resources that are used for construction materials, potable and washing water, crafts and grazing for animals, boundaries, flotation of timber, recreation and power generation (King, 2002; Miller, 1994). However, with the ever-increasing population, urbanization, agricultural and industrial development, the demand for water shall also increase. Where the populations will more than double over the next 50 years, economic and social development will place overwhelming pressure on water resources (Bruwer and Ashton, 1989 in Savenije 2002). Moreover, for many years, Malawi has been facing severe water and food shortage due to lack of adequate rainfall.

Therefore, a strategy to cope with the weather problem should be based on multidimensional considerations including the promotion of conservation-based farming systems, introduction of effective land use plan and expansion of irrigated farming (Mulat, 1998, in Dinku 2004). Rao (2002) asserts that the development of agriculture is a key factor and, hence, irrigation is indispensable to improve the agrarian economy. According to Addis (1991, in Dinku 2004), smallholder farmers, if assisted properly, can be the engine of growth that provides the surplus needed for economic development of the nation.

On the other hand, Bullock (1998, in van der Zaag 2002) observed that the environment is a legitimate water user. This is not merely a nice gesture to animal and plant life. It is also simply a survival strategy for human beings because water is the basis of life. Therefore, this study is very important since it will assist smallholder farmers in terms of wise and sustainable use of river water for irrigated agriculture but at the same time maintaining the environmental flows in the river systems in Machinga district.

1.4. Organisation of the thesis

This thesis contains five chapters. The present chapter mainly gives background information to the study, problem statement, objectives and justification of the research. Presented in Chapter 2 is the literature review. Chapter 3 analyses the study area and methods applied to examine the problem while chapter 4 presents results and discussions. The conclusion, recommendations, and areas for further research are given in chapter 5.

CHAPTER TWO: LITERATURE REVIEW

2.0. Introduction

Presented in this chapter is a review of the available literature on issues pertinent to the study, particularly an assessment of the river basin, and rice irrigation in Malawi. The effects of irrigation and climate change on water resources are also discussed.

2.1. River basin analysis and management

A river basin is an area of land surface drained by a river and its tributaries that contributes towards run-off and spring water flows into the sea at a single mouth, estuary or delta (Waugh, 1990; Mazumder, 1983). It comprises of one or more catchments. Therefore, the river basin is a ridge of highland beyond which any precipitation will drain into adjacent basins.

The river basin is an open system (Waugh, 1990), into which and from which energy and matter flow, and it forms part of the hydrological cycle. As an open system, it has characteristics that include inputs in the form of precipitation (rain and snow), outputs where the water is lost to the system either by the river carrying it into the sea or through evapotranspiration and storage, either in lakes or in the soil or passes through a series of transfers like infiltration, percolation, and throughflow.

River basin analysis involves the understanding of river systems and their landscape operations within a given watershed (Shaw, 1985). The physical approach to basin analysis also involves understanding the effects of changes in specific hydroclimatic elements on streamflow (Mather, 1978). This is because river systems have profound effects on various processes taking place in the catchment. Therefore, river basins need scientific analysis because of their role in eroding and transporting sediments (Gregory and Walling, 1973).

River basin analysis concentrates on individual drainage basins and is based on the available information on riverbeds, land use, water quality, water quantity and river biota (Heikkinen, Feyen and Barrow, 2005). River basin analysis lays the foundation for developing a systematic approach in river status assessment, as well as for planning and implementing water resources management control methods. Therefore, river basin analysis can be used to form an overall view of the ecological state in the drainage basin and in riverbeds, the factors affecting the ecological state and the possible need for water resources availability (Heikkinen *et al*, 2005).

River basin management consists of all activities aimed at better functioning of the system, particularly water and land systems (Savenije, 1999). This implies that in most cases land and water resources are managed conjunctively in river basins. Mostert (1998 in Savenije 1999), distinguishes at least six areas of river basin management which include natural science, engineering, social optimization, law, decision-making and ethics. All these perspectives are important for river basin management.

Withdrawal of water for irrigation leads to decreased inflow to the lake, increased salt and other pollutant discharge to the river system, and an increase in pollutant concentration in downstream river reaches (McKinney, 1999). Therefore, activities in communities within river catchments that withdraw water like irrigation need to be better understood by resource managers for proper management of the resource (van der Zaag, 2002).

The analysis of existing data indicates that the volume of water used within the Lingoni catchment is not currently known and hence, the total volume of domestic water used within the catchment is also unknown (Wigginton and Raine, 1999). This is because there are no mechanisms for monitoring stream flow in this river since at present, the only fully operational gauging station in Machinga district is on Shire River at Liwonde barrage (GOM, 2004).

However, starting from 2005, competition between water users in the Lingoni basin has increased tremendously. The competition is between the rice irrigators, and downstream users. The great concern was due when Lingoni River dried up downstream of the rice irrigation scheme in the dry season of 2005 resulting into zero flows (Labana, *Personal Communication*). Since then, the period of flow of the river through each consecutive year has been shrinking as the problem was continually ignored and the situation was getting worse. This zero flows downstream implied no water for domestic use and riparian vegetation and this led to severe degradation of Lingoni River (GOM, 2008).

Many possible causes for the phenomenon were narrated and that, various studies looking at water resources availability in river catchments were conducted in the area (Ngongondo, 2003; Chavula, 1999). However, of great interest in this study are the water resources management practices in the irrigation scheme and climate change and variability.

2.1.1. Lingoni river water catchment availability and irrigation requirements

River water plays a vital role in the field of irrigation. Therefore, understanding the quantity of water in a catchment at different times of the year prevents its destruction from human activities such as unplanned water abstraction for irrigation (King, 2000). Water resources engineers are primarily concerned with catchment yields and usually study hydrometric records on a monthly basis (Savenije, 2002).

Machinga district has two main catchment areas namely Liwonde and Malosa Forest Reserves. These Forest Reserves protect perennial streams and rivers like Namikomya, Likwenu, Chagwa, Naminga and Lingoni. The streams and the rivers form the back bone of water gravity fed schemes. The catchment area of Lingoni River consists of physical features which include the mountainous and hilly zones of Liwonde Forest Reserve, Ntanja Escarpment, and Lungwe Hills in Nyambi area and the Lake Chilwa Plain. Besides, the vegetation type found in the area comprises of evergreen forest *Brachystegia* woodlands, which occupy the highest area of Liwonde Forest cover located to the north of Mposa.

However, both catchment areas are under threats for various reasons which encompass encroachment for cultivation and settlement; uncontrolled bush fires, wanton cutting down of trees which is contributed by activities such as curios carvings, pit sawing, firewood collection and charcoal production (MDA, 2008). There has also been massive deforestation in the area by charcoal burners and illegal cultivators on *Colophospermum mopane (tsanya)* and *Eucalyptus* trees (Sabola, 2002; GOM, 2004; Bloomfield, 1965).

An estimated 40.067 people in Mposa and Chamba Traditional Authorities depend on the Lingoni catchment for their water needs (GOM, 2008). With proper maintenance, Lingoni River can provide water that is relatively free from contamination, soft, clear and odourless; this water can be used for bathing, cooking, washing and gardening. It is very important that all those using water from the catchment understand all the potential dangers of disturbing the catchment. Unfortunately, in this catchment area, there are no government agencies overseeing the safety of the Lingoni river system (Labana, *Personal Communication*).

Therefore, before an irrigation scheme is established, it is important to quantify the amount of water in the river source to avoid its degradation or depletion (Scheltema, 2002). This is because no single factor is of great importance to the successful operation of an irrigation project than the evaluation of the adequacy of the water supply (FAO and IPTRID, 2002).

Suitability of a water source for irrigation depends on several factors such as legal constraints, quality of water (the amount and identity of suspended solids and dissolved materials in the water), and the ability of the water source to supply the total irrigation requirement and seasonally varying requirements year after year. It is also important to determine the amount of water required when extending an existing scheme, changing the cropping pattern, designing new irrigation scheme, adding a second or third irrigation season, and switching from a crop of low water demand to a crop of higher water demand.

2.1.2. River water budget concept

A water budget is an account over some period of time of all moisture gains, losses, and storages for a particular place or area (Mather, 1978). A detailed study of the water budget (Figure 1) provides useful background knowledge for the geomorphologist evaluating catchment response, by indicating the apportionment of precipitation input between runoff, evapotranspiration losses and storage, for a given drainage basin (Edwards and Rodda, 1970). The evaluation of water budget components is critical to the development of irrigated agriculture in any given catchment so as to be sure whether the water available will be enough for the activity.

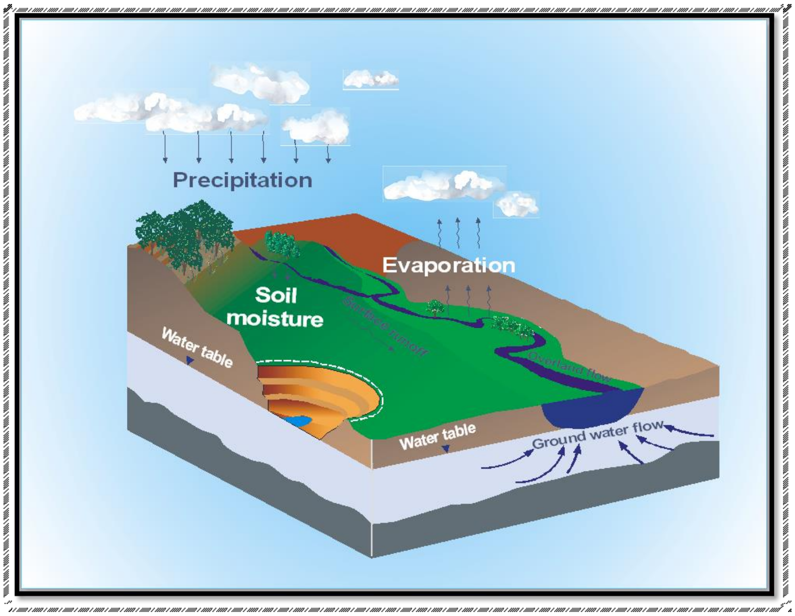

Figure 1: The water budget of a normal catchment area

Source: GEO-SLOPE International Ltd (2012)

According to Savenije (1999), if no water moves across the catchment boundary, the input equals the precipitation (P) while the output comprises the evapotranspiration (E) and the river discharge (Q) at the outlet of the catchment. Hence, a water-budget equation can be given as:

$$(P-E)\,A-Q = \Delta s / \Delta t \quad \text{..equation 1}$$

Where Δs is the change of storage over the time step Δt, and A is the surface area of the catchment upstream of the station where Q has been measured (Savenije, 1999). Storage here refers to both surface water and groundwater as well as to rivers (Savenije, 1999).

The water budget equation can provide a valuable check on the accuracy of measurement of the various river components. It is usually evaluated on an annual basis, for a period beginning and ending with similar conditions of minimum natural storage, so that the storage terms can be largely ignored (Gregory and Walling, 1973). According to Manning (1997), precipitation and runoff are both measured over a period long enough (a year or period of years) that the net change in water storage is essentially zero within the basin.

The water year which runs from 1 October to 30 September has been designated to fulfil these requirements in most instances (Gregory and Walling, 1973). Evaluation on a shorter term basis is more difficult, because changes in storage will have to be monitored or carefully estimated, but this would provide a clearer insight into the relative importance of the various storage volumes.

Ward and Robinson (1990), proposed three theories that have analyzed the role of interception and transpiration on catchment water balance namely: the neutral hypothesis which assumes that interception losses are essentially evaporative and that, since only a certain amount of energy is available in any period of time, this will be used either to evaporate water from within the leaf, that is in transpiration, or to evaporate water from the surface of the leaf, that is interception loss; the negative hypothesis regards interception as a loss of precipitation that would otherwise have been available at the ground surface for direct evaporation, for infiltration through the surface or for overland flow. The third theory, the positive hypothesis, holds that in certain circumstances, the interaction of water loss and gain in vertical and horizontal interception respectively may result in a net gain in a catchment area. From the three hypotheses, Ward and Robinson (1990) observed that each of the cases is dependent on factors including climatology, altitude and geology of the area.

The difference between long-term measurements of precipitation and runoff is estimated to be the quantity of evapotranspiration for that period and to determine catchment runoff characteristics, a comparison should be made between rainfall and runoff (Savenije, 1999). However, precipitation may not be the only input to a basin in an arid or semi-arid region. In addition, groundwater storage may change over time as in California in the USA where inputs also include inflow from canals and surface streams as well (Manning, 1997).

Each drainage basin can be regarded as an individual system receiving quantifiable inputs of precipitation and transforming these via various flows and storages, into quantifiable outputs of evaporation and stream flow. In some cases, leakage from deeper sub-surface water may represent either an additional input or an additional output from the river basin (Ward and Robinson, 1990).

Water resource developments especially along riverbanks should be designed and operated to minimize detrimental effects on the river or, at least, to hold change to an acceptable level (King, 2000). Irrigation, in addition to the direct physical disturbance of the habitat, often produces long range impacts on communities downstream which are not in the immediate sphere of activity (Weeks, Lawson and Harrison, 2003).

River basin hydrological processes rarely operate completely uninfluenced by human activities. It is, therefore important to recognize that human modifications may be made to virtually every component of the system. At present, the most important of these relate to large scale modifications of the channel flow and storage, for instance by means of surface change such as afforestation, deforestation and so on, which affect surface runoff and incidence or magnitude of flooding, the widespread development of irrigation and land drainage and the large scale abstraction of groundwater and surface water for domestic and industrial uses (Ward and Robinson, 1990).

2.1.3. Seasonal variation of river discharge

River discharge is the gravity movement of water in channels which may vary in size from the ones containing the smallest ill-defined trickle to the ones containing the largest rivers given in a unit volume of water flowing in a stream per unit of time (Ward and Robinson, 2003; Manning, 1997). The discharge of a river (Ngongondo, 2003) has three components which are base flow, surface flow and inter flow (Figure 2). Base flow is the groundwater contribution (Ngongondo, 2003). It may be steady and long lasting and suitable for irrigated agriculture and hence a dependable source of water supply.

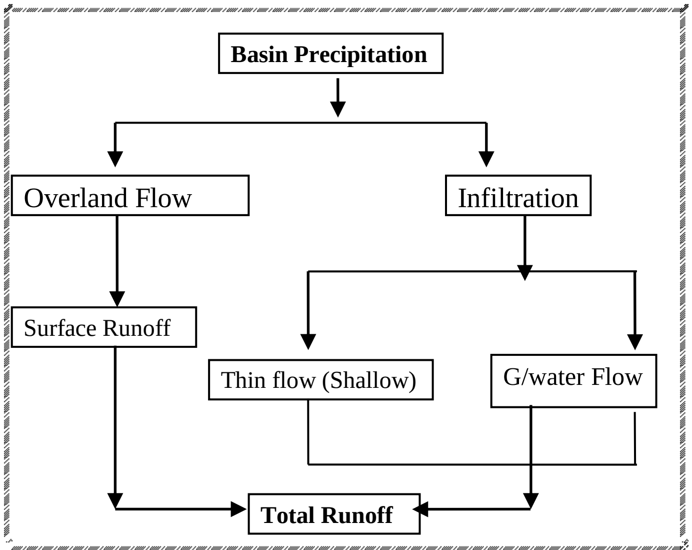

Figure 2: The runoff process in an undisturbed catchment area

Source: Adopted and modified from Ward & Robinson (1990, in Ngongondo 2003)

Surface runoff is short lived. Runoff is the water that does not infiltrate the soil but flows over the soil surface into lakes, streams, wetlands and oceans (GOM, 2004b). It may be defined as part of run off that reaches the drainage basin outlet via overland flow and the stream channels. Inter flow is part of the rainfall that infiltrates into the soil and flows laterally below the ground surface in direct response to the slope of the area.

River discharge may vary from year to year (Scheltema, 2002). According to Ngongondo (2003), Drayton (1981) correctly noted that the Mean Annual Runoff (MAR) of a stream or river does not alone demonstrate its usefulness as a resource, rather, stream flow distribution and its temporal variability are factors that determine the stream's utility. Rivers also exhibit seasonal variations, which affect the water balance and water availability. In studies conducted in thirty-eight catchments in Malawi, Kidd *et al* (1990, in Ngongondo 2003) showed that stream flow and MAR are strongly correlated with rainfall.

Ward and Robinson (1990) stated that precipitation is the principal factor controlling the hydrology of a region; it determines soil moisture, groundwater recharge and stream flow. Other factors include filtration, type of soil and canopy. Ward and Robinson (1990) hence classified the various river regimes as follows, mostly based on seasonality and variability of rainfall:

Simple Regimes: These are rivers whose flow throughout the year varies between high and low flows. This is common in tropical areas where high evaporation rates throughout the year result in high flows during the rainy season and low flows in the dry season. Most rivers in Malawi including Lingoni River fall in this category. The largest flows of this river are recorded in the rainy season while relatively low flows are recorded in the dry season.

Complex 1 Regimes: These rivers are characterized by at least four and sometimes six hydrological phases with low runoff phases coupled with two high runoff phases. Common in European streams, the phases are a result of alternating snowmelt followed by low runoff and then convectional rains or Mediterranean storms followed by low runoff.

Complex 2 Regimes: This regime is typical of most large rivers that flow through several distinct relief and climatic regions. These may in the course receive water of large tributaries that also flow in varied terrain and climate. Snow or glacier melt may also play a big role in this regime. These factors together contribute to the flow characteristics of rivers in this regime. The River Congo, flowing through areas with rainfall typical of two distinct climatic zones is an example. The River Rhine (Netherlands) also falls in this category.

2.1.4. River discharge measurements

According to Gregory and Walling (1973), discharge is the most important parameter of channel flow and its measurement usually involves consideration of both stage and velocity. Units used are those of volume/ time, and values are generally reported in cubic metres per second (m^3/s) or for small catchments litres per second (l/s). Flow measurements in water distribution system and at farm or field inlet are made for efficient water distribution, equitable water distribution among farmers and effective water management (Zaw, 2004).

Flow measurements ensure maintenance of proper water delivery schedules, determination of the amounts of water delivered and estimation and detection of conveyance losses. Increased demand on available water resources, increasing cost of irrigation development and conservation of environment, demand that water be used economically and without waste, and that experience shows that this cannot be accomplished without measurements of water flow.

The most commonly used methods of discharge measurement are the velocity area technique, dilution gauging or tracers, volumetric gauging, the slope area technique, weirs and flumes, the rated section, floats and current metres (Shaw, 1983; Gregory and Walling, 1973).

Tracers or dilution gauging are used to compute time taken for a tracer (chemical) to travel through a test section of known length. The method is used where excessive turbulence, high velocities and rocky or shallow sections of a river would make the operation of current metre difficult (Gregory and Walling, 1973). The principle involved is that discharge is calculated from the degree of dilution by the flowing water of an added tracer solution. Gregory and Walling (1973), suggested that the choice of tracer is important, because it should conform to several specific requirements, for example, Sodium Chloride (NaCl) and sodium dichromate ($NaCr_2O_3$) are the two commonly used chemical tracers which satisfy most of these conditions, while radioactive tracers such as Gold 198 (^{198}Au) possess very good detection properties, but may involve a health hazard.

Volumetric gauging involves the collection of the total volume of flow over a given period of time (Discharge = Volume/ Time), it is limited in application and presents several practical problems (Gregory and Walling, (1973). However, the method is very useful in measuring the outflow from a small runoff plot where water can be collected in a large tank. Furthermore, the method involves theoretical estimation rather than direct field measurement. The Manning equation below is used to calculate the mean velocity of a channel reach, and if this value is combined with the average cross sectional area, discharge values are computed (MBERU, 2008).

$$V = \frac{R^{2/3}S^{1/2}}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{equation 2}$$

Where V is the mean velocity, R is the hydraulic mean radius (stream cross sectional area/ wetted perimeter), S represents slope of the channel, and n is the Manning's roughness coefficient.

Another method involves the use of weirs and flumes. Weirs may be classified into sharp-crested or thin plate weirs and broad-crested weirs (Gregory and Walling, 1973). In the former case the weir notch and crest is formed by a sharpened metal plate, whilst in the latter case a thicker construction, usually made of concrete is used. However, Gregory and Walling (1973) noted that the flume differs from a weir in that flow velocity and head are controlled not by the water falling over a crest under the influence of gravity, but by the passage of water through a constricted section where critical velocity is attained. The constricted section or throat is formed by raising the channel floor into a hump, or by contracting the sides, or by a combination of both measures. Zaw (2004) summarised that weir method is the most practical and economical if sufficient head is available, while measuring flumes require small head loss, provide accuracy and little affected by sediment.

Float method requires a straight channel that has a uniform cross-section and is free of surface disturbances. River discharge or flow in open channels like rivers and canals using a float method determines the area that can be irrigated (Scheltema, 2000). The rated section technique enables the principles underlying control structures to be extended to situations where use of a structure would be impractical (Gregory and Waling, 1973). A rated section utilises a natural control to provide a stable relationship between stage and discharge. The control may be the outcrop of a hard rock band across a stream, or more simply a stable channel reach, and bed and bank stabilisation measure may be employed to improve the stability of the control. In addition, water flow measurement can be done by recording the time taken to fill a container of known volume (MOIWD, 2009). In this case discharge is volume divided by time as given by the following equation;

$$Q = V/T \qquad \text{……………………equation 3}$$

Where Q is the river discharge, V is the volume of a container, while T is time taken to fill the container.

The most direct method of obtaining a value of discharge to correspond with a stage measurement is by the velocity-area method in which the flow velocities are measured at selected verticals of known depth across a measured section of the river (Shaw, 1983). Gregory and Walling (1973), also supported the above argument by stating that the velocity-area technique is the most widely used method for spot measurements of discharge.

Discharge is by definition the product of velocity and cross-sectional area of flow and is given by the equation 2.3 as follows;

$$Q\ (m^3/s) = \text{Average velocity } (m/s) * \text{Cross Sectional Area } (m^2) \text{......equation 4}$$

Current meters are used to measure velocity at several depths across the channel. When immersed in moving water the meter's impellers revolve at a speed that is proportional to the water velocity. However, information is lacking on the impact Lingoni rice irrigation scheme might have on the discharge of the river since the river is not gauged. For proper planning and management of such a river system, it is therefore important to have adequate tools to reliably estimate the demand for irrigation water by frequently measuring river discharge (van der Zaag, 2002).

There is the need therefore, to ascertain the impact of this scheme on Lingoni River discharge with regards to irrigation development and its water control infrastructures. This can assist in the planning and construction of appropriate small-scale irrigation rice schemes across the country in order to minimize the effects of river degradation. There is also the need to find out the efficiency of the scheme and its impact on river flow downstream.

2.2. Irrigation water efficiencies

Like all other resources, the management of irrigation water is vitally needed for its conservation and efficient use (Mazumder, 1983). To express which percentage of irrigation water is used efficiently and which percentage is lost, the term irrigation efficiency is used. Irrigation efficiency is more broadly defined than water application efficiency in that irrigation water may have more uses than simply satisfying crop water requirements (Rogers, Hedges and Lehmann, 1997).

Efficiency in the use of water for irrigation consists of various components and takes into account losses during storage, conveyance, and application to irrigation plots (Palacios-Velez, *undated*). In general, irrigation water efficiency is related to the percentage of water delivered to the field that is used beneficially.

Studies indicate that irrigation water efficiencies are important because they assist in evaluating performance of irrigation systems, designing irrigation systems, and facilitating future repair and maintenance work of the irrigation system (FAO, 2001). Since not all water taken from a source (river or well) reaches the root zone of the plants, part of the water is lost during transport through the canals and in the fields and the remaining part is stored in the root zone and eventually used by the plants. Hence, only part of the water is used efficiently, and the rest of it is lost for the crops on the fields that were to be irrigated.

In a world where water is such a precious resource, no one has the right to waste water which other people need; hence efficient use of irrigation water is an obligation of each user. Natural conservationists require efficient water systems that deliver water for its intended use without loss due to leakage, spills, or contamination (Rogers *et al*, 1997). Since irrigation is the largest appropriated water user, irrigation systems also receive merit based on how efficient they are reported to be. With increasing scarcity of good-quality fresh water resources and the growing food demands, the challenges to the irrigation and drainage sector are greater than ever (The Dutch Water Sector, 2005).

This therefore, requires efficient operation, long term cost-effective infrastructure, sound financial management and revenue streams, and workable institutional arrangements, including active roles and representation of the users of public irrigation and drainage services. Adequate control and management of irrigation water requires that methods be available to evaluate irrigation practices from the time water leaves the point until it is utilized by plants.

Hence, this requires efficient operation, long term cost-effective infrastructure, sound financial management and revenue streams, and workable institutional arrangements, including active roles and representation of the users of public irrigation and drainage services. Efficiencies also vary in time and with management (Rogers *et al*, 1997). Very "efficient" systems by some definitions can be very poor performers by other definitions, for example, if distribution uniformity and delivery amount are inadequate to fulfill crop need. Because the benefits of applying water are not immediately attained, definitions containing a measure of beneficial use are usually applied over a longer timeframe than for individual events.

2.2.1. Scheme irrigation efficiency (e)

The scheme irrigation efficiency in percentage is that part of the water pumped or diverted through the scheme inlet which is used effectively by the plants. The scheme irrigation efficiency can be sub-divided into:

- the conveyance efficiency (Ec) which represents the efficiency of water transport in canals, and
- the field application efficiency (Ea) which represents the efficiency of water application in the field.

2.2.1.1. Conveyance efficiency (ec)

The earliest irrigation efficiency concept for evaluating water losses was water-conveyance efficiency. This is the percentage of source water that reaches the field (Rogers *et al*, 1997). Pelacios-Velez, (*undated*) documents that conveyance efficiency is the ratio between the volume of water delivered to irrigation plots and the volume diverted from the supply source. Conveyance efficiency is generally a concern for irrigation districts that supply a group of farmers through a system of canals and open ditches (Rogers *et al*, 1997). The conveyance efficiency mainly depends on the length of the canals, the soil type, or permeability of the canal banks and the condition of the canals. In most cases losses of water occur during transport from the river to the scheme, during distribution of water in the scheme, and on the farmer's plot (Scheltema, 2002).

Scheltema (2002), further reports that on average, conveyance and distribution losses amount to 20% and of every 100 l/sec at the intake, only 80 l/sec will reach the farmer' field. The 20% loss is due to seepage and leakage in the canals. Furthermore, in lined or very short canals of less than one kilometre, these losses may be lower and in very long canals of over three kilometres or canals in sandy soils they may be higher. Similarly, in large irrigation schemes more water is lost than in small schemes, due to a longer canal system. From canals in sandy soils more water is lost than from canals in heavy clay soils. Again, when canals are lined with bricks, plastic or concrete, only very little water is lost but if canals are badly maintained, bund breaks are not repaired properly, and rats dig holes, a lot of water is lost.

Table 2 provides some indicative values of the conveyance efficiency, considering the length of the canals and the soil type in which the canals are dug. The level of maintenance is not taken into consideration: bad maintenance may lower the values by as much as 50%.

Table 2: Indicative values of the (ec)

	Earthen canals			**Lined canals**
Soil type	**Sand**	**Loam**	**Clay**	
Canal length				
Long (>2000m)	60%	70%	80%	90%
Medium (200-2000m)	70%	75%	85%	95%
Short (<200m)	80%	85%	90%	95%

Source: (FAO, 2008)

2.2.1.2. Water application efficiency (ea)

This is also known as field application efficiency. Having conveyed the available water to the farm through diversions and conveyance structures, the need is apparent to apply the water efficiently. Often, considerably more water is applied to a rice scheme since the crop requires a lot of water. The water or field application efficiency (Ea) mainly depends on the irrigation method and the level of farmer discipline (FAO, 2008). Water application efficiency gives a general sense of how well an irrigation system performs and its primary task of getting water to the plant roots (Rogers *et al*, 1997).

However, it is possible to have a high Ea but have the irrigation water so poorly distributed that crop stress exists in areas of the field. It is also possible to have nearly 100% Ea but have crop failure if the soil profile is not filled sufficiently to meet crop water requirements. It is easy to manipulate water delivered to the field (Wf) so that Ea can be nearly 100%. Any irrigation system from the worst to the best can be operated in a fashion to achieve nearly 100% Ea if Wf is sufficiently low. Increasing Ea in this manner totally ignores the need for irrigation uniformity.

For Ea to have practical meaning, water available for use by the crop (Wc) needs to be sufficient to avoid undesirable water stress. Water application efficiency sometimes is incorrectly used to refer to the amount of water delivered to the surface of the soil in an irrigated field by a sprinkler system. Water losses can occur after reaching the soil surface, leading to overestimation of the application efficiency.

Ea is also often confused with water storage efficiency (Es), which is the fraction of an irrigation amount stored in the crop root zone. The use of this term is discouraged because of the difficulty in determining the crop root zone and because Es can be very low while sufficient water is provided to the crop. Water losses include surface runoff and deep percolation. If a centre pivot is equipped with a properly designed nozzle package and operated using best management practices and irrigation scheduling, these losses can be negligible. However, for many systems, these losses can be large and result in poorly distributed or non-uniform irrigation.

Several studies conducted elsewhere revealed greater variations in field application efficiency. Using the hydromodule system in Usangu rice scheme in Tanzania, it was established that the water application efficiency was 20%, although irrigation officers argued that the figure was underestimated (Machibya, 2003). It is assumed that if the efficiency was around 20% in Usangu, it was difficult to justify where, when and how does the 80% of the water got lost in an irrigation system that was well constructed (Machibya, 2003). However, studies in New Zealand by Lincoln Environmental (LE) on different irrigation methods indicated that the Ea was increasing, decreasing, or average (SFF and INZ Report, 2006).

SFF and INZ Report (2006) further states that research on the centre-pivot farm indicated that application efficiency ranged from 34% to 100% in 1997, with an average of 78%. In 1998, with improved irrigation management, application efficiency rose to 96% on average. On the border-strip farm, application efficiency was 45% on average in 1997, with a range of 31-61%. This decreased to an average of 34% in 1998, mainly due to variable flow rates and irrigation management decisions being based on the effects of water supply restrictions rather than soil and crop requirements, that is irrigating when water was available and keeping soil moistures as high as possible (SFF and INZ, 2006).

The study further stated that on the rotary boom farm, application efficiency was measured in excess of 90% when water was applied to potatoes and wheat. It was assumed soil moisture traces showed that high levels of efficiency were obtained as a result of deficit irrigation due to limited irrigation system capacity. Some loss of yield may have occurred, due to surface runoff, whereby water ends up in the drain and deep percolation to soil layers below the root zone, thereby decreasing water use efficiency (FAO, 2002). Hence, the variation in efficiency illustrates the fact that field application efficiency varies with every irrigation event, depending on how the water is applied and the conditions existing at the time of the irrigation event (SFF and INZ, 2006). Some indicative values of the average field application efficiency (Ea) are given in Table 3. Lack of discipline may lower the values FAO, 2008).

Table 3: Indicative values of the field application efficiency (ea)

Irrigation method	**Field application efficiency**
Surface irrigation (border, furrow, basin)	60%
Sprinkler irrigation	75%
Drip irrigation	90%

Source: (FAO, 2008)

2.2.1.2.1. Irrigation crop water needs or requirement (ET crop)

In order to establish the field water application of the scheme, there is a need to calculate crop water needs or crop evapotranspiration (ETc). It is defined as, "The quantity of water required by a crop in a given period of time for normal growth under field conditions," (The World Bank, 2010). It includes the amount of water needed to meet the loss through evapotranspiration. Usually water requirement for crop is expressed in water depth per unit area. It is the amount of water needed by various crops to grow optimally (Zaw, 2004). A crop grown under optimal conditions means a uniform crop, actively growing, completely shading the ground, free from diseases and favourable soil conditions including fertility and water. Major climatic factors which influence the crop water needs are sunshine, temperature, humidity and wind speed.

Zaw (2004) states that influence of climate on crop water needs is given by the reference crop evapotranspiration (ETo). The ETo is usually expressed in mm/day, mm/month and mm/season and that grass has been taken as the reference crop. Zaw (2004) further observes that there are several methods to determine the ETo. They are experimental using an evaporation pan and theoretical using climatic data like the Blaney-Criddle method. Evaporation pans provide a measurement of the combined effect of temperature, humidity, wind speed and sunshine on the reference crop evapotranspiration. The Blaney-Criddle method is used if no measured data on pan evaporation are available.

2.2.2. Water-use efficiency (WUE)

Wittwer (1975) identified water as the second-most important factor, behind land area, to increasing food production. He argued that a high research priority should be given to improvement in the efficiency of water-use by crops. In addition, Sinclair (1984) defined water-use efficiency (WUE) as a ratio of biomass accumulation, expressed as CO_2 assimilation (A), total crop biomass (B), crop grain yield (G), to water consumed, expressed as transpiration (T), evapotranspiration (ET), or total water input to the system (I). The time-scale for defining WUE can be instantaneous (i), daily (d), or seasonal (s). WUE is written symbolically as a function of these three variables (Mkandawire, 1987 in Kadyampakeni 2004). For example, WUE (B,I,s) refers to water-use efficiency expressed as total crop biomass (B) to total water input into the system (I) for a seasonal observation (s).

WUE calculated on the basis of total biological yield production during both the vegetative and reproductive periods increase under drought from that under well-watered conditions. WUE (calculated on the basis of seed yield and evapotranspiration) increases when drought is imposed during the vegetative period and it decreases when drought is imposed during the reproductive period. The amount of water used by a crop is expressed in hectares-centimeters. WUE is a relative term and is generally used in comparing crops or crop management schemes (Mloza-Banda, 1994 in Kadyampakeni 2004).

The effect of WUE on reproductive yield depends on the timing of growth restrictions and internal stresses relative to the phonological cycle of flower initiation, flowering, and growth. Prolonged flowering (undetermined habit in rice) allows plants to compensate for loss of flowers during a stressful period. However, if stress can be avoided during flowering, the strategy is inferior to determine flowering in which an optimum balance can be achieved between vegetative and reproductive growth for a given availability of water and cycle length (Loomis and Connor, 1992). Experimentally, irrigation water-use efficiency can be determined for each experimental plot based on yields. The grain yield data can be used to compute the irrigation water-use efficiency (IWUE) using the equation derived by Clegg (1996).

IWUE is used to determine WUE under irrigated conditions. The amount of water used is directly related to yield in all crops. As yield increases, total water-use increases because more water is needed for the increased plant growth. Within the limits of available moisture, nutrients, and other variables, as stand densities increase, yields and total water-use also increases. Water-use efficiency may also increase because the soil is permeated with roots so that the maximum amount of moisture that enters the soil is extracted from it and transpired by the crop. The amount of moisture available in the soil affects water-use efficiency. Crop plants use less energy in extracting water from a soil at field capacity than it is close to wilting percentage. This saving is converted into greater yields (Mloza-Banda, 1994 in Kadyampakeni 2004).

This explains in part why an irrigated crop has higher water-use efficiency than a rain-fed crop within limits of available resources. If natural annual precipitation is inadequate for crop production, irrigation becomes essential. The objective of irrigation is to supply the soil with the amount of water required by crop plants to produce optimum yields. Because irrigation is costly per unit of water (compared with natural precipitation), a thorough knowledge of how irrigation water is measured and how it can be applied most effectively for efficient irrigation management is required.

2.2.3. Water distribution efficiency (Ed)

Water distribution efficiency is the percentage of the average application depth delivered to the least-watered part of the field (Rogers *et al*, 1997). Under most conditions, the more uniformly water is distributed, the better will the crop respond. Similarly, uneven distribution has many undesirable characteristics, like drought areas appear in a field which is not irrigated uniformly unless excess water is applied, which in turn results in a waste of water. The water distribution efficiency indicates the degree of uniformity in the amount of the water infiltrated into the soil.

2.3. Irrigation development and rice schemes in Malawi

Irrigation is the controlled artificial application of water to a particular area of land, by means of rivers, channels, or pipes for the purpose of adding water to the soil to supply the moisture essential to sustain plant growth (Kadyampakeni, 2004). Irrigation is basically an attempt by humans to locally alter the hydrologic cycle and to promote increased agricultural productive (Cuenca, 1989). The main objective of irrigation is to provide crops with sufficient water to prevent stress that may cause yield reduction or poor quality to harvest; hence, irrigation is a way of growing a crop in the dry season (Kadyampakeni, 2004).

Irrigation offers a means of increasing agricultural productivity and can ensure a crop even in a drought year. The amount of water required by crops and the timing of irrigation water are governed to a large extent, by prevailing climatic conditions, crops, and stage of growth, soil moisture holding capacity and the extent of root development (Mloza-Banda, 2004 in Kadyampakeni 2004). The major crops grown under irrigation in Malawi are rice, maize, beans, tomatoes, Irish potatoes, vegetables, and sugar cane. These crops are grown under traditional irrigation practiced soon after the end of the rainy season to take advantage of the residual moisture in the soil (Kadyampakeni, 2004) and also by using river water.

Irrigation is being promoted in Malawi not only as a way of fostering rural development, but also as a means of reducing rural poverty, malnutrition, diseases and social and economic inequalities between the rural and the urban areas (Magreta, Zingore and Mwagombo 2010). Therefore, irrigated agriculture is gaining importance in Malawi, both in plateau areas and the rift valley floor (Bweya and Kellow-Webb, 1985).

Crop estimates from the Ministry of Agriculture and Food Security indicate that between 1983 and 1996, the total area planted with rice varied from 18.241 hectares in 1991 to 41.223 hectares in 1996, with an average per annum of 26.683 hectares of which 2.117 hectares were under irrigation and 23.564 hectares were rain fed (Kumwenda, 1997 in Drayton 1981). With high growth in population, these figures are likely to have changed. A list of rice irrigation schemes in Malawi is provided in Table 4.

Table 4: summary of gravity fed rice irrigation schemes in Malawi

ADD	RDP	EPA	Name of Scheme	Scheme Area (ha)		Number of Beneficiaries		
				Gross	Irriga ble	M	F	Total
SLADD	Nkhotakota	Nkhunga	Kasitu	55	32	74	39	123
MADD	Balaka	Bazale	Khwisa	110	78	197	103	300
	Machinga	Nsanama	Zumulu	85	72	214	89	303
			Chibwana	183	55	107	259	366
			Domasi	500	470	800	756	1556
			Namasi	19	18	55	28	83
			Lingoni	20	18	55	62	120
		Nayumbu	Mikoko	80	55	237	142	379
			Naming'azi	75	50	147	202	349
		Chikweo	Kamwaza	100	50	257	138	395
	Zomba	Mpokwa	Likangala	405	397	1040	260	1300
			Njala	56	38	111	74	185
			Segula	40	32	79	46	125
			Chiriko	20	16	49	16	65
			Bibi (Khome)	32	20	67	89	165
		Nsondole	Khando	74	68	190	126	316
		Malosa	Nsanama	15	5	39	27	66
BLADD	Phalombe	Wowo	Nkhulambe	210	110	345	175	520
MZADD	Nkhata-Bay	Nkhata-Bay	Limphasa	420	324	763	295	1058
KRADD	Karonga	Kaporo	Lyamoyolo	10	0	55	35	90
			Ngolombe	12	9	18	9	27
			Upper Kasantha	5	4	12	13	25
			Lower Kasantha	5	4	15	13	28
		Vinthukutu	Tovwirane	10	7	13	13	26
			Nsanambe 1	20	20	24	13	37
			Nsanambe 2	5	5	9	13	22
			Mpinga Complex	120	90	180	120	300

Source: Ministry of Irrigation and Water Development (MOIWD, 2009)

The first large-scale rice irrigation scheme to be established in Malawi was the Limphasa Scheme in Nkhata-Bay district (MOIWD, 2009). This Scheme supports livelihood of 1,409 farming families and the scheme draws its water from Limphasa River to irrigate 487 ha of land (Nyirongo, 2003). Later, the Taiwan-Chinese team started rice irrigation at Kaporo in Karonga district (Tsoka, 1999 in Matalawanda, 2006). In 2006, Nkhate Rice Irrigation Scheme was also established in Chikhwawa District by the International Center for Tropical Agriculture (CIAT) in Africa with the aim of piloting an intervention strategy known as Enabling Rural Innovation (ERI) (Magreta *et al*, 2010). Other rice irrigation schemes in Malawi are: Zumulu and Domasi in Machinga District and Likangala in Zomba District (Ferguson and Mulwafu 2004; GOM, 2004).

All these are gravity- fed schemes and the quantity of water available in the river determines the area cropped in the dry season (GOM, 2000). However, GOM (2000) rightly observed that not so much is known about the current level of water abstraction in the Lake Chilwa basin in which Lingoni Rice Irrigation scheme is located. By 1986, permissions for water abstraction and water supply and irrigation uses were granted to an estimated capacity of 9,000 m^3 per day (GOM, 2004). The report further states that despite additional permissions for abstraction being granted since 1985, Machinga district faces no problem of excessive abstraction of water resources, although there are no integrated management plans in place to be used as guidelines for water resources utilization, development, conservation and protection by all sectors.

In Malawi rice is not enough to meet national demand and as a result, the country depends on imports to meet the shortfall (Magreta *et al*, 2010). The imported rice is mainly sold and consumed in urban areas. In 2002, rice production was about two-thirds of the national demand and according to Margreta *et al* (2010), during the period 2001 to 2005, the average milled rice production in Malawi was 49.990 million tones. Growth rate for yield, harvest area and production were -11.79%, 5.88% and -16.97% respectively. But the growth rate for rice consumption was 8.53%. In this period, Malawi had a rice self-sufficient ratio of 0.97% and rice imports represented 3% of the total quantity consumed. Low income levels from rice are the major problem for rice smallholder farmers' in Malawi (Magreta *et al*, 2010). The major cause of this problem has been lack of farmers' linkage to better or profitable rice market outlets as well as lack of farmers' intelligence in timing their rice sales.

2.3.1: Water and irrigation policy framework in Malawi

Policy is a course of action aimed at achieving one or a set of objectives and usually adopted on the basis of an assessment of opportunities, constraints, and alternative options (Barley and Pullin, 1999 in MBERU 2008). Water and irrigation development are two major issues of great concern which the Malawi government has always attached great importance. Water is a finite resource and a strong policy framework and strategies to achieve the policy objectives must therefore guide its conservation, allocation, and utilization (Malawi Government, 2005).

In 1994, the Government of Malawi developed the first coherent Water Resources Management Policy and Strategies to guide the country in the sustainable use of water and sanitation and this was revised and approved by Government in 2000, in order to strengthen the management aspect of water resources, which was considered weak in the 1994 Policy (GOM, 1994). According to the GOM (1998), the National Water Resources Management Policy developed in 1994 outlines the policy and strategies for water resources management in Malawi that had salient features as follows:

- Water should be managed and used efficiently and effectively in order to promote its conservation and future availability in sufficient quantity and acceptable quality.
- All programmes related to water should be implemented in a manner that mitigates environmental degradation and at the same time, promotes enjoyment of the asset by all beneficiaries.
- Water allocation should recognize that water is not only a social but an economic asset.
- Investment of public funds in water and related programmes should be guided by the expected net income, social and environmental benefits of the programme to the country as a whole.
- In planning and providing water services, consideration should be given to safe disposal of the resultant wastewater.
- The pricing of water should reflect demand and the cost of water services. Pricing should aim at the reduction of government financial support to the sector over time.

- The government shall facilitate the participation of stakeholders in water management programmes (including users and special target groups) both in the public and private sectors to ensure that the needs of their relevant interests are taken into account.

In addition, The National Water Policy (2005) addressed all aspects of water including resource management, development and service delivery (Malawi Government, 2005). The policy articulated a new water sector vision of 'Water and Sanitation for All, Always.' It embraces and reflects the Government's overall development objectives of poverty reduction and economic prosperity, and at the same time aims at conforming to the regional and global trends and the requirements as reflected under the UN Millennium Development Goals (MDGs) and the World Summit on Sustainable Development targets of 2015.

The National Water Policy of 2007 includes sustainable management and utilisation of water resources, in order to provide water of acceptable quality and of sufficient quantities and ensure availability of efficient water and sanitation services that satisfy the basic requirements of every Malawian and for the enhancement of the country's natural ecosystem (Malawi Government, 2007).

Following the United Nations Conference on Environment and Development (UNCED) also known as the Earth Summit held in June 1992 in Rio de Janeiro Brazil, the world's leaders developed a 'blueprint' for future survival on planet Earth (Overseas Development Administration, 2000). The blueprint now known as Agenda 21 highlighted the importance of integrated water resources management so that what human beings do today does not undermine the development and environmental needs of present and future generations. Key principles for integrated water management as cited in Agenda 21 include:

- that water is a scarce resource and should be treated as both social and economic good;
- that water should be managed by those who use it most and all those who have an interest in its allocation and use particularly women, should be involved in decision-making and;

- that water should be managed within a comprehensive framework, taking into account its impact on all aspects of social and economic development.

On the other hand, agriculture is and will continue to be the backbone of Malawi's economy, since the country is not well endowed with mineral resources (GOM, 2000). However, due to high pressure on land, climate change, and low level of farm technology, many farmers in Malawi produce only 40 to 70% of their staple food requirement, and by June only a few months after harvesting, many rural people are reduced to eating two meals per day and that 60% of smallholder farmers live below the poverty line facing increasing poverty and food deficits (Bunderson *et al*, 2002 in Mweta, 2006; GOM, 2000; Ngwira, 1984). Hence, irrigation development is one of the tools that could help Malawi in fighting hunger and realizes the MDGs. Moreover, the occurrence of droughts and their effect on crop production have resulted in increased emphasis on irrigation development (GOM, 2010).

In June 2000, the Ministry of Agriculture and Food Security formulated a new National Irrigation Policy and Development Strategy (The World Bank, 2010). Key statements include that the Department of Irrigation would facilitate the development process in order to create an environment in which the private sector, smallholders, and commercial farms invest in irrigation development; irrigation would be promoted to increase incomes and commercialization of the sector; development of irrigation schemes would ensure the full participation of farmer beneficiaries at every phase, from identification to planning, designing and implementation; an environmental impact assessment would be undertaken for all medium to large-scale irrigation development; financing would ensure minimal government subsidy, and the principles of cost sharing and cost recovery would be applied.

In July 2006, the MOIWD prepared a strategic plan to be in effect from July 2006 to July 2010. It stipulates the following objectives;

- increase water availability through construction of multi-purpose dams and water harvesting technologies by 2011;
- Achieve sustainable and integrated water resources management;
- Contribute effectively towards meeting the country's regional and

international obligations with regard to the exploitation and management of water resources to ensure they are effectively implemented and managed;

- Improve efficiency and effectiveness of monitoring and data management systems to 80% by 2011;
- Bring about 80% of Malawi's water resources to national standards on water by 2011;
- Provide support to mitigate effects of water- related disasters by 2011 and;
- Bring 120,000 hectares under manageable and effective irrigation schemes by 2011.

Finally, in August 2009, the Ministry of Irrigation and Water Development elaborated the strategic document "Implementation of the Irrigation Green Belt Initiative". This initiative aims to exploit the high irrigation potential by expanding coverage and providing complementary infrastructure services with the ultimate objective of increasing productivity for income generation for the farmers in the country, consequently contributing to economic growth and ensuring food security. By the nature of the program, it would have a broad spectrum of beneficiaries, primarily medium and large-scale farmers, agricultural produce processors, manufactures and small-scale business entrepreneurs.

The specific objectives of the Green Belt Initiative are to; increase agricultural productivity and production; offer agricultural production diversification; increase income generation opportunities; increase availability of raw materials for the manufacturing industry; and increase export opportunities.

In the process of intensifying irrigation agriculture, water resources management should be of paramount importance, hence the establishment of the Irrigation Act. The Act attempts to make provision for the sustainable development and management of irrigation, protection of the environment from irrigation related degradations, establishment of the National Irrigation Board and for matters connected therewith or incidental thereto (GOM, 2001). The vision of the Department of Irrigation is "Prosperity through Irrigation by the year 2020" and its aim is to manage and develop water and land resources for diversified, economically sound and sustainable irrigation and drainage systems under organized smallholder and estate management institutions and to maintain effective advisory service (GOM, 2003).

The irrigation policy makes it very clear about the need to use water efficiently but the reality on the ground is very different as much depends on the level of education of the users as well as the amount of water available (Mulwafu, 2002). FAO (2001), documents that the National Irrigation Policy and Development Strategy published by the Department of Irrigation in October 1998 includes the following policy objectives; to contribute to poverty alleviation by targeting resource poor farmers for irrigation development to enhance farm income; to increase agricultural production and enhance food security through irrigation and to extend cropping opportunities and provide a wider variety of cops in both wet and dry seasons.

It should therefore be noted that, for the country to achieve food security and irrigation development, water resources management and conservation principles have to be put into consideration. Water is the lifeblood of agriculture and for hundreds and sometimes thousands of years; rural watersheds across the globe have been dominated by various agricultural water management systems (AWMS) (Mulat 1998, in Dinku 2004). This calls for strict adherence of the irrigation legislation and laws by the country. Suitable legislation and policy innovation should be decided to create an enabling environment to recognize and maintain multifunctionality of agriculture water management systems within the framework of integrated watershed/ river basin water resources management (Chen and Falcon, 2005). Laws and regulations will therefore provide the rules pertaining to the use of this public resource (van der Zaag, 2002).

2.4. Impact of rice irrigation and climate change on water resources

2.4.1. Impact of rice irrigation on water resources

Irrigated agriculture depends on supplies from both surface and ground water resources. It represents an alteration of the natural conditions of the landscape by extracting water from an available source, adding water to fields where there was none or little before, and introducing man-made structures and features to extract, transfer and dispose of water (Stockle, 2010). Unfortunately, water resources for irrigated agriculture are often overused and misused. This has resulted in depriving downstream users of sufficient water due to pollution of fresh water resources with contaminated return flows and deep percolation losses (Global Water Partnership, 2000).

Stockle (2010) rightly observes that the largest single consumer of water is irrigation agriculture but this use is usually inefficient. Water is lost as it is distributed to farmers and applied to crops. Consequently, as half as all the water diverted for agriculture never yields any food. Thus, even modest improvements in agricultural efficiency could free up large quantities of water.

An excessive withdrawal of water for irrigation clearly impacts the water and river systems in some areas across the world. This excess water use in the scheme has resulted in lower water availability downstream. Therefore, the introduction and spread of water saving irrigation practices are of great importance to save water in the upstream areas and reallocate water to downstream areas short of water (Bin, Young and Tiessen, 2002).

A study of the Yellow River (China) indicates that excessive water was diverted to the irrigation districts and the flooding irrigation method was widely used (Bin *et al*, 2002). However, there was a lack of experience in large-scale irrigation management and drainage related problems in the irrigation districts. Additionally, the large-scale programs were poorly planned and sometimes not completed. This combination resulted in a considerable surface and groundwater loss, since the excess irrigation water and rainfall could not match in the area.

In the United States the equivalent of 4 million hectares, one fifth of the irrigated area, is irrigated by pumping in excess of groundwater recharge (Postel, 1993). Postel (1993) further shows that the Ogallala aquifer, which stretches from South Dakota to Northwest Texas, has been heavily depleted in its southern portions, where water supplies dropped from 550 million acre-feet prior to large-sale irrigation development down to 417 million acre-feet in 1990.

Reports also show that the Colorado River (USA) often contains essentially no water by the time it crosses the border into Mexico, owing to both urban and agricultural withdrawals and in most years, this river does not make it to the ocean (Stockle, 2010). The same author further argues that this has consequences for the river and its riparian ecosystems, as well as for the delta and estuary system at its mouth, which no longer receives the recharge of fresh water and nutrients that it normally did. The same is true for the Yellow River in China and the San Joaquin River in California which are so permanently dewatered that trees are growing in their beds and developers have suggested building houses there (Stockle, 2010).

2.4.2. Impact of climate change on water resources

In many parts of the world, water is rapidly becoming a scarce commodity. Some of the more widely accepted and well known contributors to this situation include population growth and raising living standards. It was only recently acknowledged that the possible impact of a changing climate on water resources could be a further stressor that could exacerbate the situation, since it is widely recognized that the impact of climate change will be felt mostly severely in the water sector. This in turn has the potential to impact on the livelihoods and well-being of people. Several developing countries, including Malawi and South Africa are regarded as being highly susceptible to climate change due to a combination of possible increases in the variability and the magnitude of the water system, in addition to weak institutional and financial capacity to mitigate and adapt to the possible changes.

The potential impact of climate change was simulated for six major sub-regions of the Zambezi River Basin. These are Upper Zambezi, Kafue River Basin, Middle Zambezi, Shire River and Lake Malawi sub-basin and Lower Zambezi Delta (The World Bank, 2010). It is widely accepted that human-induced climate change is underway (IPCC, 2001a, b).

Kwadijk and Middelkoop (1993) state that the climate is expected to change due to the enhanced green-house effect. This will cause changes in precipitation and temperature distribution in time and space. Consequently, river discharges are expected to change in amount and distribution over the year. Long-term strategies for future river management require quantitative information on these changes.

According to (Rosenzweig, Johnson and Knox, 2009), the impacts of climate change on the freshwater surface and groundwater systems that are principal of urban water supply are primarily due to expected increase in temperature, increases in worldwide mean in precipitation and its variability, and higher sea levels. Higher temperatures will impact urban water supply systems in a variety of ways. Such ways result in greater evapotranspiration, a factor in the expected increase in drought events in many areas.

Rosenzweig *et al*, (2009) further notes that there is evidence that this effect is already occurring in the Western and Northeastern United States. Besides, the distribution of precipitation changes is expected to increase in tropical areas of high rainfall (such as monsoon areas), to decrease generally in the subtropics, and to increase in higher latitudes. However, as Rosenzweig *et al*, (2009) noted, many areas are expected to experience decreases in precipitation together with increased evapotranspiration, putting intense pressures on urban and irrigation water supply.

Increasing evidence suggests that anthropogenic climate change is already underway (Zhu and Ringler, 2012). Climate change affects hydrological cycles locally and globally. It alters the amount and timing of river flow, challenges the coping capacities of working water infrastructure and management systems, and brings higher risks of water shortages and floods. In general, the water and agricultural sectors experience the most direct impacts from climate change due to their direct exposure to and dependence on weather and other natural conditions.

Changes in local weather, particularly in rainfall and evapotranspiration patterns, will affect the soil water balance and hence the irrigation needs (Downing, Weatherhead, Knox and Stocholm 2003). A study by Herrington (1996 in Lorenzo 2007) shows that an increase in UK temperature by 1.1 ^{0}Celcius would bring a 35% increase in water use for lawn sprinkling. Furthermore, a specific study for Cambridge (Harte, Tom, Chang *et al*, 1995) demonstrated that a 3^0 Celcius rise in soil temperature would entail a 25% decrease in soil moisture, which consequently would enlarge irrigation needs. This is proved by Döll (2002), who confirms that the net irrigation requirement (mm/year) for South East England will switch from 77 (current baseline) to 129 in the 2020´s scenario.

In recent years, Malawi has experienced extreme climatic events, ranging from drought (1991/2) to flood (1996/7) (GOM, 1998). Bisgrove and Hadley, (2002) state that the main impact of climate changes on all water bodies will be the fluctuation of water throughput. This will vary from falling water levels during the summer months due to high surface evaporation, to overflow in excess supply periods originated by the concentration of rainfall events. The same applies to the lower Mekong (China) where it is assumed that in future, climate just like much of the world will be warmer (Chinvanno, Souvannalath, Lersupavithnapa, Kerdsuk and Thuan, 2000).

It has been reported elsewhere that drought recurs at varying periods in Malawi. In the analysis made of annual time series for selected representative stations, it has been noted that drought phenomenon repeats every nine years in Malawi, and reported years are 1923/24, 1932/33, 1948/49, 1967/68, 1982/83, 1990/91, 9192/93, 2000/01, 2004 and 2005 (GOM, 2004; Ngwira, 1994). Such recurrent of droughts makes the country to experience increased depletion and degradation of some of its water resources.

Chavula (1999) presented some climate change scenarios for the Lake Chilwa catchment using four General Circulation Models (GCMs): the Geophysical Fluid Laboratory (GFDL or GFD3), the Goddard Institute for Space Studies (GISS), the Canadian Climate Centre (CCC) and the United Kingdom Meteorological Office (UK 89). According to these climate change scenarios, temperature in the Lake Chilwa catchment will increase by 2.6 to 4.7 ^{0}C, with carbon dioxide (CO_2) doubling by the year 2075. Similar results were also established in the UK (Lorenzo, 2007).

An increment in atmospheric CO_2 concentration of about 90 ppm for the period 1750 to 2000 has been demonstrated by the IPCC (Lorenzo, 2007). Wang, McGrath, Semmler, Sweeney, and Nolan (2006), predict that as increased temperatures will lead to greater amounts of water vapour in the atmosphere and an accelerated global water cycle, it can be expected that river catchment areas will be exposed to a greater risk of flooding. On the other hand, higher recurrence of extreme events such as El Nino evidences the negative effects of a changing climate (Lorenzo, 2007).

Variations in earth's climate and likely future changes, not only present a serious threat to human society in general (Her Majesty Government, 2006), but also in particular to the water sector, bringing consequences and implications that will affect the future management of water resources. Climate change, among others, put pressure into water resources and become water scarcer, therefore reducing its availability for the different water users, including the irrigation sector (Lorenzo, 2007).

The impact of climate change on local discharge variability was also investigated in the Suir River Catchment which is located in the south-east of Ireland (Wang *et al*, 2006). In this paper, the Rossby Centre Regional Atmospheric Model (RCA) was driven by different global climate data sets. In the investigated Suir catchment, the 10-year return value of the maximum river discharge increased by more than 20% when using the moderate ECHAM4 B2 emission scenario for 2021 to 2060 compared to 1961 to 2000, whereas in the more aggressive ECHAM5 A2 scenario, the future extreme discharge even slightly decreased. This shows that there is still large uncertainty in the global climate projections, which are probably mainly connected with the Global Circulation Model (GCM) formulation and not so much with the chosen emission scenario (Wang *et al*, 2006).

A local study to analyse the impact of climate change on catchments water availability in the Mulunguzi River catchment area, Zomba was done by Ngongondo (2002) and used raw data (1953/54 to 1987/88) obtained from the Meteorological Department in Blantyre. The study used non-parametric Mann-Kendall statistical package for the analysis of data. Phalira (2006), used secondary total monthly rainfall data from 1967/68 to 2004/2005 for Dzonzi forest reserve, a meteorological region for the Mpira catchment, collected from the Meteorological Department in Chileka, Blantyre. Both papers show that climate changing is having a negative impact on water availability.

CHAPTER THREE: METHODOLOGY

3.0. Introduction

Presented in this chapter is a description of methods used in data collection and analysis. The study used specific methods to achieve each of the specific objectives. The methods used to generate data included the following: a questionnaire to analyse Lingoni Rice Irrigation Scheme's development, management, and rice production; physical observation to identify the scheme's water control infrastructure and to analyse river discharge upstream, midstream and downstream; field experiments to measure river flow, canal discharges and irrigation efficiencies; and secondary data to analyse rainfall trends. Statistical tools such as graphs, Krustal-Wallis, univariate statistics, a non-parametric Mann-Kendall test and Ecosim 7.0 software were used for the analysis of data.

3.1. Area of study

Lingoni rice irrigation scheme, which is the focus of this study, is located in Mposa area, within the district of Machinga, in the Southern region of Malawi (Figure 3). The area is bounded by the 15^0 00' S and 15^0 10' S parallels of latitude, and the 35^0 30' E and 35^0 45' E parallels of longitude, into the western shores of Lake Chilwa basin (Simbeye, 2005; Bloomfield, 1965). Machinga district has a total land area estimated at 3,771 square kilometres (GOM, 2004).

Smallholder farmers in the Lingoni Irrigation Scheme abstract water in the middle part of Lingoni River for rice production. The irrigation system was first built by the local farmers in the early 1980s. This followed advice from some members of the Malawi Young Pioneers (MYP), whom having observed the abundance of water supply in the river felt that the basin was conducive for rice production (Labana, *Personal communication*).

These members had been trained by the Malawi Government in various community works including irrigation development with the aim of utilising undeveloped wetlands and river banks and intensify rice production (Mazunda, 2006). Intensive rice production at the irrigation scheme was then started in 1994 due to an increase in demand for the crop, both as a source of food and for sale (Mbando, *Personal Communication*).

Lingoni rice scheme is still a small-scale irrigation project. A small-scale irrigation scheme is defined as irrigation, usually on small plots with discharges of less than 700 l/s in which small farmers have the controlling influence, using a level of technology that they can operate and maintain effectively (IWMI, 2000; Smout and Shaw, *undated*). Small-scale irrigation is, therefore, farmer-managed; farmers are involved in the design process and, in particular, with decisions about boundaries, the layout of the canals, and the position of outlets. Like most other small-scale irrigation projects in Malawi, Lingoni rice scheme was developed and is managed entirely by the local farmers without any external financial and technical assistance; hence no subsidies are received from the government.

Lingoni River was selected for the study because this river, which used to be perennial in the past, is now being considered as one of the interrupted or ephemeral rivers in Machinga District. Mathews (1988 in Calow and Petts, 1992) defines ephemeral streams as those which flow less than 20% of the time and so are dry, or exist as series of pools, for much of the time. At the same time, there has been considerable competition for water among the users in the area of late in that population density which is at 184 is comparatively higher than the national density of 139 (GOM, 2008) and that both economic growth and demand for water are increasing since the topography and soils are well suited for irrigation.

In addition, its location which makes it accessible, its physical conditions and its importance both agriculturally and as a source of water supply for people in Mposa area made the river a good choice for the study of its discharge. Although other agencies and organizations have been involved in planning for flood moderation and drought mitigation practices, none has had the opportunity to undertake a detailed analysis that can accurately depict current water discharge conditions of the river due to the irrigation scheme and or climate change and variability and be used to evaluate reasons for changes in both water supply and demand in the near future (GOM, 2004).

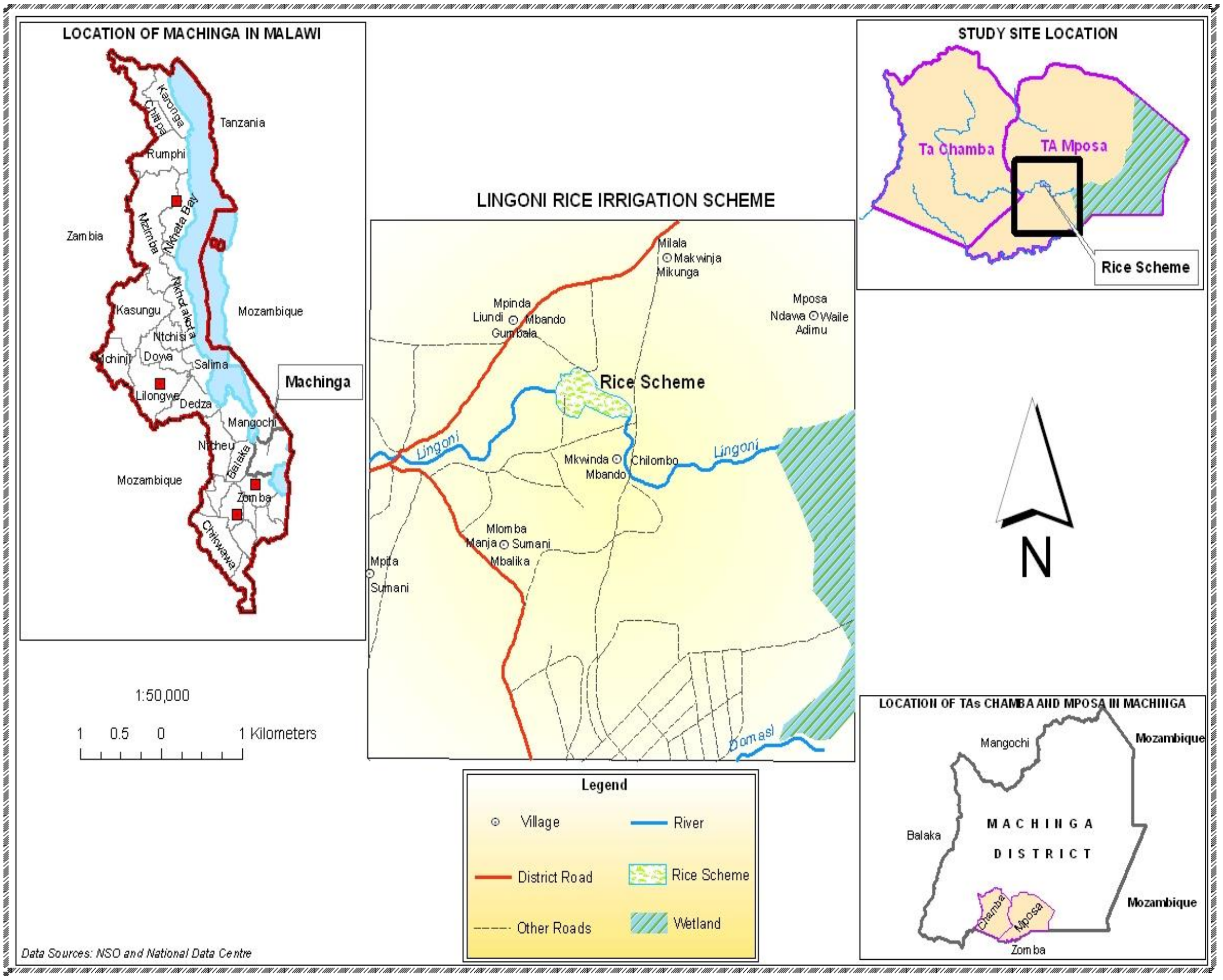

Figure 3: Lingoni Rice Irrigation Scheme in Mposa Area, Machinga District

3.1.2. Lingoni rice irrigation scheme area

Lingoni rice irrigation scheme was divided into two irrigation areas, the northern and the southern parts. Secondary data from the Ministry of Irrigation and Water Development (MOIWD), Ministry of Agriculture and Food Security and a Global Positioning System (GPS) using new GIS (Appendix A) data were used to delineate the scheme boundary. This enabled the total area of the scheme to be established.

Table 5: Total and net irrigable areas of Lingoni rice scheme

Scheme	**Total Area (ha)**	**Net Area (ha)**
Northern	6.50	5.85
Southern	13.50	12.15
Total Scheme	**20.00**	**18.00**

However, not all of this area is suitable for rice irrigation because the soils in the upper part of the northern area are shallow to medium and soils in the lower part of the southern area are shallow and poorly drained (GOM, 2008). Therefore, the net irrigation area of Lingoni Rice Irrigation Scheme was established to be 18 ha assuming that 10% of the total area would be taken up by irrigation canals, drains and roads (footpaths), (Republic of Kenya, 1987). However, recently there has been a significant expansion of the scheme due to the growing demand for rice.

3.1.3. Lingoni rice irrigation scheme layout

According to GOM (2008), Mposa area has a gradient of less than two percent (2%) has generally a flat area making it suitable for basin irrigation. This makes it possible for the growth of rice since the crop grows best when its roots are submerged in water for periods longer than 24 hours. Basins are flat areas of land, surrounded by low bunds which prevent the water from flowing to the adjacent fields (Zaw, 2004). However, Zaw (2004) states that flat lands with a slope of 0.1% or less are best suited for basin irrigation. This is because on flat land, only minor levelling may be required to obtain basins.

The technology of water diversion and conveyance being used in the scheme is simple and rudimentary. This supports Vandersypen, Bengalyk, Keita, Sidibé, Raes, and Jamin (2006) observation that the type of irrigation practiced throughout the area is flood irrigation through gravity-fed system using field basins, a technology that is simple but does not use water efficiently. Water is distributed using open channels and is applied onto the rice scheme where it covers the entire surface of a field by soaking into the soil and making pools. Small soil walls or dirt mounds called dikes or levees are built up to hold water and divide the Lingoni rice field (paddy) into sections or plots.

The scheme is fed gravity through two main canals constructed on both sides of the river. The main canals are further sub-divided into several branch canals (BCs) covering a total length of $1^{1}/_{2}$ km to the Northern part of the scheme and 1km to the South. Branch canals further divide into tertiary canals. Farmers obtain water for irrigation from the tertiary canals.

The intake structure is not built into a diversion box, hence there is serious erosion taking place, increasing siltation of the river channel. The structure allows a maximum of 145 l/s (0.145 m^3/s) during the dry season from the river into the scheme. Figure 4 below shows the general layout of the Lingoni Rice Irrigation Scheme.

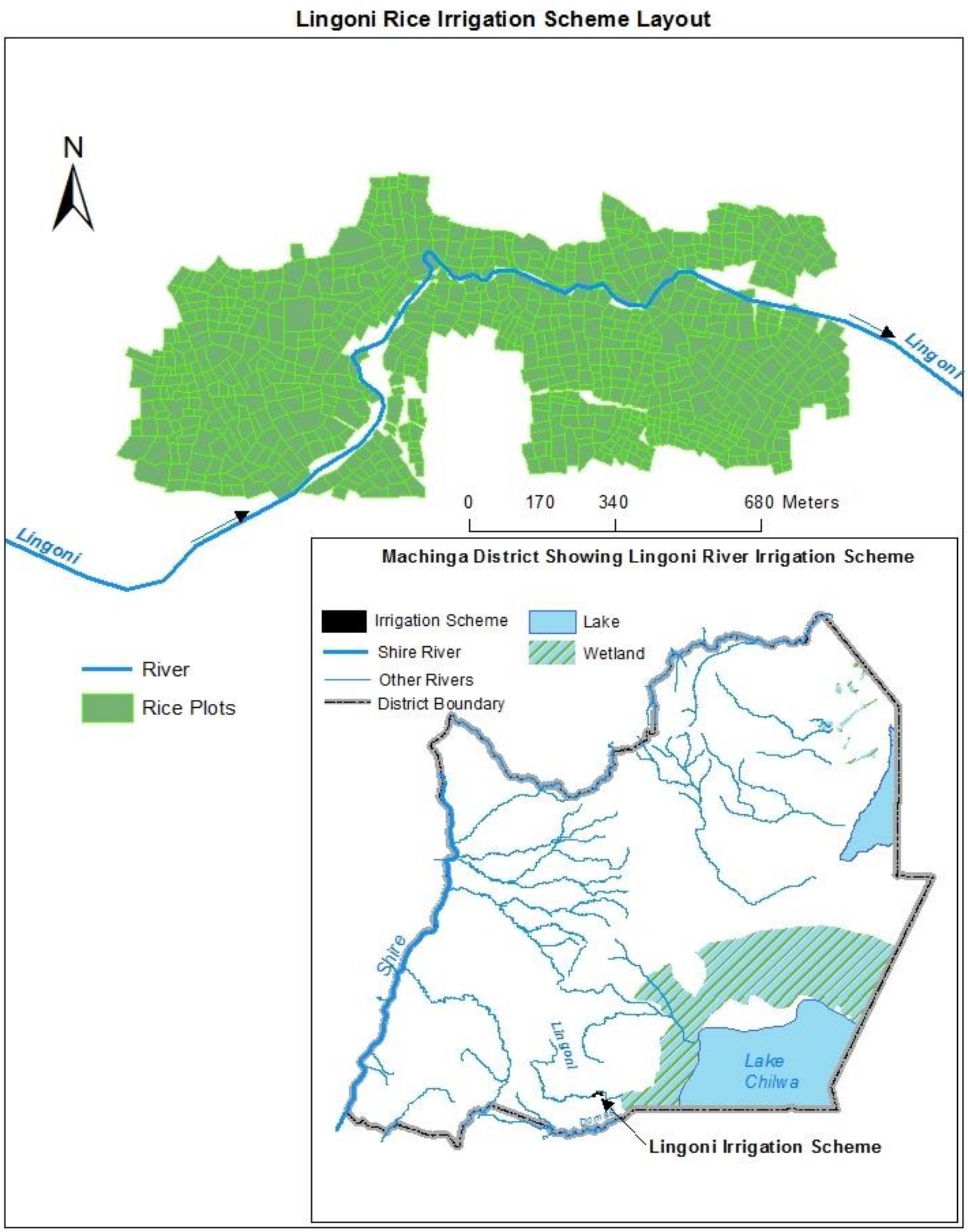

Figure 4: Lingoni Rice Irrigation Scheme layout

3.2. Rainfall regime of Lingoni catchment

Lingoni River is within the Lake Chilwa basin (GOM, 2004). This river originates from Chikala Hills at an elevation of 1,626 metres above sea-level (ASL) and flows southwards for a distance of 35 kilometres, draining an area of approximately 2,189 km^2 before entering the Lake Chilwa basin (Simbeye, 2005), which is the second largest lake in Malawi located to the East of the study. This river cuts across two Traditional Authorities (TAs) of Chamba and Mposa (Figure 3). This river depends on both groundwater and rainfall for its recharge, (GOM, 1994), and has seasonal tributaries such as Chibulubulu, Namiyala, Kokanguo and Mlombe.

Ngongondo (2003 in Chavula 1999) indicated that rainfall in the Lake Chilwa Basin results from one synoptic system namely the Inter Tropical Convergence Zone (ITCZ) and takes place from November to April. Occasionally, rainfall over the catchment area also results from the Tropical cyclones as they cross the Mozambique Channel into Malawi. The Zaire Air Boundary (ZAB) which has its source in the Southern Hemisphere Subtropical high pressure belt just off the western coast of the Republic of South Africa and Namibia accounts for a very small amount of the total rainfall that occurs in the basin (Ngongondo, 2003).

Ngongondo (2003) also observed that when both the ITCZ and Tropical cyclones are concurrently overhead in the basin, flood disasters are a common occurrence as heavy rainfall takes place. Besides, there is always a high rainfall belt confined to the highlands that extends from Malosa, Chikala and Northeast of Ngokwe (GOM, 2008). This belt contributes an annual rainfall of about 1,000 mm. The rainfall is both conventional and orographic in nature resulting in light to moderate intensities except in severe storms, (GOM, 2004). This implies that Lingoni river basin receives all the three types of rainfall.

3.3. Data collection techniques

3.3.1. Primary data collection

Primary data were collected using formal and informal survey methods. Formal surveys were carried out with the help of a standard questionnaire designed to obtain information from selected sample rice farmers. The questionnaire had both structured and semi-structured questions (Appendix B). The content of the questionnaire was prepared to get information on demographics of irrigators (e.g. age, level of education, district of origin); general farm attributes (e.g. number of rice plots held, years spent growing rice, livelihood, issues related to irrigation practice, irrigation schedule, irrigation cycle, organization, development and management of the scheme, maintenance of water control infrastructure in the scheme, and problems being faced), and production/output (e.g. water use, and yields per plot).

In addition, informal discussions were held with key informants including committee members of the Water User's Association (WUA). The leading questions discussed, emphasized policy issues, external support for the scheme, institutional and managerial issues, major problems, and future plans to further develop the irrigation scheme. Personal observation was also employed.

3.3.2. Sample selection and sampling techniques of the study population

The total number of rice farmers practicing irrigated agriculture at Lingoni small-scale irrigation system is 120, out of which 58 (48%) were males while 62 (52%) are females (MOIWD, 2009). Each farmer has an average plot of about 0.15 ha which they manage individually. Sixty rice farmers were randomly selected within the different strata of the scheme. To get the sample population of the study, the following formula by Sabola (2002), was used;

$$k = N/n \qquad \text{equation 5}$$

Where k = the sample frame or interval

N= the total number of rice farmers

n = the sample size

For this sample; N = 120, k = 2 and n = unknown. A sampling interval of two was predetermined between rice farmers due to time and financial constraints. To get the sample size (n), the following formula was then applied:

$$n = N/k \qquad \text{equation 6}$$

$$= 120/2$$

$$= 60$$

Therefore, the sample size for the study was established to be sixty and was well sampled. This is because it is assumed that a large sample with a poor sampling design will probably contain less information than a smaller but carefully designed sample (Chatfield, 1995 in Kitchen and Tate, 2000). From the sample size, 35 (62.5%) were females and 25 (37.5%) were males. This is because in most cases women are more concerned with water-related issues than men since fetching water is principally a woman's task (Vandersypen *et al*, 2006; DfID, 2000).

In addition, in the majority of developing countries, women play a very important role in agriculture, particularly in rice production (Carney, 1998; Quisumbing, 1996 in Kinkingnhoun-Madagbe, 2007). In cases where the respondents were not present at the predetermined interval, the next rice farmer was chosen for questionnaire interviews and the rest of the respondents at the set interval would shift automatically (Phalira, 2006).

Besides the survey method, non-structured technical consultations were conducted with key personnel dealing with water resources and related issues. Included in these consultations were officials and technical personnel from the Ministry of Irrigation and Water Development and Ministry of Agriculture and Food Security. The survey methods and design were based on the assumption that the respondents were conversant with issues affecting integrated management of water resources in the Lingoni Rice Irrigation Scheme. It was also assumed that they were willing to share information for the purpose of this study. The primary data used were for the 2008 cropping season and were collected in November 2008.

3.3.2.1. Designing questionnaire

Before designing the questionnaire, the irrigation system was regularly visited from July to August 2008. These trips were conducted in order to gain an insight in setting the study area and supplement knowledge gaps (Ngongondo, 2003). During the visits, a number of informal discussions were conducted with the beneficiaries and local government officials. Based on the information gathered and personal observation, interview questions were developed and then pre-tested before they were administered.

In order to conduct the survey, an enumerator who had completed the Malawi School Certificate of Examination (MSCE) and able to speak the local languages, that is Chichewa and Yao, was recruited to assist with the survey. The enumerator was also trained by the researcher before launching the survey in order to make him (the numerator) gets acquainted with the questionnaire and understands the purpose of the study. The interviews with farmers were then conducted with the close supervision of the researcher.

3.4. Experimental design

Lingoni River was demarcated into three sections, comprising the upstream (unirrigated), midstream (irrigated) and downstream (unirrigated). The midstream is where Lingoni Irrigation Rice Scheme is located. Lingoni river discharge was then repeatedly measured for each section for the first eleven days of each month throughout the irrigation period from August when rice was planted up to November when rice was harvested.

In addition, these three sections were further subdivided into three points in order to measure variations in cross-sectional area of the channel. Riverine or riparian plants in the three sections were also counted in order to identify the effects of the irrigation scheme on species diversity (SD). The availability of riverine plants implies that river discharge is optimum for their growth.

3.4.1. River and canal discharge measurements

A river discharge and canal abstractions measurement programme was set up to monitor the discharge of both Lingoni River and the canal. The canal selected for this experiment was located to the northern part of the irrigation scheme and was about 250 m long. The irrigation impact of the scheme on downstream flow was measured by comparing water discharges (water flow measurements) at key sites of upstream, midstream and downstream where the rice scheme is located. The discharge measurement was conducted at least for eleven days of each month starting from August up to November of 2008.

Velocity Area Streamflow Method - Neutrally Buoyant Object Procedure or float method was used to measure river discharge because Lingoni River is not gauged. In this method, stream velocity and water depth measurements were taken along a transect perpendicular to the stream. Total streamflow or discharge (Q) was estimated by integrating the stream velocities with the cross sectional area of the stream profile defined by the transect (Gordon 2004: Hauer and Lamberti, 1996). Jamu and Chimphamba (2005) showed that the discharge obtained from float methods were not significantly different from those obtained by using a current metre. The method was also chosen because it is one of the simplest for determining river discharge (Shaw, 1985).

The average area of the stream cross-section (A) was calculated using the following formula by FAO, (2001);

$$A = \frac{b + a}{2} * h \text{ ....equation 7}$$

Where:

A = stream cross-sectional area
b = the streambed width
a = the surface water width
h = the water depth (height)

The average flow velocity (V) was calculated using the following formula by FAO, (2001);

$$V = 0.8\ L/t \text{ ....equation 8}$$

Where:

V = streamflow velocity
t = the average travel time of a float object in seconds
L = the distance travelled by the float object between two points
0.8 = a reduction factor because not all the water flows as fast as that in the centre

Therefore, river discharge (Q) for Lingoni was calculated using the following formula by FAO, (2001);

$$Q = V.A \ m^3/s \quad \text{……………………………………………………equation 9}$$

3.4.2. Establishing irrigation efficiencies

A sample irrigation area was chosen for a detailed investigation of how efficiently water abstracted for irrigation was being used. The selected area was located in the northern part of the scheme, thought to be one of the inefficient areas in the scheme. In addition, the area is more easily accessible than the southern part of the scheme. Hence, all the irrigation efficiency measurements were conducted in this part of the scheme. A rice plot or basin was then purposively chosen to be the representative of the local situation in terms of size (Zaw, 2004).

All field experiments to establish the efficiencies were carried out at the irrigation site in October 2008, except for water use efficiency that was determined at harvesting period in November. The measurements were conducted when rice was at its development stage, 40 days after planting. An expert from the Irrigation Department at Zomba R.T.C was hired to measure these efficiencies.

3.4.2.1. Water-conveyance efficiency (Ec)

Water-conveyance efficiency was obtained by measuring the amount of water entering the transmission network (canal) and the amount of water leaving the canal at the receiving end (field). In this case, water conveyance efficiency was taken as the ratio of water received at the inlet of a block of field (basin/rice plot) to water released at the headwork (river). Thereafter, water was measured by calculating the volume (velocity x cross- sectional area) at entry and volume (velocity x cross sectional area) at exit of the canal network.

Ec for the scheme was then calculated using the formula by (Rogers et al, 1997; Olivier, 1972; Israelson and Hansen, 1962) as follows;

$$Ec = \frac{Wf}{Wr} * 100\% \quad \text{……………...equation 10}$$

Where:

Wf = water delivered to the farm through a canal
Wr = water withdrawn from the river

3.4.2.2. Water or field application efficiency (Ea)

Water application efficiency is the ratio between the volume used by plants throughout the evapotranspiration process and the volume that reaches the irrigation plots. Pelacios-Velez (*undated*) reported that it is important to point out that the volume used during the evapotranspiration process is equal to the volume of evapotranspiration by plants minus the volume of effective rainfall.

Hence, water application efficiency was calculated by measuring the amount of water entering the system (basin/rice plot) as per the design against the water leaving the system through the drains after calculating the water taken up by the crops and evaporation. This is the ratio of water available to the crop in relation to the water received at the block or basin inlet. Water application efficiency was then calculated using the following formula by Rogers *et al*, (1997) and Israelson and Hansen, (1962);

$$Ea = \frac{\text{Crop water requirement (mm)}}{\text{Water entering the rice plot (mm)}} * 100\% \quad \text{…………………….......equation 11}$$

Crop water requirement (mm) for the rice plot was established by calculating the crop reference evapotranspiration using the following formula by van der Zaag (2002);

$$(ETm) = Kc * ETo \, [mm/d] \ldots\ldots\text{equation 12}$$

Where:

Kc = crop coefficient (crop dependent and crop stage)

ETo = reference crop evapotranspiration

The crop coefficient (Kc) for rice was obtained using a table (Appendix C). Since there was no measured data on pan evaporation available locally, a theoretical method, the Blaney-Criddle method to calculate the reference crop evapotranspiration ETo was used. However, this method is not very accurate as it provides a rough estimate or "order of magnitude" only. Furthermore, especially under "extreme" climatic conditions, the Blaney-Criddle method is inaccurate in windy, dry, sunny areas. The ETo is underestimated up to 60%, while in calm, humid and clouded areas: the ETo is overestimated up to 40%. Despite these problems, the Blaney-Criddle method works the same as the modified Penman method (Scheltema, 2002).

Hence, the Blaney-Criddle method was calculated using the following formula (Zaw, 2004):

$$ETo = p\,(0.46\,T\,mean + 8) \ldots\ldots\text{equation 13}$$

Where:

ETo = Reference crop evapotranspiration (mm/day) as an average for a period of one Month

T mean = Mean daily temperature (^{0}C)

p = Mean daily percentage of annual daytime hours

8 = Coefficient factor

Since the Blaney-Criddle method always refers to mean monthly values, both for the temperature and the ETo, Ntaja temperature for October, 2008 was used (see Appendix D).

In order to determine the value of p, the table (Appendix E) was used. To be able to determine the p-value, it is essential to know the approximate latitude of the area: the number of degrees north or south of the equator (Zaw, 2004). Mposa area was established to be within the latitude of 15^0 South. The ETo was then calculated as 0.28 (0.46 x 25.1 + 8) giving 5.5 mm/day. Therefore, the ETm was obtained by multiplying 5.5 mm/day by 1.20 (crop factor) to get 6.6 mm/day.

In order to determine how much of the rainfall was needed to reduce irrigation requirements, the notion of effective rainfall or precipitation was then introduced. Effective rainfall (*P eff or Pe*) is that portion of the rainfall, which is not lost through unnecessary percolation and surface runoff (van der Zaag, 2002). The two most commonly methods used to estimate effective rainfall (Zaw, 2004; van der Zaag, 2002), are as follows:

$$Pe = 0.8\,P - 25, \text{ if } P>75 \text{ mm/month}$$
$$Pe = 0.6\,P - 25, \text{ if } P<75 \text{ mm/month}$$

Where P = Rainfall or precipitation (mm/ month). Since during the summer period, rainfall is very low such that it cannot sustain irrigation, the formula Pe = 0.6 P – 25, if P<75 mm/month was used. In addition, the monthly mean rainfall (Pe) of Mposa area for October 2008 was calculated to be 11.6 mm (Appendix F).

To establish the Net Irrigation water needs (IN), similar to crop water need, the following formula by (Zaw, 2004) was computed:

$$IN = ETo - Pe \text{ (mm/day)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equation 14}$$

This daily irrigation need, IN is presented as a water layer which was applied on the rice scheme. However, water flows are not actually expressed in millimetres of water covering a scheme over a certain period of time, but in litres per second or cubic metres per second. Therefore, the IN per day was converted into a current irrigation water flow. SINnet (net scheme irrigation need) in litres per second was calculated using Zaw (2004) formula as follows;

$$INnet = \frac{IN\ (mm/day) \times Area\ (ha) \times 10{,}000\ (litres/mm.ha)}{86{,}400\ (seconds/day)} \quad \text{…....equation 15}$$

3.4.2.3. Water-distribution efficiency (Ed)

This is the ratio of water received at the field inlet to the water received at block inlet. In the field, water distribution efficiency was calculated by measuring the water volume entering the system (rice plot) against the water leaving the system at exit into the next plot after removing the water taken by the crops and evaporation in the field. The following formula by Israelson and Hansen (1962) was used:

$$Ed = 100\ [1 - (y/d)] \quad \text{……………………………....……equation 16}$$

Where:

y = Water entering the system
d = Water leaving the system
1 = Coefficient factor

3.4.2.4. Water use efficiency *(WUE)*

Water use efficiency was obtained by establishing the amount of water entering the system, and then calculating the crop water requirement. Thereafter, the total harvest of the system (plot) in kilograms was established. Since there were no records for the previous years' rice production and crop water requirement, the 2008 season information obtained during field experiments was used. Water Use Efficiency of Lingoni Rice Irrigation Scheme was computed using the following formula by Aqualinc Research Limited (2006):

$$WUE\ (kg/m^3) = \frac{\text{Production } (kg/ha)}{\text{Irrigation Water Use } (m^3/ha)} \quad \text{………………equation 17}$$

3.4.2.5 Project or scheme irrigation efficiency (e)

Project or scheme irrigation efficiency was established after all the other efficiencies were calculated. The scheme irrigation efficiency (e) was calculated, using the following formula by (Cuenca, 1989).

$$E = \frac{Ea}{100} * \frac{Ec}{100} * \frac{Ed}{100} * \frac{WUE}{100} * 100 \text{ ………equation 18}$$

3.4.2.6. Establishing the irrigation time

Irrigation time is very important in order to establish whether the size of the river would support the rice irrigation scheme or not (Zaw, 2004). In most cases, the following "rule of thumb" called quarter time rule is used. The quarter time rule says that the stream size should be large enough for the water to cover the entire field (basin irrigation) in a quarter of the time needed to fill the root zone with sufficient water (the contact time) (FAO, 2002).

The contact time is the time needed to infiltrate the required amount of water. Similarly, the irrigation time (in minutes or hours) is the time needed to supply the required irrigation depth (in mm). The irrigation time depends on; the stream size (l/s) or (m^3/s), the required irrigation depth (mm) and the size of the field to be irrigated (ha). Applying the quarter time rule would mean that the water has to cover the basin in the calculated time (minutes). If it takes longer the stream size per basin has to be increased or the basin size reduced.

This method was conducted in order to compare the volume of water being diverted in the rice scheme and the size of the scheme. The following formula by van Keulen (2001) was used to determine the irrigation time:

$$\text{Irrigation time (hours)} = \frac{2.78 * \text{Irrigation depth (mm)} * \text{Field size (ha)}}{\text{Stream size (l/s)}} \text{ ......equation 19}$$

Where:

Average irrigation depth for rice = 450 to 700mm/growing period = 575 mm
(FAO, 2001)
2.78 = conversion factor
Stream size = 0.120 m^3/s or 120 l/s
Field size = 50 m x 30 m = 1.500 m^2 = 1.500/ 10, 000 = 0.15 ha

3.5. Physical or direct observation

Physical or direct observation was mainly used to study the water control infrastructure of the scheme, namely: canals and head works, vegetation species diversity in the three sections of the river, and the downstream flow. In addition, the major physical features of Lingoni River like the cross-sectional areas upstream, midstream, and downstream were also noted and measured. To reduce observer-introduced biases, the information gathered was cross-checked with literature and relevant experts in the field of study since perceptions and interpretation of the observer may not always be a true reflection of the situation on the ground (Phalira, 2006). Still photographs captured in the Lingoni Rice Irrigation Scheme during the study period were used to further explain the status of the scheme. The aim was to supplement data generated by physical observation.

3.6. Vegetation species sampling

The study of riparian vegetation species to establish their mode of occurrences in Lingoni catchment involved the division of the site into upstream (unirrigated), midstream (irrigated) and downstream (unirrigated). The presence of riverine or riparian vegetation is an indicator of water availability in the catchment. For each section, a transect was laid that measured 50 m long and 20 m wide. The width of the transect was cut across the river under study so that plant species both in water and on land would be studied (Lyne, 2003 in Ndengu 2010).

Time spent on each section or quadrat was not fixed, but depended on finishing the counting and identification of species (Ndengu, 2010). An expert from the National Herbarium was requested to assist with species identification and counting. The results were recorded on a data sheet

(Appendix G). The numbers per species per section of the site were calculated. The process was carried out for all the three sections, and the data was fed into Ecosim 7.0 software to generate diversity indices.

3.7. Secondary method

Monthly rainfall data for Mposa area used in this study was for Ntaja and Chikweo Meteorological Stations (1982 to 2008). The data was used to study rainfall trends and variations in Mposa area in order to eliminate the possibility of any changes in the river hydrology resulting from climatic change (Sarma, 1976).

In addition, other secondary data collected from different sources included documents and reports, studies and other useful written materials. Organizations contacted during the survey period were the Ministry of Agriculture and Food Security and the Ministry of Irrigation and Water Development. In addition, detailed desk study was conducted using books and reports obtained from Chancellor College Main Library, and Geography Library, Machinga District Water office and from online publications.

3.8. Data analysis techniques

Quantitative and qualitative data was analyzed using selected methods that were deemed to present the best output. Statistical analyses were done using a variety of computer packages. Data from the rice farmers' survey was coded and analyzed using Excel Micro software and cross-tabulations were calculated (Nyirongo, 2003). Descriptive and inferential statistics were used in analyzing the data. Descriptive statistics were used to describe the basic features of the data by summarizing frequencies.

Data obtained from the activity in 3.8 was fed into software called EcoSim7,0 to be rarefied (Gotelli and Entsminger, 2002 in Ndengu 2010). This was to ensure that estimates were not biased or influenced by abundances or sampling intensity (Gotelli and Colwell, 2001 in Ndengu 2010). The software was then commanded to calculate and give out PIE Hurlbert´s species index.

PIE Hurlbert´s index calculates the probability of an interspecific encounter (PIE). In other words, this index gives the probability that two randomly sampled individuals from the assemblage represent two different species. Let N equals the total number of species in the assemblage, and let p (i) represents the proportion of the entire sample represented by species i. PIE is calculated as follows (Gotelli and Entsminger, 2002 in Ndengu 2010):

$$PIE = \left(\frac{N}{N-1}\right)\left(1-\sum_{i=1}^{s} p_i^2\right)$$

There are several advantages of using PIE as a simple index of evenness. First, the index is easily interpreted as a probability. Secondly, the index is one of the few that are unbiased by sample size, although the variance increases at small N. Third, PIE has an important analog in population genetics. It is equivalent to the calculation of heterozygosity (H), the probability that two alleles are not identical by descent.

One way ANOVA using Paleontological statistics package (PAST) was used to compare river and canal discharges from August up to November 2008, from which a graph was generated to differentiate between water flowing in the stream and water flowing in the canal. This technique was used because it tests differences between two independent groups on a continuous measure (Pallant, 2001). Microsoft Excel was used to generate pie charts because it has a range of functions that can be utilized for analysis and presentation of experimental results (Liengme, 2000).

Hydrological data, which was mostly quantitative, was analyzed using the non-parametric Mann-Kendall Test and Sen.'s slope estimator, from which a chart was generated to illustrate trends in the rainfall pattern in Mposa area (Helsinki, 2002). The nonparametric Mann-Kendall test (S) was applied to monthly, seasonal and annual time series to detect the presence of a monotonic increasing or decreasing trend and the slope of a linear trend was estimated with the nonparametric Sen.'s method (Gilbert, 1987 in Mbano and Ngongondo, 2009).

The free spreadsheet based software MAKESENS developed by Sami, Scholes and Edwards (2002) of the Finnish Meteorological Institute was used to find the trends in the rainfall series. The spreadsheet has in built Mann-Kendal (S) test statistic and Sen.'s Slope estimator functions. The procedure was based on the nonparametric Mann-Kendall test for the trend and the nonparametric Sen.'s method for the magnitude of the trend. The Sen.'s method uses a linear model for the trend.

Thematic analysis was carried out especially on qualitative data generated from the field surveys and consultations with key informants. Literature and observations were used to interpret the collected data.

3.9. Limitations of the study

The following may be considered as major constraints faced by the researcher during field data collection:

- The fact that this research was conducted in the specified period obliged the researcher to limit the sample population to sixty irrigation rice farmers. As compared to the study population of 120 irrigation farmers, the sample household limited to 60 may affect the degree of representation.
- Weak recording system by the Irrigation Water Users Associations, and Machinga District Water Offices regarding the history of the irrigation system.
- Problem of getting time series data of river discharge since farmers' ability to recall was not strong and that Lingoni River is not gauged.

Nevertheless, these limitations have not significantly affected the comprehension of the subject matter, the quality of the study and the conclusions drawn herein, owing to the comprehensive literature search and stakeholder consultations that were conducted.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0. Introduction

This chapter presents, discusses and analyses results of the study by describing the irrigation management of the Lingoni Rice Irrigation Scheme, analysing its water control infrastructure, establishing its irrigation efficiencies, analysing the impact of the scheme on river downstream discharge and assessing long-term rainfall variability in the Lingoni catchment. This provided an in-depth understanding of the general overview of the impact of the scheme and climate change on Lingoni River discharge.

4.1. Development of Lingoni rice irrigation scheme

4.1.1. Household source of livelihood and income

Lingoni Rice Smallholder Irrigation Scheme was playing a vital role in the livelihood strategies and local economy of the rice farmers in Mposa area. The survey revealed that farmers had diverse livelihood strategies. In addition to their irrigation scheme plots, 93% of respondents reported having upland rain fed fields (*munda*), 16% had wetland gardens and 29% had stream bank gardens (*dimba*). Further, many plot holders had sources of income in addition to farming: 40% listed casual labor (*ganyu*), 19% marketing of crops, 23% owned a small business, and 9% had other occupations.

When asked to rank which of their fields produced the most food for family consumption, 84% identified irrigation scheme plots, 12% said upland rainfed plots, and the remainder 4% said wetland gardens. In addition, 71% stated that three-quarters or more of their food for household consumption was scheme generated, 23% said approximately one-half of their food was produced on the scheme, and only 6% reported that less than half came from scheme farming (Figure 5).

In addition, the survey also revealed that most cash earnings for the farmers were as well irrigation scheme-generated. When asked to rank which fields produced the most cash income, many farmers said rice scheme plots. Eighty-five percent reported that three-quarters or more of their income came from the scheme, 12% stated that approximately one-half came from the scheme, and only 3% said that scheme farming constituted less than half of their income. The fact that most of the foodstuff and income for the farmers were scheme- generated, suggests that river water was heavily used for maximum yield in the scheme.

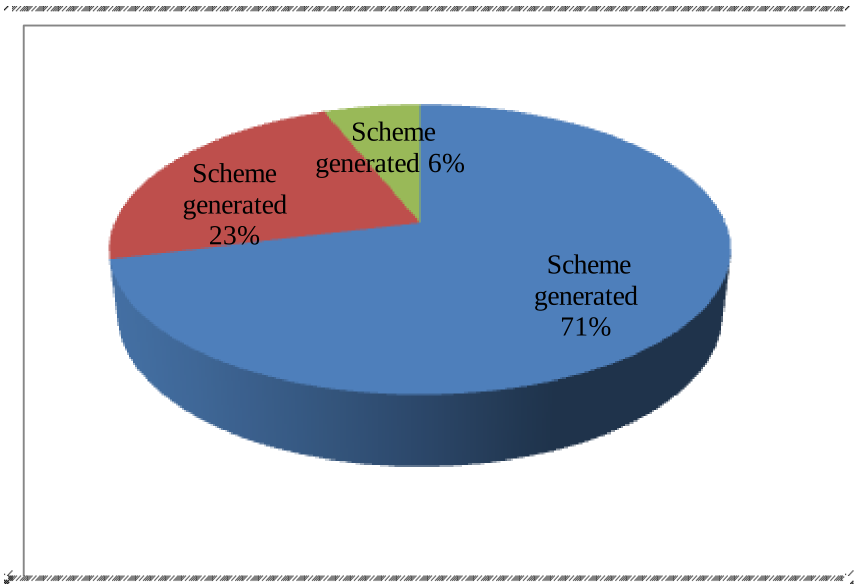

Figure 5: Rice farmers whose household food is generated from the scheme

There is an urgent need, therefore to properly conserve and manage river water for future use. This is because the demand for water keeps on increasing due to its increasing consumption for agricultural, industrial, environmental and domestic purposes (Mazumder, 1983). Good management practice right from the inception of the project is essential; otherwise, farmers once accustomed to irrigate with plenty of water find it difficult to change their practice during periods of scarcity. Besides, proper and efficient management ensures not only the conservation of water, but also helps in increasing the productivity and preservation of soil fertility.

4.1.2. Number of years farmers had worked on Lingoni rice irrigation scheme

Table 6 summaries the period farmers had spent growing rice in Lingoni irrigation scheme.

Number of Years Worked on the Scheme	Females	Males	Total	Percentage
1 – 4 Years	18	10	28	46.6
5 – 10 Years	8	8	16	26.7
11 – 14 Years	0	0	0	0
15 – 19 Years	6	0	6	10.0
20 + Years	2	8	10	16.7
Total	**34**	**26**	**60**	**100**

From Table 6, differences existed between the numbers of years farmers had held plots in the rice scheme. The study revealed that 46.6% of the respondents had farmed their plots in the scheme for at least four years, 26.7% had farmed for at least ten years, 10% represented the number of farmers who had been on the scheme for at least nineteen years and 16.7% had grown rice for more than twenty years. The results imply that the majority of the rice farmers (46.6%) had been on the scheme for some few years.

In most cases, it is always assumed that rice farmers who have farmed in the scheme for a long time have a vast local knowledge and experience on water resources management. This also gives them a sense of ownership and autonomy in managing the rice scheme and the water resource from degradation and dilapidation. The results agree with the findings of Sabola (2002) on the relationship between length of stay and knowledge of interrelationships of forest and lake resources management.

The paper indicated that there was much lower knowledge of resources interrelationships among those respondents who had stayed on Chisi Island for 1 to 9 years compared to those who had stayed there for more than 10 years. The same results also showed that the knowledge was very high for the respondents who had stayed on the island for over 50 years. This is probably because under conditions where the local people are recent migrants from a quite different area, they may not have much experience with resources (Langill, 1999 in Sabola 2002).

4.1.3. Number of Plots Held by the Rice Farmers

Table 7 shows the number of plots owned by rice farmers.

Number of Plots Held	**Females**	**Males**	**Total**	**Percentage**
1- 2 Plots	28	14	42	70.0
3 – 4 Plots	6	8	14	23.3
5 – 6 Plots	0	0	0	0
6 + Plots	0	4	4	6.7
Total	**34**	**26**	**60**	**100**

The overall response, 70% of the total sample reported that they farmed two plots only. Those with three to four plots constituted 23.3% and those with more than six plots were 6.7%. In addition, a majority of the farmers had had relatively adequate land holding size. This then implies that land was not a limiting factor to their productivity. This is because one of the most important factors of production is land (Mwafongo, 1996). In addition, the quality and quantity of land determines the amount of harvest from that particular land (Mwalwanda, 2008).

More over, when the irrigation scheme land was originally parceled out to farmers in the late 1980s, each farmer received two plots, constituting about 0.15 ha. However, the study established that some rice farmers who had positions in society, especially the local leaders had plots that measured more than the required size. This indicates that a lot of water could be used to irrigate such big plots. Hence proper demarcation of plots in the scheme is very important for design purposes, since it is easy to establish water requirements in the field (Republic of Kenya, 1987).

4.1.4. Literacy and education level

Table 8 indicates the literacy and education level of the rice farmers in the scheme

Education Level	Proportion (%) of Respondents		
	Female (n=34)	Male (n=26)	Both (n=60)
None	59	23.1	43.3
Some Primary (Std 1 – 8)	35	76.9	53.4
Sec-Junior (Form 1 – 2)	6	0	3.3
Sec-Senior (Form 3 – 4)	0	0	0
Adult Literacy	0	0	0
Technical College	0	0	0
Total	100	100	100

Table 8: Highest literacy and educational level of respondents by sex

Literacy is defined as ability to read and write in any language (NSO, 2008). In the study population, the majority (53.4%; n=60) of the respondents had at least attained some primary education. About 3.3% had done some secondary education while 43.3% reported to have never gone to school at all. Male respondents had on average, higher literacy (73.9%) than females (41%). Besides, the total number of both male and female rice farmers that had attended some primary and secondary education was 56.7%.

During the last census of 2008, there were 10.6 million people aged 5 years and older, out of this, 6.8 million were literate, representing 64% literacy rate (NSO, 2008). Therefore, for the study population, it could be concluded that the level of literacy (56.7%) was not satisfactory.

Education empowers a society to understand and articulate the socio-economic and environmental issues affecting their lives. Studies (WRI, UNEP, UNDP and World Bank, 1996 in Phalira 2006) have shown that education coupled with employment, especially of women, yields substantial improvements in environmental management. On the other hand, lack of adequate educational background amongst the farmers poses a very big threat to river water. This is because in most cases, water is taken as a public resource, hence; it is always wasted by its users (van der Zaag, 2002). The situation in Lingoni Rice Irrigation Scheme is further worsened by the fact that women, who are the custodians of water resources management and conservation, have a lower literacy rate than men.

4.2. Management and institutional issues of the irrigation scheme

4.2.1. Weed control in canals

There were two main canals in the rice scheme constructed on both sides of the river to maximize the area that could be irrigated. These canals were used to divert water using controlled surface flooding or gravity flow into rice plots. This is because in most small irrigation projects, diversion conveyance method is the best option for the irrigation users (Dinku, 2004). In addition, the diversion method in the scheme was made possible because the topography of the area was plain, with high slope at the upstream and low slope at the downstream. However, the physical observation of the scheme revealed that these main canals were earth lined, without proper care and maintenance since both had aquatic weeds growing inside them (Figure 6).

Figure 6: One of the main canals with aquatic weeds (Courtesy: LRIS)

In most cases, aquatic weeds in irrigation canals are seen as a threat to the water management system as a whole (Moris and Thom, 1990). This is because the presence of aquatic weeds could probably reduce the speed of water flow in the canals, hence encouraging high rate of seepage and evapotranspiration. Aquatic pests, such as rooted aquatic macrophytes, reduce storage capacity in reservoirs, block screens and intakes on pumps, interfere with hydroelectric production, distort canal design features (increase sedimentation, decrease channel flow, etc.), degrade recreational uses, and reduce water quality and wildlife habitat value (Systma and Parker, 1999).

Hence, poor design of the irrigation canals in particular, and of the scheme in general, significantly promoted wastage of river water. This fact is in agreement with results (Vandersypen *et al*, 2006) that, because of the minimal management strategies of farmers and water bailiffs, efficiency in the scheme was low and showed no sign of improving. Furthermore, these observations were similar to earlier observations by FAO (1999), who reported that present project designs are not capable of supporting economically and technically the intensified, diversified and more water efficient production systems of the future. This shows that, modernization or improvement efforts of Lingoni Rice Irrigation Scheme have been inappropriate and poorly adapted to present circumstances; hence, rice-based production system in the scheme remains incomplete.

This also suggests that farmers themselves, not only Executive or Scheme Management Committee members, should be involved in weed-control decision-making processes from the onset (Ferguson and Mulwafu, 2004). Besides, the Irrigation Act of 2001, states that no farmer shall fail to maintain irrigation canals, drains and associated infrastructure in his or her agricultural holding if the holding is within a communal irrigation scheme and that any person who contravenes this subsection shall be guilty of an offence (Malawi Government, 2001).

4.2.2. Irrigation management

Lingoni Rice Irrigation Scheme was poorly managed. The resulting deterioration is evidenced by lack of several management issues such as inoperable equipment, weed-choked canals, the erosion and failure of physical works and improper care of the facilities, rehabilitation, and maintenance. This is probably because there were no laws to regulate the management of the scheme. In addition, the scheme lacked a strong and vibrant Irrigation Committee, lack of inputs such as plastic papers for lining, heavy rains that destroyed renovated structures, farmers' reluctance to provide labour, and numerous other complications and there were no signs of infrastructural management and rehabilitation of the whole scheme. Besides, structures such as headworks, roads, and other facilities on the scheme were very old and dilapidated. The situation was further aggravated by the fact that many farmers regarded rehabilitation as a committee responsibility and were reluctant to effectively take part in the management of the scheme (Ferguson and Mulwafu, 2004).

Lack of a strong Irrigation Committee made it difficult for the rice farmers to have a platform where issues of water management could be discussed. However, it is encouraged that irrigation systems managed by the community should have full responsibility that involve some kind of organizational and management mechanisms that help to ensure efficiency and sustainability (Dinku, 2004). This would help to analyze possible constraints that can arise due to policy, institutional and social factors in the implementation and operation of the rice irrigation project.

According to Stern (1988) where several farmers are carrying out irrigated cultivation on adjacent farms or plots of land using a common source of supply and draining to a common drainage system, certain tasks and activities should be properly coordinated. This would help to ensure the smooth running of the irrigation system to avoid conflicts that could possibly arise among irrigation users. Generally, insufficient attention to the institutional environment in which irrigation takes place creates built-in defects in operation and management (Dinku, 2004). As Stern (1988) noted, where issues of organization and management of irrigation are not well considered, problems may arise such as: existence of indefinite regulations or instructions about the share of responsibilities; lack of coordination between different work groups; absence of a common meeting point for discussing and settling differences, and absence of an effective association to represent the irrigators' interests.

In Zimbabwe, a study of the ten irrigation schemes revealed that all of them had Irrigation Management Committees (IMCs) and their sub-committees whose main tasks were to look into issues of marketing, water management, crop production and security (FAO, 2000a). The report further documented that the IMCs also used a system of by-laws to manage and run the schemes. Studies (Vandersypen *et al*, 2006) indicated that major physical rehabilitations, economic and institutional reforms carried out from the 1980s onwards succeeded in making a success story of the irrigation projects in Niger because the irrigation committee attempted to restrict the influx of new water users by introducing an entrance fee, and that in 1976, by-laws regulating access and distribution of water were drafted and put into force.

A study of the Gediz basin irrigation scheme in Turkey (IWRM, 2000) also noted that there was an active Irrigation Association whose major tasks included liaison with State Hydraulic Organization (DSI) over matters of water resource allocation before each season, the operation of secondary canals and tertiary head gates, maintenance of secondary and tertiary canals, and monitoring. The report further suggested that the Gediz Basin Irrigation Association was probably the most successful example of irrigation management associations because it was financially viable in that it collected sufficient irrigation fees from members to cover all operation and maintenance costs, and pay for the salaries of the technical staff it employed. Again, there were no longer any disputes over water since allocation rules were clear and perceived as fair, so that farmers could go about their tasks in a routine that was non-confrontational.

Hence, lack of an activity irrigation committee in Lingoni Rice Irrigation Scheme posed a great threat to river water conservation and management practices. Since not all renovation problems can be addressed at once, meetings are needed where farmers, together with specialists, can identify and prioritize the most salient ones.

4.2.3. Irrigation extension

According to the baseline survey and physical observation of the researcher, most rice farmers in the scheme (97%) reported that they had no opportunity to acquire modern irrigation skills from Agricultural Field Assistants or Irrigation Engineers while only 3% admitted to have attended a one day training course at Domasi Government Irrigation Scheme. In Malawi, Agricultural Field Assistants or Irrigation Engineers are specialists employed by government to demonstrate how sustainable irrigation farming is supposed to be done (GOM, 2004). Ferguson and Mulwafu (2004) pointed out that a critical aspect of rehabilitation of the irrigation scheme is capacity building and that, farmer training in scheme maintenance and water management is an integral part of the rehabilitation process.

Furthermore, for farmers to irrigate successfully, they require a number of specialized skills such as knowledge of how to level their fields, the signs of moisture stress in plants, when to stop watering, control of salinization, interactions between watering and fertilizer use, how to avoid waterlogging and unnecessary erosion, synchronizing irrigation activities with rainfed farming, how and when to do maintenance, the rotation system, signs of nematode buildup, and how to recognize and control weed growth (Moris and Thom, 1990). This listing is sufficient to indicate that there is a fairly large element of skill and local experience needed to achieve sustainable irrigation.

According to van den Ban and Hawkins (1988), the main aim of extension program is to initiate change, in order to bring about sound agricultural development especially on the part of smallholder farmers. It offers them technical advice and also supplies them with the necessary inputs and services. On the other hand, extension work is not an arbitrary activity. It requires systematic planning in order to bring about the desired change (Dinku, 2004). Therefore, the results of the findings imply that farmers in Lingoni Scheme were practicing rice irrigation without essential technical knowledge on crop water management.

Kansungwi (2002) asserted that due to lack of technical skills, capital to invest in water control structures, and small land holdings, Lingoni Rice Irrigation Scheme farmers tend to have no proper techniques of water management. Irrigation of crops is a highly skilled task if it is to be successful because farmers must not only be able to predict when crops will need water to counteract the effects of excessive evapotranspiration, but also apply the right amount of water and control its quality (Briggs and Peter, 1993). Therefore, farmers' lack of proper knowledge on irrigation water management in the scheme could result in wastage of water (Dinku, 2004). Moreover, the Irrigation Act (2001) encourages District Assemblies, non-governmental organizations, the private sector and other relevant institutions to contribute towards provision of irrigation extension services, in accordance with guidelines provided by the Government (Malawi Government, 2001).

4.3. Water resources management practices in the scheme

4.3.1 Analysis of Lingoni River and canal discharges

Figure 7 analyses river and canal discharges during the irrigation period.

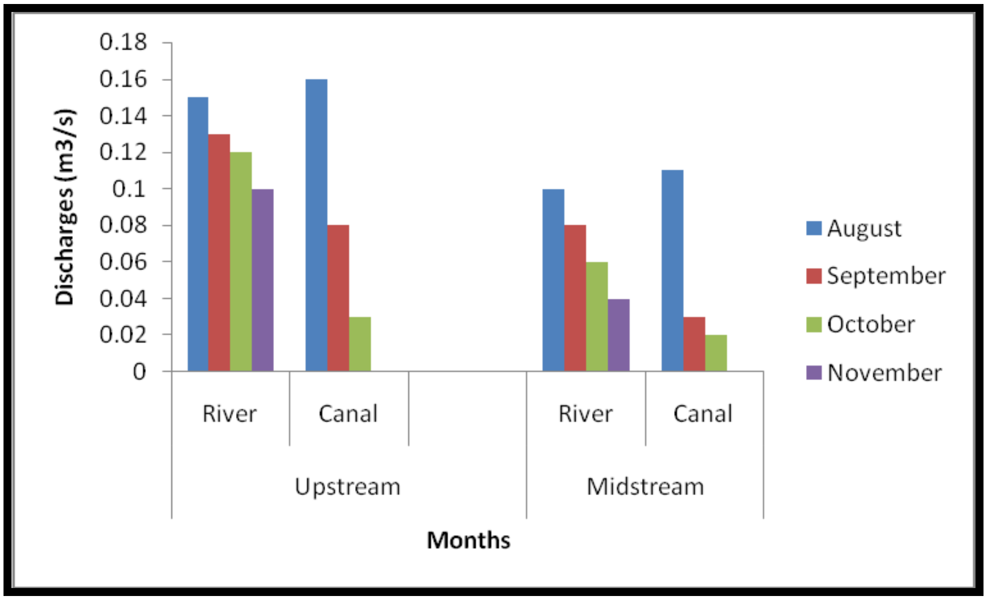

Figure 7: Lingoni River and Canal Discharges

The study established that unproportional amount of water was being abstracted by the rice farmers from the river through the canals to irrigate their plots upstream and midstream of the Lingoni Irrigation Scheme. The amount of water abstracted was very high in the month of August in both sections of the river, with no major impact from September, October, up to November. High amount of water diverted in August was due to heavy dose of water required by rice in the early vegetative and flowering stages.

This implies that the irrigation method being practiced by these farmers applies a large amount of water to the rice plots in the initial stages of rice production. This amount is much higher than in other schemes (Domasi Rice Irrigation Scheme) where water saving techniques have been adopted (Labana, *Personnel Communication*).

Rice requires different amounts of water during different stages of growth. The crop takes approximately 130 days to mature and undergoes four stages of growth which include the initial stage (20 days), crop development stage (40 days), mid-season stage (40 days), and late stage (30 days) (FAO, 2001). FAO, (2001) suggests that at planting and during the initial stage, the evaporation is more important than the transpiration and the evapotranspiration or crop water need. During the initial stage, evapotranspiration is estimated at 50% of the crop water need and during the mid-season stage, when the crop is fully developed.

During the crop development stage, the crop water need gradually increases from 50% to 60% of maximum crop water need. The maximum crop water need is reached at the end of the crop development stage which is the beginning of the mid-season stage. During the late stage, starting from late October up to the end of November, no water is supplied into the field because rice is a dry harvested crop, hence it is allowed to dry out or die, and no irrigation is given to rice during this late stage. The results therefore imply that water abstractions had no significant impact on the reduced flows of Lingoni River on the downstream of the irrigation scheme as a whole.

4.3.2. Variation of Cross-Sectional Area of Lingoni River Sections

Table 9 shows mean cross-sectional area of the three sections of Lingoni River in square metres (m^2).

Mean Cross-sectional Area	Section	N	Mean	Std. Deviation	Std. Error Mean
Upstream	A	11	5.398	0.224	0.067
	B	11	4.957	0.112	0.034
	C	11	4.860	0.069	0.021
Midstream	D	11	1.453	0.280	0.084
	E	11	1.007	0.042	0.013
	F	11	0.889	0.168	0.051
Downstream	G	11	0.797	0.192	0.057
	H	11	0.074	0.107	0.032
	H	11	0	0	0

Table 9: Mean cross-sectional area of Lingoni River sections

The results (Appendix I) were then analysed using univariate statistics. Changes in form and shape of Lingoni River at the mid-stream (irrigated area) showed that there was heavy sediment deposition taking place as compared to the up-stream (unirrigated area).

Deposition taking place in the irrigation site was a result of stream bank cultivation that encouraged loose soil to fall into the river channel and reduce discharge (Morisawa, 1985). In most cases, land use changes from natural vegetation cover to agriculture affects sediment yield. Van Dijk and Vogelgang (1948, in Morisawa 1985), observed an increased sediment yield resulting from conversion of areas protected by natural vegetation to grazing and farming in the tropics. River sedimentation most often causes the shape of the river to dwindle in area.

Furthermore, recent human activities in the catchment area have greatly reduced the stream flow of Lingoni. Studies show that the catchment area of Lingoni River basin, namely Liwonde Forest Reserve is under threats from human related activities such as deforestation and poor agricultural practices, thereby affecting water flow. This tends to agree with results on forest resources degradation in the area documented by Sabola, (2002).

Afforestation and deforestation are known major human activities responsible for altering river flows behavior in many catchments (Calder, 1992 in Ngongondo 2002). A number of causes of deforestation included encroachment for cultivation and settlement due to high population in the area, uncontrolled bush fires and wanton cutting down of trees which is contributed by activities such as curios carvings, burning of bricks, pit sawing, firewood collection (for fish smoking and tea rooms), charcoal production, and unlawful cultivation.

In Malawi, water and land use planning has been the responsibility of the government through the Water Resources Board to ensure that catchment areas are not utilized for agricultural production and human settlements (GOM, 1998). This issue is addressed by the Water Resources Act, which prohibits agricultural production in catchment areas, and bars people from developing the area at a distance less than 50 metres from the water body. However, it seems this Act is not being adhered to in Lingoni Rice Irrigation Scheme.

4.3.3. Irrigation water application duration

Figure 8 shows the daily irrigation cycle being followed by rice farmers in the Lingoni scheme.

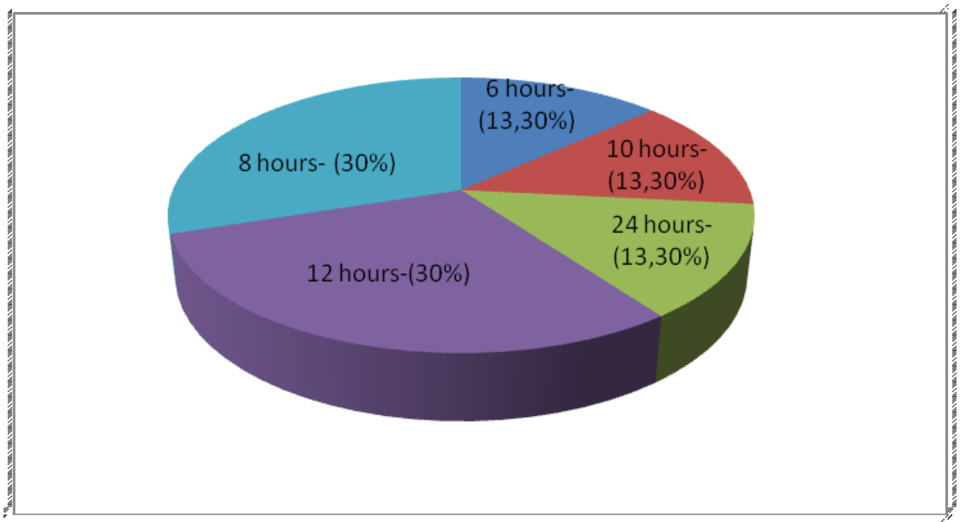

Figure 8: Daily irrigation cycle in Lingoni Rice Scheme

Water application duration (WAD) is the time the farmer is allocated the water for irrigation (Muchangi, 2000). During this time (Zaw, 2004), the farmer must supply his or her crops with enough water to last the whole time of the interval decided after calculating crop evapotranspiration or crop water need (ETc).

Despite this arrangement, it seems that there were differences in the daily irrigation cycle of farmers in the rice scheme. This is evidenced by the results of the study that indicated that a bigger number (30%) were either irrigating their plots for 8 or 12 hours while the rest (13,3%) were either irrigating for 6, 10 or 24 hours. A difference in water application duration may be perceived by some farmers as receiving unequal amount of water (Muchangi, 2000). This is a potential cause for conflicts. Informal discussions with the rice farmers on irrigation duration indicated that they wished the number of hours per day should be 10, from 0700 till 1700 hours, and certainly not be over 12 hours. Those who were irrigating for more than 10 hours reported that the soil type in the scheme usually became very dry probably due to intense heat in the area.

4.3.4. Irrigation scheduling

Figure 9 shows the irrigation schedule in the Lingoni Rice Irrigation Scheme.

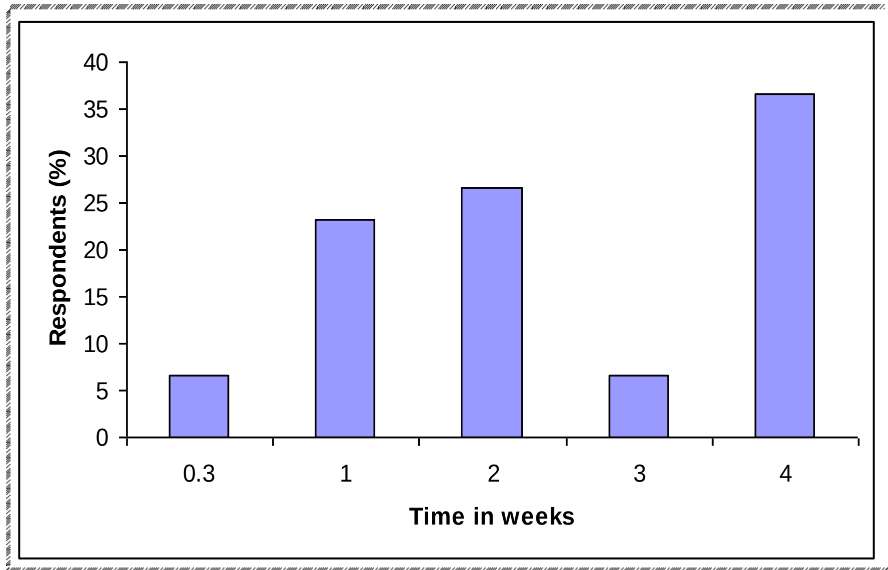

Figure 9: Irrigation schedule of the scheme

The study found out that farmers in the rice scheme had a low rate of adoption of objective scheduling techniques and irrigation system that were perceived to increase water use efficiency. A bigger number (36,6%) of them irrigated their plots throughout the month, 26,6% irrigated for two weeks, 23,3% for one week and those irrigating for less than a week and three weeks constituted 6,6%. This disagrees with the objectives laid down during the inception of the scheme. When the scheme was established in 1994, water in the rice scheme was issued on a more or less continuous basis to the two main canals for most of the summer period. Canal discharges were not fixed, but varied during the season based on estimates of amount of water in a rice plot. However, in response to the very difficult period of 2004/5 growing season, important changes were made in water allocation practices.

Current practices allow for the determination of the number of days of irrigation every week. This was done by assuming that all communities in the Lingoni basin would have equal share of water from the river. This study therefore, established that an irrigation schedule proposed that rice farmers were supposed to irrigate their plots for seven consecutive days from Thursday of one week up to Thursday of the following week thereafter the canals were to be closed for the downstream communities to use the river water. The interventions succeeded in establishing a good adequacy of water supply, thus creating the necessary conditions for boosting rice production (Vandersypen *et al*, 2006). Again, for optimum yields, timing and quantity of irrigation applications must be such that plants never suffer from a lack of water (Mather, 1978).

However, the problem with this arrangement was that there were no laid-down rules to bind this agreement and measures to follow in order to punish the offenders. In most cases rice farmers were violating this agreement because their crops were always suffering from water stress. Consequently, they were continuing opening their canals even if they were not supposed to irrigate that week because rice is a water intensive crop and for optimal growth it needs permanently flooded conditions for about four months of its growing season (Singh, 2005). This forced the downstream water users to cut the river so that they too could continue receiving the water, hence affecting the flow of Lingoni River (Figure 10).

Figure 10: Unplanned diversion of Lingoni River (Courtesy: LRIS)

Since the cut area was not constructed into a diversion box, there was severe soil erosion taking place such that another river had been formed and it is a source of conflict between rice irrigators and downstream water users. This situation is similar to the irrigated farming in Rombo scheme in Kenya that was characterized by a significant level of ongoing conflict between competing water uses and users (Krugmann, 1994).

However, the situation was worse in Rombo rice scheme because according to Krugmann, the conflicts arose at different levels: within particular furrow systems (within or between subsections); between different furrows; and between irrigation and other uses of water. In this case, the most common cause of conflict within and across basins is water stealing.

Because water is scarce and profits depend on having access to sufficient amounts at a particular time, farmers may try to extend the duration of their water allocation at the expense of the next one in the queue. A study of water use and management in Likangala River (Mulwafu, 2000) indicated that although water supply in this area was generally sufficient, its distribution and use was extremely skewed and that this generated conflicts that underscored the deeply entrenched power relations existing in the area particularly between the primary and productive users of the water resources. Hence, the irrigation schedule currently followed in Lingoni Rice Irrigation Scheme is a source of conflict because it has prevented stream flow downstream.

4.4. Impact of the scheme on downstream flow

4.4.1. Reduced flows in Lingoni River

Figure 11 shows the boundaries used to demarcate the plots.

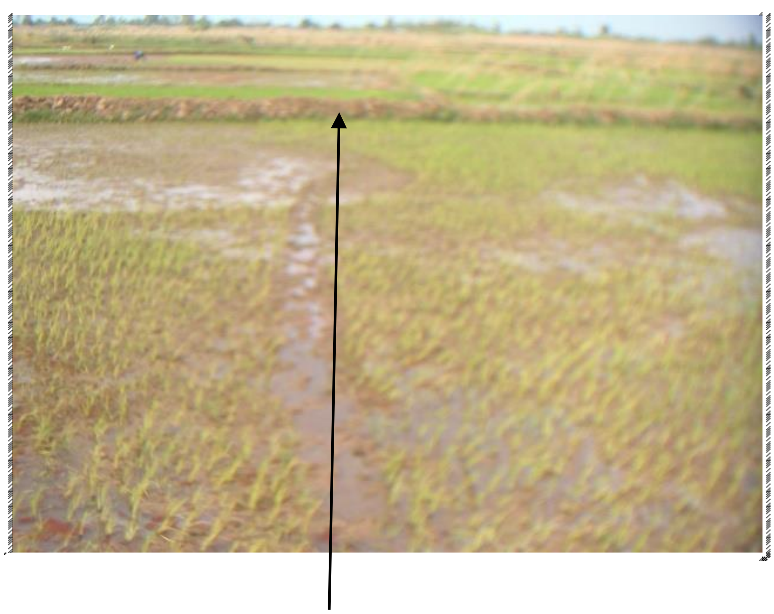

Figure 11: A levee demarcating rice plots (Courtesy: LRIS)

The study established that there was zero flow in Lingoni River on the downstream of the rice scheme. This was as a result of the levees used to demarcate the rice plots that were as high as 60 cm since the method being used in the scheme involved the construction of basins. Basins are flat area of land, surrounded by low bunds, which prevent water from flowing to the adjacent fields or plots (Zaw, 2004). The layouts of the basins were so made that each of them gets one or more inlets. Usually, the basins were filled by admitting a large stream of water in one basin. As soon as the basin was filled in, the next basin was opened and filled, and so on.

This meant that a lot of water was needed by each farmer to fill their basins during irrigation period resulting into river water being overused. Therefore, it is important that before rice plots are constructed, the heights of the bunds or levees or embankments be properly measured to avoid river water wastage. In Usangu Rice Irrigation Scheme (Tanzania), farmers have been advised to reduce water depth from 18 to 12 cm and that agronomists suggest 5 cm to be sufficient (Fox, 2004).

4.4.2. Comparison of the scheme size and water diverted to the rice plots

Water diverted from Lingoni River took a long period of time before it filled a rice plot. This was established after applying the quarter time rule. Water applied to the plot had to reach the end of the basin or cover the whole basin in 160/4 that was equal to 40 minutes. However, during the experiment, it took almost 150 minutes for the basin to be filled with water. This was probably caused by the soil type in the basin that had developed several cracks probably due to intense heat and severe shortage of water in the rice field (Figure 12). The cracks in the scheme implied that a lot of water had to infiltrate the soil before it started flowing; hence it took a long time before the water reached the far end or covered the entire field.

Figure 12: Dry rice field due to shortage of water (Courtesy: LRIS)

Since it took longer to supply the required water in the basin, either the tertiary canals per basin have to be increased or the size of the basins should be reduced. The suggestion tend to agree with FAO (2001), documentation that under such a situation whereby it takes longer for the basin to be filled with water, the stream size has be chosen in a way that indeed the field be covered with water within some calculated (40) minutes because if it took longer then the distribution of water in the root zone would be poor.

Besides, if it was for some reasons not possible to increase the stream size and it took longer than the calculated (40) minutes to cover the field, then it would be necessary to reduce the area or the size of the basin such that it is possible to cover the field within the calculated time. In the People's Republic of China, it was noted that the reduced flow of Yellow River due to diversions resulted in a decline of rice area in the 1980s, and the rice area became less than 20 % of the total area planted under summer crops (Bin, Chang and Tanaka, 2002).

Bin *et al*, (2002) further established that compared with maize and cotton, the irrigation duty of rice was about ten times as high and that the increase in water diverted from the Yellow River might have been caused by an expansion of the scheme in recent years. The study further stated that the annual irrigation water volume from the same river was 150 m^3 in the early stage when only upland crops were planted, but after the large-scale introduction of rice the annual irrigation water volume became much larger and reached, as an average of 500 m^3. This therefore, calls for a reduction in the size of the Lingoni Rice Irrigation Scheme.

4.4.3. Change on the cropping pattern

Lack of water downstream of the Lingoni Rice Scheme forced some rice farmers to switch to other crops such as maize, beans and pumpkins during the irrigation period. During the field study, some rice farmers were found irrigating these plants with watering cans, abstracting water from a well dug inside Lingoni River (Figure 12). The change of the cropping pattern was probably caused by improper construction of the rice plots in the scheme.

Figure 13: Farmers drawing water for irrigating other crops (Courtesy: LRIS)

Furthermore, reduced flows down stream of the scheme might have been as a result of expansion of the scheme without taking into consideration the capacity of the river. These results agree with the findings of Bin *et al*, (2002) who documented that the change of the cropping pattern was caused due to several factors such as reduced flow of water in the river caused by unplanned diversions, the continuous expansion of the rice scheme and that the percentage of land occupied by rice compared to the total cropping area was also increasing.

The situation did not please these rice farmers since the prime reason for the establishment of Lingoni irrigation scheme was to grow only rice (Labana, *Personnel Communication*). If the water supply was enough, these local farmers preferred to growing rice over maize, beans, and other upland crops, because of the high yield, high quality, and high price of rice (Bin *et al*, 2002). The situation therefore implies that a lot of water was being used in the upper part of the rice scheme, which caused shortage of water downstream. This assumes that much of river water was wasted through inappropriate method of irrigation in the scheme (Mulwafu, 2002). Mulwafu further reported that often, over-irrigating occurred with basins being filled with water until the ridges were submerged.

Besides, the absence of water pricing means those smallholder farmers had no incentive to conserve water or to change to alternative techniques, such as improved scheduling of irrigation. Hence, the farmers were irrigating other crops in the scheme because they had no alternative, due to absence of water down the scheme. Considering the growing water shortage in the Lingoni river basin, it is pertinent that the rice scheme be reduced in area.

4.5. Vegetation Species on Lingoni River Banks

Vegetation diversity indices by Herbert PIE in the upper stream, middle stream, and downstream sections of Lingoni River are shown in Figure 14.

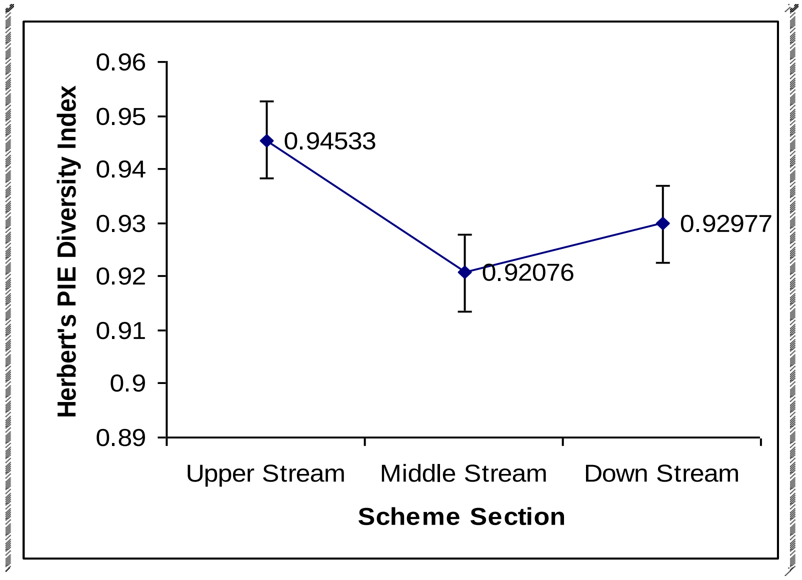

Figure 14: Vegetation species diversity in three sections of Lingoni River

The results showed that there was a big difference in species diversity (SD) between the three sections with the lowest number being in the irrigated site. The upper stream had the largest number of species at both low and high 95% confidence interval, followed by the down stream and then the middle stream. The reason is that rice farmers were growing rice very close to the river banks, hence affecting species diversity in the middle stream of Lingoni River. This was determined from the 0.94533, 0.92076, and 0.92977 frequency values in the simulated data respectively.

The decrease in the SD in the irrigated section could be attributed to the high disturbances caused in the site (Gotelli and Colwell, 2001; Woodwell, 2004). Irrigation agriculture requires the clearing of land to remove any unwanted plants to prevent them from competing with the plants for sunlight, nutrients and moisture needed for plant growth (Sarma, 2005). This indicates that irrigation has an impact on the river ecology.

The abundance of species in the upper stream is indicative that the site has not been disturbed. Again, water availability in this section made conditions favourable for vegetation growth. The downstream section had equally fewer species as compared to the upper stream but more as compared to the middle stream due to lack of water, an indication that rice irrigation has a big impact on the river discharge. The results agree with the findings of Fox (2004), who carried out a similar study. Fox results state that there was an undisputed correlation between rice irrigation farming and the recent drying up of the Great Ruaha River and that the main causes behind this were the so called “Small Holder Irrigation Improvement Schemes.” These were set up by the donors to assist the 20-40,000 ha of smallholder rice irrigation in the Usangu catchment to further expand their production with no regard for the environmental consequences or impact on downstream users.

4.6. Efficiencies of Lingoni Rice Irrigation Scheme

Table 10 shows the efficiencies of the scheme.

Types of efficiency	**Water entering scheme**	**Water leaving scheme**	**Efficiency (%)**	**Overall scheme efficiency**
Conveyance Efficiency (Ec)	0.0160	0.0053	46	21%
Distribution Efficiency (Ed)	0.0181	0.0038	79	
Application efficiency (Ea.)	0.0160	0.0116	79	
Use Efficiency (WUE)	0.0143	0.0160	73	
Mean	**0.0161**	**0.0092**	**69.25**	

Table 10: Mean efficiencies of the LRIS

The scheme irrigation efficiency of the Lingoni rice project was established to be 21%. The irrigation efficiency was far below that set by the Malawi government of 50%. The scheme irrigation efficiency of Lingoni was poor (FAO, 2002) due to lack of canal maintenances which were not lined and also had aquatic weeds during the period of study.

FAO (2002) documented that a scheme irrigation efficiency of 50 to 60 % was good; 40% was reasonable, while a scheme irrigation efficiency of 20 to 30 % was poor. Scheltema (2002) indicated that with day-time irrigation only, scheme irrigation efficiency of 70% is possible if farmers irrigate accurately. Therefore, there is a need for frequent maintenance of the canals to increase water flow that would subsequently increase the conveyance efficiency. High irrigation efficiency of the scheme is likely to be achieved if both conveyance and application efficiencies are improved. However, some efficiencies like water application, distribution efficiency and water use efficiency showed high efficiencies because they used the water that had already passed through the canal.

4.7. Impact of climate change and variability on Lingoni River discharge

4.7.1. Assessing the long-term rainfall trends of Mposa area (1982-2008)

Figure 15 shows annual rainfall trends of Lingoni catchment.

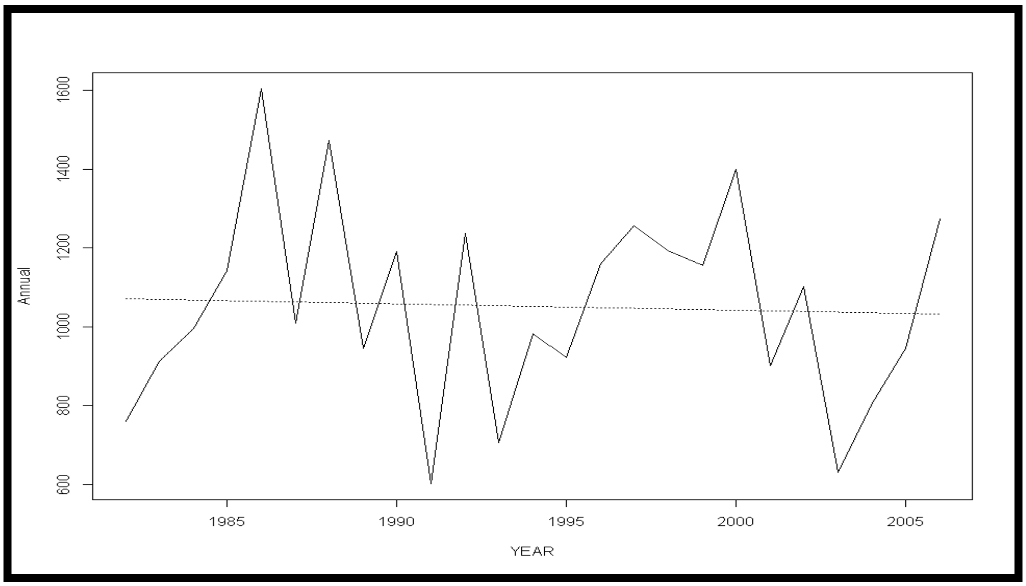

Figure 15: Annual time series and trend statistics of rainfall pattern in Mposa Area

Rainfall mean between 1982 and 2007 was 870.6 mm/year with a minimum of 470.8 mm/year in 1992 and a maximum of 1.600 mm/year in 1986. This figure indicates that rainfall mean has been the same over the years. Mann Kendall Trend suggests that there was no significance trend in the annual rainfall at 95% confidence interval. There are high values of rainfall between 1995 and 2003. The average yearly rainfall within this period was 910.8 mm/year, which is above the yearly average for the whole period. In 2005, rainfall for Mposa area was 510.4 mm/year, which is below the mean (870.6 mm/year) for the whole period indicating a slight negative trend but not significant.

4.7.2. Trends in rainfall

Table 11 shows summaries of monthly rainfall medians.

Months	**Median**	**Trend**
November	6,521	Increase
December	-1,140	Decrease
January	-1,342	Decrease
February	-0,833	Decrease
March	-0,045	Decrease
April	-0,008	Decrease
May	-0,013	Decrease
June	-1,423	Decrease
July	-1,165	Decrease
August	-0,029	Decrease
September	-1,573	Decrease
October	-0,560	Decrease
Total	**-1,61**	**Decrease**

Table 11: Summaries of medians for rainfall

Results in table 11 suggest that total median of annual rainfall was negative sugesting a decreasing trend in rainfall except November. The results show that the rainfall trend was decreasing at -1.61 mm/year during the period 1982 to 2007. The conclusion can be made that rainfall is slightly decreasing over the years.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.0. Introduction

This chapter draws conclusions on the water resources management practices in the Lingoni Rice Irrigation Scheme and climate change and variability of the Lingoni catchment. It goes further to make recommendations on areas that need improvement to ensure continuous flow of Lingoni River, downstream of the irrigation scheme.

5.1. Conclusion

The study demonstrates that Lingoni Rice Irrigation Scheme was playing a pivotal role in enhancing the economic status of the rice farmers in Mposa area. However, sustainable utilisation of Lingoni river water was threatened by a mix of inadequate river management practices by the rice farmers, unsatisfactory educational levels, archaic irrigation infrastructure, and conflicts among the beneficiary communities, unplanned river diversions and a decreasing rainfall over the years. Hence, generally river water was being wasted due to inefficient irrigation water management.

When asked to rank which fields produced the most cash income through a questionnaire, 84% of the farmers said rice scheme plots, 71% reported that three-quarters or more of their income came from the scheme, 23% stated that approximately one-half came from the scheme, and only 6% said that scheme farming constituted less than half of their income. This implies that most farmers in the area were dedicating most of their time to rice farming through irrigation, hence putting river water under pressure.

The situation was further worsened by lack of experience of rice irrigation by the rice farmers. Most of them (46,6%) had been practicing rice irrigation for less than four years. In addition, a big number of them had low levels of education, whereby the majority (53,4%) had only attained some primary education: about 3.3% had done secondary education while 43.3% reported to have never gone to school at all. This puts water resources management and conservation practices in jeopardy since lack of experience and enough basic education make rice farmers unable to appreciate the importance of river water which is always regarded as a public resource.

The study further revealed that the scheme lacked a vibrant and strong Irrigation Committee that could oversee the rehabilitation and maintenance of the rice project. As a result of this, the two main canals that were used to divert water from Lingoni River to the rice scheme were not properly maintained. During the study period, these canals had aquatic weeds that could have an impact on the speed of water flow, hence this could encourage high rate of seepage and evapotranspiration. This trend is also an indication that a big amount of water in the river was being unwisely wasted.

Besides, most rice farmers in the scheme (97%) reported that they had no opportunity to acquire modern irrigation skills from Agricultural Field Assistants or Irrigation Engineers. These results imply that farmers in Lingoni Rice Irrigation Scheme were practicing rice irrigation without essential technical knowledge on crop water management, water application methods and irrigation intervals that could also result in wastage of river water.

The study also found out that discharge abstractions from Lingoni River through canals during the four months period was highly significant in August. This is the month in which rice was being planted. The significance of water diversion in this month was probably because rice requires a lot of water during the first or the initial stage of development.

Therefore, Lingoni river discharge was very low during the planting time and expected to pick up in other months. However, the situation on the ground was different since no downstream flow was seen during the study period probably due to high levees used to demarcate the rice plots that were very high. Again, the cut that was made upstream of the river might have had an impact on low flows in the river downstream.

The study also discovered that the overall irrigation efficiency of the scheme was low, up to 21%. This was due to the fact that few rice farmers (3%) had acquired some basic training in irrigation from Domasi Rice Irrigation Scheme. In addition, the results were due to the fact that the two main canals were not lined: hence increasing the rate of seepage and prevented enough water from reaching the rice plots.

It also took a long time (150 minutes or 2 hours 30 minutes) for the basin to be filled with water. This was probably caused by the soil type in the basin that was heavy known as ferrous (*makande*) that had developed several cracks probably due to intense heat and severe shortage of water in the rice field. The cracks in the scheme implied that a lot of water had to infiltrate the soil before it started flowing: hence it took a long time before the water reached the far end or covered the entire field.

Irrigation activities in the Lingoni Rice Irrigation Scheme also caused a reduction in the species diversity (SD) of vegetation in the irrigation site, probably through changes introduced on the critical physical environment (soil texture, water holding capacity etc). The results showed that there was a big difference in species diversity (SD) between the three sections with the lowest being in the irrigated site. The upper stream had the largest number of species at both low and high 95% confidence interval, followed by the down stream and then the middle stream. This is determined from the 0.94533, 0.92076 and 0.92977 frequency values in the simulated data respectively. There were also evidences of chronic vegetation disturbances especially in the irrigation site, which may finally result into total plant growth failure if nothing is done to reduce these disturbances.

The study further documented that there was a -1.61 mm decline of rainfall over the years. The figure seems minute but may have a significant impact over a long period of time. This trend was probably due to climate variability caused by global warming.

5.2. Recommendations

Firstly, an active management strategy aimed at the conservation and preservation of river discharge is recommended in order to improve the distribution of river water throughout the Lingoni river basin, during both the dry and wet periods.

It is again, recommended that sporadic monitoring of the irrigation site should be carried out by experts from the Ministry of Irrigation and Water Development, through the Department of Water to regulate the irrigation activities within the environmentally acceptable standards.

It is also recommended that rice farmers should construct their rice plots away from the river banks to control soil erosion that may cause the river to be silted up or water to become turbid.

Most rice farmers (97%) in the scheme reported that they had no opportunity to acquire modern irrigation skills from Agricultural Field Assistants or Irrigation Engineers while only 3% had had one training opportunity. This cannot bring any positive impact as far as irrigation development and management is concerned, hence the need for more opportunities. Training should be a continuous process. A one-time training cannot bring about a desired effect on the production and productivity of irrigation agriculture.

Lastly, Lingoni River needs to be gauged so as to establish the volumetric water flow of the river in both dry and wet seasons throughout the year.

5.3. Future research

Large quantities of agrochemicals like fertilizers were being used in rice cultivation in the scheme. This means that Lingoni River water was being heavily polluted. A research therefore is needed to establish the levels of pollution.

Adjacent to Lingoni Rice Irrigation Scheme, is Domasi Rice Scheme. The scheme is under the operation of the Malawi Government. Therefore, a comparative study between the two may be necessary to establish the differences and similarities between their water management practices.

There is also the need to assess the effects of climate change on water use including the effects of rising CO_2 concentrations, taking into account possible plant adaptations and changes in soil water regime.

The averaging rainfall period for this study was about 25 years. Linacre (1992), recommended a minimum of averaging period of 50 years, hence there is need to detect trends at a larger temporal scale.

In assessing rainfall variability and trends, the use of annual rainfall series only may exaggerate the trend due to the high seasonality of rainfall. Clearer trends may however emerge if the analysis is performed at various temporal scales like:

- In the period with the most reliable rainfall (i.e. November to April only).
- Monthly scale during the main rain season (November to April).
- Daily scale in the above period to detect evidence for intensity and frequency changes.

REFERENCES

Amin, M.S.M., Rowshon, M.K., and Masumoto, T., (2006), *Rice Irrigation Management Information System for Tanjung Karang Scheme.* Kuala Lumpur, Malaysia: Macmillan.

Anton, D. (1993), *Thirsty cities- Urban environments and water supply in Latin America*; Ontario, Canada: International Development Research Centre

Aqualinc Report Limited, (2006), Irrigation Efficiency Gaps- *Review and Stock Take:* Prepared for Sustainable Farming Fund and Irrigation New Zealand Report No L05264/2. Retrieved December 20, 2012 from *www.maf.govt.nz/sff*

Barkhordari, J. (2003), *Assessing the effects of land use change on the hydrologic regime by RS and GIS: A case study of the Minab catchment, Homozygan province. Iran.* Unpublished master's thesis, University of Twente, Enscheda, the Netherlands.

Barrow, C.J. (1991), *Land degradation: development and breakdown of terrestrial Environments.* Cambridge: Cambridge University Press

Bin, D., Chang, R and Tanaka M, (2002), *Rice impact in Hennan irrigation districts along the lower Yellow River reaches.* Retrieved November 11, 2012 from *www.iwmi.cgiar.org/Assessment/files/.../IWMI-Paper-Dong-Bin.doc*

Bisgrove, R and Hadley, P. (2002), *Gardening in the Global Greenhouse: The Impacts of Climate Change on Gardens in the UK*, Technical Report. Oxford: UKCIP.

Bloomfield, K. (1965), *The Geology of Zomba, Area*. Zomba, Malawi: Government Print Press.

Bowling, O., Strzepek P. and K.M. (1997), *Examining the Impacts of Land-Use Change on Hydrologic Resources*, INTERIM REPORT, IIASA, IR-97-031/June. Retrieved December 1, 2012 from http://www.iiasa.ac.at/publication/more_IR-97-031.php

Briggs, D and Smithson, P, (1995), Fundamentals of Physical Geography, 2nd Edition, London: Oxford.

Bweya, L.A.C and Kellow-Webb C.R. (1985), *Malawi Country Report in Preparation of the Draft Action Plan for Environmental Management of the Common Zambezi River System.* Lilongwe: Malawi: Environmental Affairs Department.

Calder, I.R. (1995), The impact of land use change on water resources in sub-Saharan Africa: a modeling study of Lake Malawi, *Journal of Hydrology,* 170, 123-135.

Calow, P and Petts, G.E., (1992), *The Rivers Handbook, Hydrology and Ecological Principles.* Oxford: Blackwell Scientific Publications.

Chavula, G.S.M. (1999), *The Evaluation of the Present and Potential Water Resources Management for the Lake Chilwa basin*. Lilongwe: Environmental Affairs Department.

Cuenca R. H. (1989), *Irrigation System Design: An Engineering Approach*. Englewood, New Jersey: Prentice Hall

Dinku, L. (2004), *Smallholders' Irrigation Practices and Issues of Community Management*: *The Case of Two Irrigation Systems in Eastern Oromia, Ethiopia*. Unpublished master’s thesis, University of Addis Ababa, Addis Ababa, Ethiopia.

Dougherty, T.C. Hall, A.W. and Wallingford, H.R. (1995). *Environmental impact assessment of irrigation and drainage projects,* Irrigation and Drainage Paper 53. Rome: Food and Agriculture Organization of the United Nations.

Downing, T. E. Weatherhead, E. K., Knox, J. W. and Stockholm Environment Institute. (2003), *Climate change and demand for water final report*. Oxford: Stockholm Environment Institute.

Drayton, R.S. (1981), *A Preliminary Survey of the Water Resources of Malawi.* Lilongwe, Malawi: Water Resources Branch, Department of Lands, Valuation and Water, Office of the President and Cabinet.

Edwards, K.A and Rodda, J. C (1970), A Preliminary study of the water balance of a small Cay catchment. *Journal of Hydrology, 9(2).*

El-Ashry, M. T. (1991), Policies for Water Resources Management in Semi-Arid Regions; *International Journal of Water Resources Development* 7 (4), 230-236.

El-Bassam, N. (1999), *Sustainable Development in Agriculture-Global Key Issues.* Natural Resources and Development, a Biannual Collection of Recent German Contributions Concerning the Exploration and Exploitation of Natural Resources v.51, Tubingen: Institute for Scientific Co-operation

FAO (2007), *Crop Water Management*, Retrieved August 16, 2012 from http://www.fao.org/ag/agl/AGLW/cropwater/tobacco.stm.

FAO (2002), Small-scale irrigation design. Retrieved November 15, 2012 from *www.lboro.ac.uk/departments/cv/wedc/*

FAO and IPTRID (2001), *Field Guide on Irrigated Agriculture for Field Assistants, Food And Agriculture Organization of the United Nations and International Programme for Technology and Research in Irrigation and Drainage*; IPTRID Capacity Building Report No.1. Rome: Food and Agriculture Organisation of the United Nations.

FAO, (1992), *Water for Sustainable food production and rural development-UNCED agenda:* Targets and cost estimates. Rome, Italy: Food and Agricultural Organisation.

GEO-SLOPE International Ltd (2012), *Training and Technical Support Manual*, Calgary: Alberta: Canada. Retrieved October 10, 2012 from http://www.geo-slope.com/support/ Geostudio2012/tutorial.aspx

Gordon, P. (2004), *Stream Hydrology-An Introduction for Hydrology*, 2nd Ed. London. Wiley Press Ltd.

Government of Malawi (2008), Machinga Socio-Economic Report (Unpublished). Machinga: Machinga District Assembly.

Government of Malawi (2004a), Machinga District State of the Environment Report (DSOER) (Unpublished). Machinga: Machinga District Assembly.

Government of Malawi (2004), *Training Course Manual, Flood Moderation and Drought Mitigation Practices.* Lilongwe: Department of Water.

Gregory, K.J and Walling D.E., (1973), *Drainage Basin, Form and Process*; A Geomorphological Approach. London: Edward Arnold (Publishers) Ltd.

Hagan, I. (2007), *Modelling the Impact of Small Resevoirs in the Upper East Region of Ghana.* Unpublished master's thesis. Lund University, Lund Sweden.

Hammett, K. M. (1990), *Land Use, Water Use, Streamflow Characteristics, and Water Quality Characteristics of the Charlotte Harbor Inflow Area.* Florida: U.S. Geological Survey Water-Supply [Paper 2359-A].

Harte, J. Torn, M. S., Chang, F., Feifarek, B., Kinzig, A. P., Shaw, R. and Shen, K. (1995), Global warming and soil microclimate: Results from a Meadow- Warming experiment. *Ecological Applications* [ECOL.APPL.] 5.

Hauer, C and Lamberti B., (1996), *Methods in Stream Ecology*. London: Academy Press.

Heikkinen, K., Laine, A., Karjalainen, S.M, M, Karppinen, M and Mustikkamaa P and Murtoniemi (2005), River Basin Analysis Analytical approach to river basin management, Retrieved August 20, 2012 from http://www.environment.fi.

Her Majesty Government (2006), *Climate Change*: *The UK Programme*. Norwich: TSO

Houghton, J. (2004), Global Warming: The complete briefing. 3rd ed. Cambridge, UK: Cambridge University Press.

Hulme, M., Jenkins, G.J., Lu, X., Turnpenny, J.R., Mitchell, T.D., Jones, R.G., Lowe, J., Murphy, J.M., Hassell, D., Boorman, P., McDonald, R., and Hill, S. (2002), (1998), *Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report*, Tyndall Centre for Climate Change Research, School of Environmental Sciences. Norwich, UK: University of East Anglia.

Integrated Water Management Institute (IWMI) (2000), *Irrigation in the basin context: the Gediz River Study*. Colombo: Sri Lanka.

IPCC (2007a), *Climate Change 2007: Impacts, Adaptation and Vulnerability; Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

IPCC (2001), *Climate change 2001*: The *scientific basis.* Cambridge: Cambridge University Press.

Israelson, O and Hansen, V (1962), *Irrigation Principles and Practices.* New York: John Wiley and Sons.

Jamu, D. and Chimphamba, J. (2005), *Land use patterns in Likangala River Catchment and its implications for management of small watersheds in developing countries.* Geophysical Research Abstracts, Vol. 7, 00248, European Geosciences Union.

Kayasseh, M. and Schenk. C. (1989), Reclamation of Saline Soils Using Calcium Sulphate from the Titanium in Industry. *Ambio* 18 (2), 124-127.

King, J. (2000), *Dams and Environmental flow requirements:* Southern waters. Rondebosh, Cape Town: University of Cape Town:

Kinkingnhoun-Madagbe, (2007), *Gendered Impact of Irrigated Rice Schemes' Governance on Farmers' Income, Productivity, and Technical Efficiency in Benin*, AAAE Ghana Conference Proceedings, August 20-22, Accra, Ghana.

Kitchen, R. and Tate, N.J. (2000), *Research Methods*. New York: Longman.

Kovda, V. A. (1983), Loss of Productive Land due to Salinization, *Ambio* 12 (2), 91-93.

Krugmann, H. (1995), *Water Management, Use, and Conflict in Small-scale Irrigation*: *The Case of Rombo in the Kenyan Maasailand*. Nairobi, Kenya: IDRC.

Kwadijk, J and Middelkoop H, (1993), *Estimation of Impact of Climate Change on the Peak Discharge Probability of the River Rhine*: *Exchange Processes at the Land Surface for a Range of Space and Time Scales.* Proceedings of the Yokohama Symposium, July 1993. Utrecht, Netherlands.

Lewelling, B. R. A. B. Tihansky, and J. L. Kindinger, (1998), *Assessment of the Hydraulic Connection between Ground Water and the Peace River*. Florida: U.S. Geological Survey [Water Resources Investigations Report 97-4211].

Liengme, B.V. (2000), *A Guide to Microsoft Excel for Scientists and Engineers,* 2nd ed. Antigonish, Nova Scotia: St Francis Xavier University.

Linacre, E. (1992), *Climate and Data Resources: A reference Guide*. New York: Routledge.

Lorenzo, D.D. (2007), *Assessing the impacts of Climate Change on Irrigation Water Use in the Cambridge University Botanic Garden*. Unpublished masters' thesis, Cranfield School of Applied Sciences, Cranfield University.

Kadyampakeni, D. M. S. (2004), *Comparative Analysis of Different Irrigation Technologies and Water Management Techniques For Dry Season Cultivation of Beans (Phaseolous vulgaris) in Chingale Area Development Program (ADD)-Zomba*. Unpublished master's theses, University of Malawi, Bunda College of Agriculture, Lilongwe.

Kansungwi, A. (2002), *Irrigation Water Management Short Course*: *General Planning for Irrigation and Fish Farming; Water Harvesting and Management*. Ntcheu, Malawi: IGPWP.

Machibya, M. (2003), *Real or imagined water competition*? *The case of rice Irrigation in the Usangu basin and Mtera and Kidatu hydropower, Tanzania*. Paper presented at the *Tanzania Hydro*-Africa Conference, 17–19 November, at AICC, Arusha, Tanzania.

Machinga District Assembly (2007), Namikomia Gravity Fed Water, Hygiene and Sanitation Proposal. Lilongwe: WaterAid Malawi.

Magreta, R, Zingore, S and Magombo T (2010), *Analysis of effective market linkages in promoting investments in natural resource management in the rice-based farming system in Malawi*: A case of Nkhate rice-irrigation scheme, Lilongwe: University of Malawi Bunda College of Agriculture.

Malawi Government (2010), *National Irrigation Policy and Development Strategy.* Lilongwe, Malawi: Ministry of Agriculture and Irrigation.

Malawi Government (2007), *National Water Policy.* Lilongwe, Malawi: Ministry of Irrigation and Water Development.

Malawi Government (2005), *National Water Policy*. Lilongwe, Malawi: Ministry of Irrigation and Water Development.

Malawi Government (2001), *Irrigation Act-2001*, Lilongwe, Malawi: Government Printing Press.

Malawi Government (2000), *National Irrigation Policy and Development Strategy.* Lilongwe, Malawi: Ministry of Agriculture and Irrigation.

Manning, J.C. (1997), *Applied Principles of Hydrology*, 3rd ed. New Jersey: Prentice Hall

Mazumder, S.K. (1983), *Irrigation Engineering*. New Delhi: Tata McGraw Hill Publishing Company.

Mazunda, G.M. (2006), *Effects of Irrigation Management Transfer on the Beneficiaries: the Experience of Wovwe Rice Irrigation Scheme in Karonga District*. Unpublished masters thesis, University of Malawi, Bunda College of Agriculture, Lilongwe.

Mbano, D. and Ngongondo C. S (2009), Impacts of Rainfall and Forest Cover Change on Runoff in Small catchments: A Case Study of Mulunguzi and Namadzi catchment areas in Southern Malawi. *Malawi Journal of Science and Technology,* 9(1), 11-17.

McKinney, D.C, Cai X. and Lasdon L.S., (1999), *Integrated Water Resources Management Model for the Syr Darya Basin*. Retrieved December 11, 2012 from http://www2.adb.org/documents/reports/CAREC/Water-Energy-Nexus/appendix-A-20.PDF

Molecular Biological and Ecology Research Unit (MBERU) (2002), *Regional Training Seminar on Wetland Ecosystem Dynamics and Integrated Management Techniques-Lake Chilwa Wetland*. Zomba, Malawi: Chancellor College, University of Malawi.

Moris, J.R. and Thom D.J., (1990), *Irrigation Development in Africa:* Lessons of Experience, London: Westview Press [Westview Studies in Water Policy and Management, No. 14]

Morisawa, M. (1985), *Geomorhology texts*: *Rivers, Form and Processes.* London: Longman.

Mpaka, C. (2009), Machinga's billion water, sanitation solutions, *The Daily Times* (2009, April 7).

Muchangi, P.W (2000), *Surface Irrigation System's Design for Effective Water Management (Draft)*. Lilongwe, Malawi: Ministry of Agriculture and Irrigation.

Mulwafu, W, Chipeta C, Chavula G, Ferguson A, Nkhoma B.G and G. Chilima, (2002), *The Status of Water Demand Management in Malawi and Strategies for promoting it*. Zomba, Malawi: BASIS Water Resources Research Team.

Mulwafu, W. (2000), *Conflicts Over Water Use in Malawi: A Socio-Economic Study of The Likangala River in Zomba District*, 1st WARFSA/WATERNET Symposium, Sustainable use of Water Resources, November 1-2, Maputo, Mozambique.

Mweta. D.E. (2006), *Phosphorus Availability and Adsorption in Gliricidia Sepium/ Maize (Zea Mays) simultaneous Intercropping Agroforestry Based System, at Makoka, Southern Malawi*. Unpublished masters' thesis, University of Malawi, Chancellor College, Zomba.

National Statistical Office (2008), *2008 Malawi Population and Housing Census*. Zomba, Malawi: National Statistics Office,

Ndengu, G.B.C.T. (2007), *Effect of Dedza Pottery Mining activities on Vegetation Diversity and selected Physicochemical Characteristics in Dedza and Ntcheu, Malawi.* Unpublished masters' thesis, University of Malawi, Chancellor College, Zomba.

Ngongondo, C.S. (2003), *An Analysis of Long Term Rainfall Variability, Trends and Catchment Water Availability in the Mulunguzi River Catchment Area*. Unpublished masters' thesis, University of Zimbabwe, Harare.

Ngwira, N.A. (1994), *The Role of Dimba Land and Small-scale Irrigation in Smallholder Farmer's Food Security in Malawi*: *An Application of Safety First Chance-Constrained Target MOTAD Mathematical Programming*, Unpublished doctoral thesis, University of Michigan State, Michigan.

Nyirongo, V.K.W. (2003), *Physico-chemical and Bacteriological Characteristics of Water Resources in Limphasa Dambo, Malawi.* Unpublished masters' thesis, University of Malawi, Chancellor College, Zomba.

Olivier, H. (1972), *Irrigation and Water Resources Engineering*. London: Edward Arnold

Olson, R.E. (1970), *A Geography of Water*. University of Oklahoma, Iowa: The Brown Foundations of Geography Series.

Overseas Development Administration, (2000), *Water for Life*. London: British Aid in Developing Countries.

Palacios-Velez, E. (undated), Water use efficiency in irrigation districts, Montecillo, Mexico. Retrieved December 22, 2010 from *www.unesco.org.uy/phil/libros/efficient_water/windice.htm#enri*

Phalira, W. (2006), *Legal and Institutional Framework for Integrated Water Resources Management in the Mpira-Balaka Rural Water Supply Scheme*. Unpublished masters' thesis, University of Malawi, Chancellor College, Zomba.

Postel, S. (1993), Water and agriculture. In P.H. Gleick (Ed.) *Water in Crisis A Guide to the World's Fresh Water Resources*. New York: Oxford University Press.

Rao, N. S. (2002), *Geochemistry of groundwater in parts of Guntur district, Andhra Pradesh, India*. Mumbai, India: Hydrogeology Laboratory, Department of Geology.

Republic of Kenya (1987), *SCHEME DESIGN Manual for senior staff on gravity fed schemes with basin Irrigation operated by farmers*: Nairobi: Ministry of Agriculture Irrigation and Drainage Branch.

Rhoades, J.D. (1987), *The Problem of Salt in Agriculture*: Yearbook of Science and the Future, Encyclopaedia Britannia: Chicago.

Ringler, C., Rosegrant, M.W. and Paisner, M.S., (2000), *Irrigation and water resources in Latin America and the Caribbean*: Challenges and strategies. Washington D.C. International Food Policy Research Institute.

Rockstrom, J and Falknemark, M. (2004), *Quantifying the terrestrial component of environmental water requirements*. Extracts of a book-Balancing Water for Food and Nature: the new approach in Eco-Hydrology. London, UK: Earthscan Publications.

Rogers, H.K, Schlosser I, J and Reynolds L.F (1997), Efficiencies and Water Loses of Irrigation Systems, Irrigation Management Series. Retrieved April 2009 DEFRA (2006), Speech by Ian Pearson at the Energy Efficiency Partnership for Homes Annual Conference, London - 28 June 2006, available at: http://www.defra.gov.uk/corporate/ministers/speeches/ian-pearson/ip060628.htm (accessed 7th July 2007).

Rosegrant, M. (1995), *Water Resources in the 21st century: increasing scarcity, declining quality, implications for action*. Paper presented at the Conference on the Sustainable Future of the Global System, organised by the United Nations University and the national Institute for Environmental Studies 1994 Tokyo, Japan.

Sabola, M. (2002), *A Survey of Knowledge, Attitudes and Practices in Forest and Lake Resources Management*: *A Case of Chisi Island, Lake Chilwa, Zomba*. Unpublished masters' thesis, University of Malawi, Chancellor College, Zomba.

Salmi, T, (2002). *Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates-the excel template application Makesens*; London: Finish Meteorological Institute.

Sarma, K. (2005), *Impacts of Coal Mining on Vegetation:* A Case study in Jaintia Hills District of Meghalaya, India. Unpublished masters' thesis, International Institute for Geo-Information Science and Earth Observation Enschede, the Netherlands & Indian Institute of Remote Sensing, National Remote Sensing Agency (NRSA), Department of Space, Dehradun, India.

Sarma, V.V. (1976), *A Hydrometeorological Study of the Rainfall Trend in the Chaggar Catchment area*, New Delhi: India: Meteorological Centre.

Savenije, H.H.G. (2002), *Introduction to Water Resources Management-Concepts and Tools*. MSc WREM Lecture Notes, University of Zimbabwe/ IHE Delft

Scheltema, W. (2002), *Smallholder Irrigation Manual for schemes with basin irrigation Design*. Hague, Netherlands: Agricultural Education Department, Ministry of Agriculture and Fisheries.

Shams, F. (2011), *Monitoring for Sustainability Development of a Framework for Community-Based Managed Rural Piped Gravity-Flow Water Supply Systems and Study of the Chagwa Scheme in Malawi*, Unpublished masters' thesis, Cranefield University; Britain.

Shaw, M. (1985), *Hydrology in Practice, Department of Engineering Imperial College Of Science and Technology*. Berkshire: Van Nostrand Reinhold (UK).

Shiklomanov, I.A. (2000), Appraisal and Assessment of world water resources. *Water International*, 25 (1), 11-32.

Shuttleworth, W.J. (1993). *Handbook of Hydrology*. London: McGraw-Hill.

Singh P. (2005), *Farming Systems in the Murrumbidgee Irrigation Area of NSW*: An Economic Analysis: Canberra, Australia: Australian Water Resources Centre.

State of the Environment Report for Malawi (2008), *Lake Chilwa Basin Report, Environmental Affairs Department*, Recapitulated version. Lilongwe, Malawi.

Stern, P. H. (1988), *Operation and maintenance of small irrigation Schemes*, New York: International Technology Publications Ltd.

Systma D. P and Parker M (1999), Aquatic Vegetation in Irrigation Canals *A Guide to Integrated Management;* Oregon Department of Agriculture; U.S. Environmental Protection Agency

Teare I.D and Peet M.M., (1983), *Crop-water Relations*. New York: John Willey & Sons.

The World Bank (2010), The Zambezi River Basin; *A Multi-Sector Investment Opportunities Analysis;* Volume 4 Modeling, Analysis and Input Data, Water Resources Management Africa Region; THE WORLD BANK.

Tolba, M.K. (1978), Welcome Address. *Proceedings of Water Management for Arid Lands in Development Countries Workshop*; Volume 13. Oxford: Pergamon Press.

Van Den Ban A.W. and Hawkins H.I.S., (1988). *Agricultural Extension*. New York: John Wiley and Sons Inc.

Van der Zaag, P. (2002), *Introduction to Water Resources Management*: *Water Using Activities*. MSc WREM Lecture Notes, University of Zimbabwe/ IHE Delft.

Vandersypen, J. Bengalyk K, Keita A.C.T, Sidibé S., Raes D., and Jamin J.Y.(2006), Irrigation performance at tertiary level in the rice schemes of the Office du Niger (Mali) : Adequate water delivery through over-supply. *Agricultural Water Management*, 83, 144-152.

Wang, S. McGrath R, Semmler T, Sweeney C, and Nolan P., (2006), *The Impact of the Climate Change on discharge of Suir River Catchment (Ireland) under different Climate Scenarios*. Met Eireann, Glasnevin Hill, Dublin 9, Ireland: Natural Hazards and Earth Sciences System.

Ward, R.C., and Robinson, M., (1990), *Principles of Hydrology*. London: McGraw Hill Publishing Company.

Waugh, D. (1990), *Geography*: *An Integrated Approach.* Edinburgh: Thomas Nelson and Sons Ltd.

Weeks, J.M., Sims, I., Lawson, C., and Harrison, D.J. (2003). *River Mining*: *Assessment of The Ecological Effects of River Mining in Rio Minho and Yallas Rivers, Jamaica*. Nottingham: British Geological Survey.

Wigginton, M. and Raine, K. (undated), *Water use efficiency and irrigation practices in the Mary River Catchment*, *Queensland*. Toowoomba: National Centre for Engineering in Agriculture, University of Southern Queensland

Wolff, P. and Hubner R., (1999), *Irrigation in the World-The future will not be like the past*; Natural Resources and Development, A Biannual Collection of Recent German Contributions Concerning the Exploration and Exploitation of Natural Resources Volume 51, Institute for Scientific Co-operation, Tubingen.

Yudelmann, M. (1994), Demand and supply of foodstuffs up to 2050 with special reference Irrigation. *IIMI Review,* 89 (1).

Zaw, T. (2004), *Irrigation Water Management for Smallholder Irrigation Schemes in Malawi*; Republic of Malawi, Food and Agriculture Organization of the United Nations Special Programme for Food Security (SPFS) May 23, FAO, Lilongwe Malawi.

APPENDICES

Appendix A: Area of the irrigation scheme (GPS coordinates)

Northern part		
oint	X (East)	Y (West)
	767508	8329641
	767547	8320654
	767531	8320727
	767580	8320702
	767583	8320735
	767662	8320732
	767659	8320752
	767696	8320792
	767747	8320788
0	767751	8320799
1	767838	8320765
2	767843	8320754
3	767977	8320639
4	767959	8320609
5	767980	8320605
6	767967	8320583
Southern part		
	768152	8320494
	768389	8320261
	768313	8320251
	768260	8320270
	768172	8320251
	767834	8320382

Appendix B: Questionnaire for the Rice Farmers

A. BIODATA

1. **Sex**: a. Male **[ ]** b. Female **[ ]**

2. **Age**: 15-19 years **[ ]** 20-24 years **[ ]** 25-29 years **[ ]** 30-34 years [ ] 35+ years **[ ]**

3. **Highest education attained**: None **[ ]** **S**ome primary **[ ]** Secondary-Junior [ ]
Secondary-Senior **[ ]** Adult literacy **[ ]** **Technical** College **[ ]** University **[ ]**

4. **District of origin ____**.

B. SOCIO-ECONOMIC ACTIVITIES OF THE RICE FARMERS

5. How many rice plots do you have in the Lingoni Rice Irrigation Scheme?
a. 1-2 plots **[ ]** b. 3-4 plots **[ ]** c. 5-6 plots [**]** d. 6 + plots **[ ]**

6. For how long have you been growing rice in this scheme?
a. 1 – 4 years **[ ]** b. 5 – 10 years **[ ]** c. 11 – 14 years **[ ]** d. 15 – 19 years **[ ]** e. 20 + years **[ ]**

7. How many times a month does your agricultural field assistant visit you?
a. None **[ ]** **b**. Once **[ ]** c. Twice **[ ]** d. Thrice **[ ]**

8. Where did you acquire the skill of rice irrigation? From
a. Agricultural field assistant **[ ]** b. Friends **[ ]** c. Own initiative **[ ]**

9. Apart from rice irrigation, mention other farming fields that help you get money.
a. Upland rainfed fields (munda) **[ ]** b. Wetland gardens (dambo) **[ ]**
c. Stream bank gardens (dimba) **[ ]** d. Formal Employment (e.g. Teacher) **[ ]**
e. Ganyu (casual labour) **[ ]** f. Weaving Baskets **[ ]** g. Owning small business **[ ]**
h. Marketing of crops **[ ]** i. Other (specify) _______________________________________.

10. Put in order, the fields which produced the most food for your family consumption.

a. Upland rainfed fields (munda) **[ ]** b. Wetland gardens **[ ]**

c. Stream bank gardens (dimba) **[ ]** e. Rice irrigation **[ ]**

11. Put in order, the fields which produced the most cash income.

a. Upland rainfed fields (munda) **[ ]** b. Wetland gardens **[ ]**

c. Stream bank gardens (dimba) **[ ]** **e**. Rice irrigation **[ ]**

12. List any two problems that you are facing as a rice farmer.

____

____

C. MAGEMENT OF THE RICE SCHEME

13. How many times per month do you irrigate your rice field (s)?

a. 7 days a week **[ ]** b. 14 days a week **[ ]** c. 21 days a week **[ ]** d. Throughout **[ ]**

14. If 7 days a week, mention the days

____.

15. Which period do you prefer?

a. 7 days a week **[ ]** **b**. 14 days a week **[ ]** c. 21 days a week **[ ]** d. Throughout **[ ]**

16. Why?

____.

17. How long do you take to irrigate your field (s) per day?

a. 8 hours **[ ]** b. 10 hours **[ ]** c. 12 hours **[ ]** d. 24 hours **[ ]**

18. Which arrangement practice do you prefer?

a. 8 hours **[ ]** b. 10 hours **[ ]** c. 12 hours **[ ]** d. 24 hours **[ ]**

19. Why?

____

____.

20. Is water in Lingoni River enough to irrigate your rice field (s)? Yes **[ ]** No **[ ]**

21. Lingoni River always dries up downstream during the irrigation period despite being perennial. Why is it so?

a. Scheme too big **[ ]** b. Scheme needs rehabilitation **[ ]** c. Inefficient use of water **[ ]**

22. What should be done to maintain the continuous flow of this river? Give two ways.

a.____

b.____.

23. If Lingoni Rice Irrigation Scheme were to be rehabilitated, arrange these areas in order of your highest priorities.

a. Headworks **[ ]** **b.** Main canal **[ ]** **c.** Secondary and Tertiary canals **[ ]**

d. Roads and paths **[ ]** e. Levelling of high ground **[ ]** f. The whole scheme **[ ]**

24. Which organisation controls the activities of the rice farmers in the scheme?

a. Irrigation committee **[ ]** b. Water Users Association (WUAs) **[ ]** c. None **[ ]**

25. If the answer is either a or b, what are some of its duties?

a. Conducting meetings **[ ]** b. Maintaining the scheme facilities **[ ]** c. Allocating plots **[ ]**

d. Collecting scheme contribution fee **[ ]** e. Settling down disputes **[ ]**

26. Any general comments about Lingoni Rice irrigation Scheme?

____

END OF QUESTIONS.

THANK YOU.

Appendix C: Crop coefficients (Kc)

Crop	Growth Stage-Initial	Crop Development	Mid-Season	Late Season	At Harvest	Total Season
Beans						
-Green	0.35	0.70	1.00	0.95	0.90	0.90
-Dry	0.35	0.75	1.10	0.70	0.30	0.80
Cotton	0.45	0.75	1.20	0.85	0.70	0.85
Groundnut	0.45	0.75	1.05	0.80	0.60	0.80
Maize						
-Green	0.40	0.80	1.10	1.10	1.05	0.90
-Grain	0.40	0.80	1.10	0.90	0.60	0.85
Onion	0.50	0.70	1.00	0.95	0.90	0.80
Peas (fresh)	0.45	0.80	1.10	1.10	1.05	0.90
Potato	0.45	0.75	1.10	0.90	0.75	0.85
Rice	1.10	1.30	1.20	1.00	1.00	1.10
Sorghum	0.35	0.70	1.10	0.80	0.50	0.80
Sugar cane	0.45	0.85	1.15	0.80	0.55	0.95
Sunflower	0.35	0.75	1.10	0.75	0.40	0.80
Tobacco	0.35	0.75	1.10	0.95	0.80	0.9
Tomato	0.45	0.75	1.15	0.90	0.60	0.85
Watermelon	0.45	0.75	1.00	0.85	0.70	0.80
Wheat	0.35	0.75	1.10	0.70	0.25	0.85

Source: FAO (1979 in van der Zaag 2002)

Appendix D: Temperature data for Ntaja meteorological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	14.2	14.2	13.6	13.7	13.3	12.3	12.5	14.7	14.8	15.4	14.5	15.5
2000	24.6	24.8	24.7	23.4	20.7	20.3	20.3	20.3	23.2	25.7	23.8	26.7
2001	24.5	24.8	24.8	23.4	21.7	19.3	19.6	21.3	24.1	25.1	28.1	26.7
2002	25.2	24.5	25.0	23.4	21.3	19.7	21.6	21.7	23.7	27.4	26.3	25.4
2003	25.9	25.4	24.9	23.0	21.6	19.4	18.8	20.6	23.8	26.7	27.9	26.4
2004	25.6	24.9	26.2	23.3	20.9	19.5	19.5	21.5	24.1	26.8	25.9	25.4
2005	25.9	26.2	25.9	24.2	22.3	21.4	19.3	21.0	23.4	25.8	28.6	27.6
2006	25.5	25.2	24.6	23.6	21.9	20.0	19.7	21.6	22.0	27.2	27.2	25.9
2007	24.3	24.7	24.6	23.9	22.0	20.4	19.6	21.1	24.6	25.9	27.6	25.3
2008	25.4	25.9	24.4	24.2	23.1	22.5	20.6	21.7	25.8	27.1	27.6	26.4

Source: National Meteorological Department, Blantyre

Appendix E: Mean daily %age (p) of annual daytime hours for different latitudes

Latitude	Jan Jul	Feb Aug	Mar Sep	Apr Oct	May Nov	Jun Dec	Jul Jan	Aug Feb	Sep Mar	Oct Apr	Nov May	Dec Jun
60^0C	0.15	0.20	0.26	0.32	0.38	0.41	0.40	0.34	0.28	0.22	0.17	0.13
55	0.17	0.21	0.26	0.32	0.36	0.39	0.38	0.33	0.28	0.23	0.18	0.16
50	0.19	0.23	0.27	0.31	0.34	0.36	0.35	0.32	0.28	0.24	0.20	0.18
45	0.20	0.23	0.27	0.30	0.34	0.35	0.34	0.32	0.28	0.24	0.21	0.20
40	0.22	0.24	0.27	0.30	0.32	0.34	0.33	0.31	0.28	0.25	0.22	0.21
35	0.23	0.25	0.27	0.29	0.31	0.32	0.32	0.30	0.28	0.25	0.23	0.22
30	0.24	0.25	0.27	0.29	0.31	0.32	0.31	0.30	0.28	0.26	0.24	0.23
25	0.24	0.26	0.27	0.29	0.30	0.31	0.31	0.29	0.28	0.26	0.25	0.24
20	0.25	0.26	0.27	0.28	0.29	0.30	0.30	0.29	0.28	0.26	0.25	0.25
15	0.26	0.26	0.27	0.28	0.29	0.29	0.29	0.28	0.28	0.27	0.26	0.25
10	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.28	0.28	0.27	0.26	0.26
5	0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.27	0.27
0	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27

Source: Zaw (2004)

APPENDIX F: Mposa rainfall totals (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1982	164.7	317.7	44.1	47.1	17.5	0.5	14.0	16.9	2.6	34.0	99.0	244.4
1983	128.8	116.7	111.7	36.1	1.6	0.6	17.7	0.0	0.0	3.4	74.5	163.0
1984	110.0	339.7	194.2	15.7	2.9	3.8	0.0	0.0	9.6	0.0	74.4	168.2
1985	268.7	154.5	243.4	67.4	0.8	2.2	0.1	1.6	10.7	3.9	74.7	338.0
1986	261.8	214.5	171.5	40.4	2.2	2.2	2.9	0.0	0.0	34.6	75.2	750.0
1987	255.5	212.9	193.4	84.9	3.5	2.6	0.0	0.6	1.0	24.2	47.6	224.7
1988	168.8	348.5	119.0	26.1	24.4	1.2	0.0	0.6	0.0	47.4	33.0	197.2
1989	342.2	250.6	543.6	64.5	0.2	4.3	1.3	21.7	12.4	0.5	110.2	121.9
1990	306.6	235.3	59.3	9.8	90.0	0.0	0.0	10.8	1.0	0.0	20.9	80.1
1991	337.3	372.8	330.3	26.4	1.5	3.3	13.3	0.3	0.0	3.6	94.8	147.8
1992	210.5	23.9	104.0	16.3	0.0	2.7	0.0	0.3	0.2	1.4	53.3	161.5
1993	508.9	316.3	138.1	24.3	0.0	6.1	0.0	2.0	3.2	22.6	124.3	105.6
1994	190.8	48.3	208.9	5.4	0.0	0.0	1.4	2.2	0.0	19.2	9.5	263.1
1995	374.2	226.2	85.5	16.0	0.5	6.4	0.0	0.8	0.0	0.0	54.3	214.1
1996	0.0	181.3	352.6	76.0	36.3	3.3	0.0	0.5	0.0	3.0	14.0	320.4
1997	304.4	241.1	116.6	112.3	0.0	0.0	24.9	0.0	8.5	17.8	137.5	446.2
1998	328.6	130.6	144.7	47.1	0.0	0.0	0.0	2.0	0.0	20.2	32.6	212.3
1999	301	224.8	359.8	42	0.0	5.1	3.1	9.3	0.0	3.3	70.9	84.4
2000	384	208.4	194.3	118.2	4.9	2.5	13.2	0.0	2.0	73.7	140.7	143.2
2001	497.9	382.9	196.3	32.1	5.9	0.0	0.0	0.0	0.0	0.0	18.0	179.5
2002	378.4	201.4	75.4	32.7	3.5	4.5	0.0	1.5	0.8	6.1	4.6	146.9
2003	308.8	224.7	374.3	22.4	5.5	0.0	8.5	3.1	0.0	2.3	24.4	90.5
2004	246.1	112.3	98.7	38.7	0.0	0.0	0.0	0.0	0.0	19.3	114.1	217.6
2005	227.3	214.8	5.6	5.1	0.0	0.0	7.5	0.0	0.0	15.0	34.8	106.9
2006	360.2	142.8	274.3	11.1	0.0	2.2	1.5	0.0	0.0	11.5	130.6	289.6
2007	316.0	361.2	145.6	11.1	1.4	1.3	5.1	0.3	0.0	11.8	16.9	330.5

Source: National Meteorological Department, Blantyre

Appendix G: Analysis of Lingoni River and canal discharges (August to November 2008)

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	11	1.656	0.150545	0.001016
Column 2	11	0.583	0.053	1.6E-06

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.052333	1	0.052333	102.8891	2.49E-09	4.35125
Within Groups	0.010173	20	0.000509			
Total	0.062506	21				

Appendix H: Analysis of the cross-sectional area of Lingoni River Section

	Upper stream			Middle stream			Down stream		
Sections	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
	5.65	5.11	4.97	1.95	1.06	1.02	1.01	0.31	0
	5.67	5.12	4.82	1.84	1.02	1.03	0.99	0.23	0
	5.45	5.09	4.85	1.64	0.92	1.02	0.97	0.12	0
	5.55	5.02	4.90	1.53	1.00	1.01	0.90	0.07	0
	5.60	4.93	4.91	1.42	1.05	0.99	0.87	0.01	0
	5.41	4.91	4.93	1.34	0.99	0.99	0.85	0	0
	5.38	4.88	4.90	1.42	0.95	0.89	0.77	0	0
	5.11	4.86	4.81	1.22	1.04	0.74	0.65	0	0
	5.01	4.85	4.75	1.12	1.02	0.64	0.54	0	0
	5.15	4.80	4.85	1.05	1.02	0.56	0.42	0	0
Mean	**5.398**	**4.957**	**4.769**	**1.453**	**1.007**	**0.889**	**0.797**	**0.074**	**0**

Appendix I: Vegetation species diversity of upper Lingoni River section

Serial No.	Taxon	Habit	Family	Abundance	Reproductive stage
1	Ageratum conyzoides	Herb	Asteraceae	V.C	Flowering
2	Ageratum houstonianum	Herb	Asteraceae	V.C	Flowering
3	Nidorella microcephala	Herb	Asteraceae	V.C	Flowering
4	Anisoppapus africanum	Herb	Asteraceae	C	Flowering
5	Pennisetum puspureum	Grass	Poaceae	V.C	Fruiting
6	Vossia cuspidate	Grass	Poaceae	V.C	Fruiting
7	Echinochloa colonum	Grass	Poaceae	V.C	Fruiting
8	Phragmites mausitianus	Grass	Poaceae	V.C	Fruiting
9	Polygonum senegalensis	Herb	Polygonaceae	C	Flowering
10	Pistia stratiotes	Herb	Araceae	C	-
11	Saccharum officinasum	Grass	Poaceae	V.C	Flowering
12	Bidens pilosa	Herb	Asteraceae	C	Fruiting
13	Zea mays	Grass	Poaceae	V.C	Fruiting
14	Musa paradisiacea	Tree	Musaceae	C	-
15	Oryza sativa	Grass	Poaceae	V.C	Fruiting
16	Cucurbita maxima	Creeper	Cucurbitaecae	C	Flowering
17	Mimosa pudica	Creeper	Mimosoideae	C	Flowering
18	Phyla nodiflora	Herb	Verbenaceae	C	Flowering
19	Typha domingensis	Grass	Typhaceae	C	-
20	Cynodon dactylon	Grass	Poaceae	C	Flowering
21	Imperata cylindria	Grass	Poaceae	C	Flowering
22	Cyperus mundtii	Sedge	Cyperaceae	C	Flowering

Legend: V.C = Very Common (30)

C = Common (20)

Appendix J: Vegetation species diversity of middle Lingoni River section

Serial No.	Taxon	Habit	Family	Abundance	Reproductive Stage
1	Mimosa pudica	Herb	Mimosoideae	C	Flowering
2	Phyla nodiflora	Herb	Verbenaceae	C	Flowering
3	Ageratum conyzoides	Herb	Asteraceae	C	Flowering
4	Commelina benghalensis	Herb	Commelinaceae	C	Flowering
5	Cucurbita maxima	Creeper	Cucurbitaceae	C	Flowering
6	Echinochloa colonum	Grass	Poaceae	V.C	Fruiting
7	Pennisetum purpureum	Grass	Poaceae	V.C	Fruiting
8	Vossia cuspidate	Grass	Poaceae	V.C	-
9	Bidens pilosa	Grass	Poaceae	C	Fruiting
10	Phragmites mauritianus	Grass	Poaceae	V.C	Fruiting
11	Oryza sativa	Grass	Poaceae	V.C	Fruiting
12	Typha domingensis	Grass	Poaceae	V.C	Fruiting
13	Cynodon dactyloa	Grass	Poaceae	V.C	Fruiting
14	Imperata cylindrical	Grass	Poaceae	V.C	Fruiting
15	Cyperus mundtii	Sedge	Cyperaceae	C	Flowering

Fami

Legend: V.C = Very Common (30)

C = Common (20)

Appendix K: Vegetation species diversity of downstream Lingoni River section

Serial No.	Taxon	Habit	Family	Abundance	Reproductive Stage
1	Phragmites mauritanus	Grass	Poaceae	V.C	Fruiting
2	Imperata cylindrical	Grass	Poaceae	V.C	Fruiting
3	Echinochloa colonum	Grass	Poaceae	V.C	Fruiting
4	Bidens pilosa	Herb	Poaceae	C	Fruiting
5	Sesbania macrantha	Herb	Papilionoideae	C	-
6	Musa paradisiacal	Tree	Poaceae	C	-
7	Zea mays	Grass	Poaceae	V.C	Fruiting
8	Cucurbita maxima	Creeper	Cucurbitaceae	C	Flowering
9	Polygonum senegalensis	Herb	Polygonaceae	C	Flowering
10	Ageratum conyzoides	Herb	Poaceae	C	Fruiting
11	Vessia cuspidate	Grass	Poaceae	V.C	-
12	Mimosa pudica	Herb	Mimosoideae	C	Flowering
13	Commelina banghalensis	Herb	Commelinaceae	C	Flowering
14	Curcubita maxima	Creeper	Cucurbitaceae	C	Flowering
15	Phyla nodiflora	Herb	Poaceae	C	Flowering
16	Oryza sativa	Grass	Poaceae	V.C	Fruiting
17	Cynodon dactylon	Grass	Poaceae	C	Fruiting
18	Cyperus mundtii	Sedge	Cyperaceae	C	Flowering
19	Nidorella auriculata	Herb	Asteraceae	C	Flowering

Fa

Legend: V.C = Very Common (30)

C = Common (20)

Appendix L: Lingoni monthly rainfall trend

Ntaja 1982-2007				Mann-Kendall trend			Sen's slope estimator
Times Series	First Year	Last Year	N	Test S	Test Z	Signific	Q
Jan	1982	*2007*	*26*		2.12		-1.342
Feb	1982	*2007*	*26*		-0.53		-0.833
Mar	1982	*2007*	*26*		0.35		-0.045
Apr	1982	*2007*	*26*		-1.23		-0.008
May	1982	*2007*	*26*		-1.51		-0.013
Jun	1982	*2007*	*26*		-0.72		-1.423
Jul	1982	*2007*	*26*		0.05		-1.165
Aug	1982	*2007*	*26*		-1.02		-0.029
Sep	1982	*2007*	*26*		-2.22		-1.573
Oct	1982	*2007*	*26*		-0.04		-0.560
Nov	1982	*2007*	*26*		-0.88		6.521
Dec	1982	*2007*	*26*		-0.44		-1.140
Annual	1982	*2007*	*26*		0.00		-1.161
Dry Season	1982	*2007*	*26*		0.04		1.573
Wet Season	1982	*2007*	*26*		-1.59		-0.560

*** If trend at ά = 0:001 level of significance; ** if trend at ά = 0:01 level of significance; * If trend at ά = 0:05 level of significance; + if trend at ά = 0:1 level of significance; If the cell is blank, the significance level is greater than 0.1. Sen.'s slope estimator **Q**: the Sen.'s estimator for the true slope of linear trend i.e. change per unit time period (in this case a year)