CLIMATE CHANGE IMPACTS ON HYDROPOWER GENERATION IN MALAWI: A CASE STUDY OF LUJERI MICRO HYDROPOWER SCHEME IN MULANJE DISTRICT

MASTER OF PHILOSOPHY IN APPLIED SCIENCES [RENEWABLE ENERGY]

THESIS

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Master of Philosophy in Applied Sciences [Renewable Energy] Thesis

By

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Submitted to the Department of Physics and Biochemical Sciences, Faculty of Applied Sciences in partial fulfilment of the requirements for the degree of Master of Philosophy in Applied Sciences [Renewable Energy].

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Declaration by the Candidate

I hereby declare that no part of this work has been submitted for any degree in any university or institution of learning and is neither being submitted concurrently.

Acknowledgement has been made where other sources of information have been used.

Signature of candidate

…………………………………………………….

Osborne Kachaje

17 October 2017

Certificate of Approval

We, the undersigned, certify that we have read and hereby recommend for acceptance by the University of Malawi a thesis titled '[Climate Change Impacts on Hydropower Generation in Malawi: A Case Study of Lujeri Micro Hydropower Scheme in Mulanje District]'

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Dedication

To my grandparents with love, for their encouragement to see me excel with education.

Acknowledgements

Foremost, I am so grateful to God for providing me with wisdom, knowledge and understanding throughout this study. For entrusting me to complete all impossible opportunities; it wouldn't be possible without His will.

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Abstract

The production of hydroelectric power depends, among others, on discharge which is in turn affected by seasonal and quantitative changes in precipitation and evaporation. Climate change has caused changes in the weather patterns over Malawi, extreme episodes of rainfall and temperatures and has affected hydropower generation by reducing flows (discharge). This is the case with Lujeri hydropower – the subject. The study involved collection of hydrological (river discharge) and weather time series (air temperature and rainfall) data. The data was logically interpreted using Statistical Package for Social Science (SPSS), XLSTAT and Microsoft Excel. Ordinary least squares (OLS) regression analysis was used to determine marginal changes in the climatological time series data. Mann-Kendall (MK) test was used to detect trends in air temperature, precipitation and discharge. Correlation analysis was also used to uncover the relationship between discharge and precipitation as well as between discharge and temperature. The results showed that distribution of annual rainfall in Mulanje area (for period 1959 to 2011) has decreased at the rate of about 2.97 mm per year. The MK test gave a mix of positive and negative trends for the monthly precipitation. Only the month of January showed a positive significant trend while February, March, April, May, June September, and November had a significant negative trend. All three seasons showed decreasing trend in precipitation and the negative trend was statistically significant for cool and wet season. Similarly, temperature analysis revealed a rising trend of about 0.04 °C every year which led to high evaporation. The MK test for temperature results showed a significant increasing trend for both mean monthly and mean maximum temperature. This resulted in decrease in the Ruo River's, location of Lujeri micro-hydropower, annual mean discharge. Analysis on MK test revealed that there was a positive trend in discharge in the months of January, February, March, April and December. The increase in trend was significant for February, March and April. The results also indicated a statistically significant negative trend in discharge for the rest of the months of the year apart from May. Furthermore, there was a small positive correlation between rainfall and discharge ($r = 0.09$) although the increase in discharge due to rainfall was not significant ($p = 0.55$). On the other hand, the relationship between temperature and discharge showed a large, negative correlation ($r = - 0.64$) and the relationship was significant ($p = 0.0001$). This means that continued increase in temperature will result in a decrease in discharge. As power generated is proportion to discharge, variation in the river discharge will have direct impact on hydropower

generation. Therefore, proper adaptation measures were explored to ensure electric power is available throughout the year especially in the hot and dry season, when the discharge is very low.

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Abbreviations

DCCMS	Department of Climate Change and Meteorological Services
ESCOM	Electricity supply Corporation of Malawi
GCM	Global circulation models
GoM	Government of Malawi
GWh	Giga watt-hour
HEP	Hydro Electric Power
kW	Kilowatt
MW	Mega Watt
MK	Mann-Kendall
MAREP	Malawi Rural Electrification Programme
MEJN	Malawi Economic Justice Network
MERA	Malawi Energy Regulatory Authority
MCC	Millennium Challenge Corporation
MGDS	Malawi Growth and Development Strategy
MoNRE	Ministry of Natural Resources and Environmental Affairs
PRA	Participatory Rural Assessment
SAPP	Southern African Power Pool
USAID	United States Agency for International Development
UNDP	United Nations Development Programme
WSSD	World Summit on Sustainable Development

Appendices

CHAPTER 1: INTRODUCTION

1.1 Background

Nowadays, day in and day out, climate change is one of the hot topics being debated worldwide. Climate change, according to the United Nations Framework Convention on Climate Change (UNFCCC) (1992, p. 7), states that “it is a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” Hence, mankind activities such as the use of fossil fuels have directly or indirectly increased the amounts of greenhouse gases in the atmosphere which has resulted in increased global temperatures and consequently a change in climate. As a result, climate change has and continues to affect many sectors of the world. Drastic changes of climate are expected to have adverse impacts on many socio-economic sectors like; low-lying areas and coastal wetlands, agricultural production, water supplies, human health and terrestrial and aquatic ecosystems (Mohammed, 2013).

Climate change and the hydrological cycle are interrelated through changes in precipitation, maximum and minimum temperature and evaporation. As a result of increased temperatures due to climate change, the amount and precipitation patterns are expected to change and consequently the discharge pattern (Hout, 2013). Intergovernmental Panel on Climate Change (IPCC) (2010) also attest that climate change will reduce water availability, hydropower potential and changing seasonality of flows in many regions. However, the degree of change that climate brings in hydrology will depend on the region of study (Marahatta, 2015).

Hydropower is power that is derived from the force or energy of moving water which is harnessed into useful purposes. Prior to the widespread availability of commercial electric power, hydropower was used for irrigation, and operation of various machines, such as watermills, textile machines, sawmills, dock cranes, and domestic lifts (Kreis & Steven, 2001). Water power was the only source of mechanical energy, other than wind, until the development of the steam engine in the nineteenth century (Hinrichs & Kleinbach, 2013). With the invention of electric generators, hydropower was a natural source of power for such generators in generating electricity.

Since hydroelectricity emits near-zero emissions, Jain (2011) highlights hydropower as a proven, mature, efficient and cost competitive renewable energy source. Hydropower requires relatively high initial investment but has low operation costs and that it offers a hedge against volatile energy prices. Harrison, Whittington and Gundry (1998) argued that exploitation of hydropower potential is considered by many governments and international bodies to be a key feature in economic development.

The amount of electric power produced by a hydropower facility mainly depend on the volume of water passing through the turbine in a given amount of time, the water head and the efficiency of the turbine. While the head and the efficiency of the turbine will usually be fixed for a particular hydropower facility, the fluctuations in the quantity and timing of river discharge rate affects much the production of hydroelectric power. The discharge rate is in turn affected by seasonal and quantitative changes in precipitation and evaporation, (Koch *et al*., 2011).

Hydropower is clearly among the most vulnerable areas to global warming because water resources are closely linked to climate changes (Pathak, 2010). Since climate change will certainly increase global air temperature, considerable regional impacts on the availability of water resources will occur concerning quantity and seasonality (IPCC, 2007a). At first glance, increased global precipitation would appear to suggest more water available for hydroelectric power production. However, higher temperatures will lead to increased evaporation levels thus reducing the runoff (Harrison *et al*., 1998). Therefore, the function of water infrastructures such as hydropower, will be affected due to climate change impacts on water quantity and quality (Choi, 2011). Consequently, this is more critical to energy security for a country such as Malawi which sorely depends on hydropower for its electricity production.

1.2 Problem Statement

At the moment and in the near future, Malawi's main source of electrical energy will remain to be hydropower which currently provide about 98 % of its total electricity (GoM, 2010). The countries demand for more energy is expected to increase due to the influence of rising population, industrialization, urbanization and rural electrification. However, hydroelectric power production strongly relates to hydrological circumstances; any climate change may affect the hydrological cycle and its water balance terms (Hout, 2013; Mohammed, 2013). Almost all of hydropower facilities in Malawi are run-of-river based. These hydropower facilities are highly dependent on predictable discharge patterns which in turn are influenced by precipitation and temperature patterns and on a larger scale climate change.

The worldwide consensus is that climate change is real, rapidly advancing and widespread threat (Mishra & Herath, 2012). Hydropower will be impacted by climate change in a varying degree depending on the region and hydropower type; thereby run-of-river power plants as well as reservoir hydropower plants will be affected (Koch *et al*., 2011). Africa at large and southern Africa in particular, will be the most affected part of the world since adaptation and mitigation measures are lacking (IPCC, 2001a). Similarly, according to Hamududu and Killingtveit (2006), the East and Southern African countries have a climate that is highly variable, unreliable and unpredictable. These impacts will directly affect hydroelectric production and have the potential to make hydropower either more or less vulnerable because it may lead to timing mismatch between energy generation and demand. As hydropower is the major source of electricity in Malawi, impacts of climate change on hydropower production would lead to serious disruptions in the energy infrastructure.

1.3 Research Objectives

1.3.1 Main (or General) Objective

The general objective of the study was to assess the impact of climate change on micro-hydropower generation, specifically on Lujeri micro-hydropower scheme in Mulanje.

1.3.2 Specific Objectives

The specific objectives and tasks to achieve this goal can be summarized as follows:

(a) To assess the trend of climate changes taking place in Mulanje.

(b) To evaluate the factors influencing discharge rates of Ruo River.

(c) To analyze the potential power output with respect to changes in discharge rates.

1.4 Research Questions

(a) What are the current changes in rainfall and temperature in Mulanje district?

(b) How has the discharge been affected by changes in rainfall and temperature patterns?

(c) How is power generation influenced by discharge?

1.5 Justification

The Malawi Growth and Development Strategy (MGDS) highlight energy generation and supply as one of the key priority areas for sustainable economic growth and development. Energy is crucial input into any industrial processing and serves as the life blood of economy. A well-developed energy sector can enhance stable supply of power, increase generation and transmission capacity for improved service delivery and increase economic productivity. Despite its relative energy resource endowment potential, Malawi's energy sub-sector remains far from being realized. If the country is to break out of the vicious circle of poverty, it has to use its available energy resources more effectively and efficiently. Malawi is a hilly country having a lot of undeveloped hydropower potential sites. As one of its key strategy to improve the situation, Malawi plans to construct mini-hydro power stations along Shire River and other major rivers in the country. However, most of the feasibility studies on hydropower do not incorporate the concept of climate change which has the potential to affect hydropower generation by either increasing or reducing flows (discharge) and the head. As precipitation and temperature patterns will change due to climate change, the generation of hydroelectricity will also vary depending on the discharge. Therefore, as the country looks forward to the development of these potential hydropower sites, it is also important that the impacts of climate change on the generation profile are taken into consideration.

1.6 Study Area (Lujeri hydropower Scheme)

Lujeri Tea Estates grows and processes high quality tea on its estates under the imposing Mount Mulanje, the highest point in Malawi. Its tropical location and superior cultivar plant varieties produce excellent quality teas that are unusually high in health promoting anti-oxidants. Tea was first planted on the estate in the late 19th Century.

Electricity is required to run the machines in the factories as well as the estate's irrigation pumps and Lujeri is able to provide approximately 30 % of its electricity requirements from the two micro hydroelectric power plants it owns and operates on the estate. These power plants are constructed on two rivers, Ruo and Lujeri River that run through the estate and this study was done on a plant constructed on Ruo River (which houses three turbines referred to as Ruo 1, 2 and 3). Both plants were commissioned in the 1930's. The closed circuit system of water reticulation returns all of the water to the river from the two power stations. This makes the system eco-friendly as well.

The Ruo River (with a catchment area of about 4900 km^2) rises on the slopes of Mount Mulanje (the southern portion of the eastern Shire Highlands) and is the largest tributary of Shire River. It flows through Mulanje district and also forms part of the Malawi-Mozambique border before joining with the Shire River. The power plant is located at the base of the Mulanje Mountain as shown in Figure 1. The initial study was supposed to be conducted at Kavuzi micro hydropower scheme but due to poor maintenance of machines, the scheme is in non-operation. Hence, the study site in Lujeri was an alternative and was selected because the power plant was installed long enough that its history is worthy investigating.

Mulanje District is located approximately 65 kilometres east of Blantyre district and is named after the highest Mountain in the South-Central Africa. The district local weather conditions are greatly influenced by the Mulanje Mountain and the climate is also partly affected by Chiperoni winds causing high rainfall on the windward (South East side of the Mulanje Mountain) while limiting it on the leeward side (Taulo, Mkandawire & Gondwe, 2008). The average annual rainfall is 1600 mm and the average minimum annual temperatures ranges from 21 °C to 23 °C and the maximum temperatures of about 32 °C to 35 °C (Haarstad *et al*., 2009). Taulo *et al.* (2008) also note that one most distinctive feature of Mulanje climate is the variation of rainfall over short distances, a characteristic attributed to the influence of Mulanje Mountain.

Figure 1: Map of Southern Malawi Showing Study Location

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter provides a background review as related to the impacts of climate change on micro-hydropower generation. Mainly the chapter was divided into two: theoretical background and empirical evidence. The theoretical background encompassed all the theory regarding the generation of hydropower and the theoretical framework behind the relationship between climate change and hydropower generation. Under empirical evidence, a review of relevant studies that had looked at the impact of climate change on hydropower generation or related activities such as irrigation was outlined.

2.2 Hydropower Generation

Tamburrini (2004) outlines well the conversion process of water power to electricity. Tamburrini starts by pointing out that the energy from the sun that reaches the earth’s surface causes water to evaporate and hence a proportion of this energy causes vapour to rise against the earth’s gravitational pull. As such, the vapour possesses potential energy. This vapour then condenses into rain and snow, which again falls back to the earth’s surface. This is called the water cycle and is the fundamental reason why hydropower is possible. When rain and snow fall onto any ground, the potential energy stored in it is converted to kinetic energy. By catching this water in the controlled form of pipes, we can exploit the kinetic energy that becomes available with the movement of water. These pipes are then used to direct the stream of water, under pressure, onto a turbine blade. The water then strikes the turbine blade to create mechanical energy. This mechanical energy is then transmitted to an electrical generator through a rotating shaft. Therefore, the hydroelectric plants work by converting the kinetic energy from water falling into electric energy.

2.3 Types of Hydropower

The head and installed capacity (size) are commonly used as criteria for the classification of hydropower plants (Kumar *et al.*, 2011). According to these modes, head and size, hydropower can be classified as large (> 100 MW), medium (15 – 100 MW), small (1 – 15 MW), mini (100 kW – 1 MW), micro (5 – 100 kW) and pico (< 5 kW) hydro. However, hydropower plants are mainly classified by the type of facility; run-of-river, dam based and pumped storage hydroelectric schemes.

2.3.1 Run-of-River

A run-of-river scheme (Figure 2) facility draws the energy for electricity production mainly from the available flow of the river. As such, the scheme generation profile is dictated by local river flow conditions. In turn, generation depends on precipitation and discharge and may have substantial daily, monthly or seasonal variations due to climate change and climate variability (Kumar *et al*., 2011).

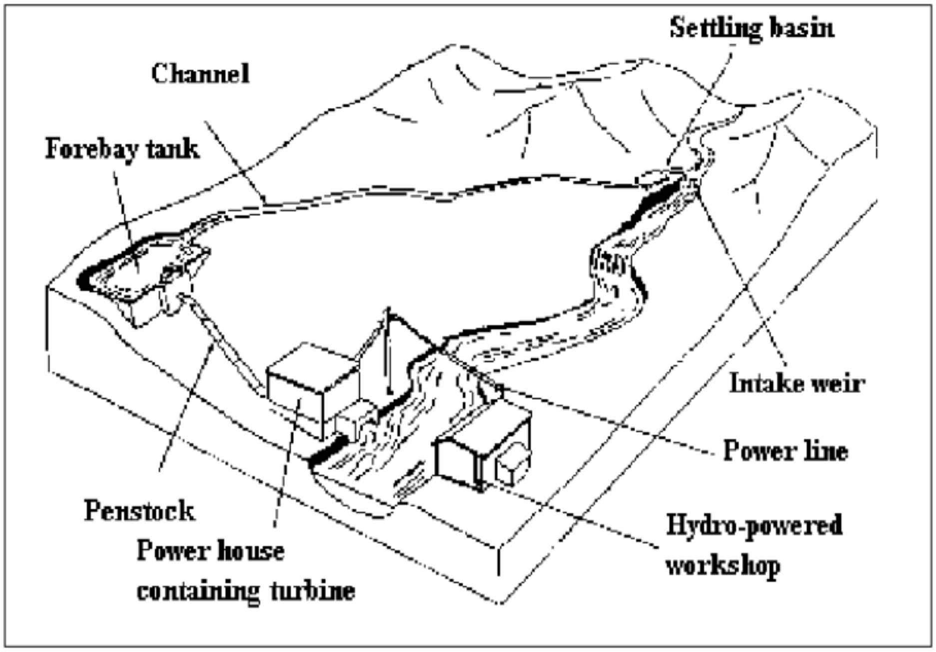


Figure 2: Layout of a Run of River Hydro Scheme

Source: Practical Action, 2007.

2.3.2 Dam based (Storage Hydropower)

Hydro schemes may also be based on the construction of a large dam to store water and to provide sufficient head for the turbine. These water storage schemes enable the power station to generate at times of peak power demand, and then allow the water level to rise again during off peak time. Construction of schemes of this type will depend on the geographical conditions of that area (Kumar *et al*., 2011). As attested by Tamburrini (2004), the advantage of this type of plant is that it is not affected much by daily and monthly variations of precipitation and temperature since they have the capability to store the energy (water) and use it when necessary.

2.3.3 Pumped Storage

On the other hand, pumped storage plants utilize a reversible pumping turbine to store hydro energy during off-peak electricity hours by pumping water from a lower reservoir to an upper reservoir (Tamburrini, 2004). This stored energy is then used to generate electricity during peak hours, when electricity is costly to produce, by distributing water from the upper to the lower reservoir.

2.4 Technical Aspects of Micro-Hydropower

Micro hydropower is the small scale harnessing of energy from falling water, typically generating between 5 kW to 100 kW (Kreis & Steven, 2001) and powering small communities or factories. Micro hydropower schemes generally follow the layout shown in Figure 2.1; a run-of-river scheme where no water storage is required. The main structure of a run-of-river plant is simply to redirect water flow from a weir towards the penstock, which feeds the water downhill to the power station (Bjørnåvold, 2009). The natural force of gravity generates the energy used to spin the turbines located in the power station which converts the energy from the water to generate electricity. After this process, the water is redirected back to the natural flow of the rivers.

2.5 Climate Change and Hydropower

Climate change and variability, manifested by environmental change, is no longer a mythical discourse; the scientific consensus is not only that, human activities have contributed to it significantly, but that the change is far more rapid and dangerous than thought earlier (IPCC, 2007b). Climate change and variability are now becoming one of the significant development challenges due to shift in the average patterns of weather. While climate change results from activities all over the globe, with rather unevenly spread contributions to it, it may lead to very different impacts in different countries, depending on local, regional environmental conditions and on differences in vulnerability to climate change (UNEP/Earthscan, 2002).

The Millennium Ecosystem Assessment (MA, 2005) shows that, in all ecosystems of the world, the climate change impacts are rapidly increasing, such as on water resources, environmental services and other livelihoods capital assets for sustainable human development. In the World Summit on Sustainable Development (WSSD) held from August 26 to 4 September 2002 in Johannesburg, South Africa, the UN Secretary General outlined priority areas for sustainable development as water and sanitation, energy, health, agriculture and biodiversity protection and ecosystems management (WSSD, 2002). Dhakal (2011) also attest that the energy sector is one of the major users of water resources.

The conceptual framework for this study is based on the fact that the ecosystem provides a number of services that benefit the human being and that human beings play a vital role by directly or indirectly affecting the ecosystem (MA, 2005). The services people receive from ecosystems are many and varied but the Millennium Ecosystem Assessment divides the services into four categories as illustrated in Figure 3 which include; provision of services, regulating services, cultural services, and supporting services. These services in turn constitute the well-being of individuals.

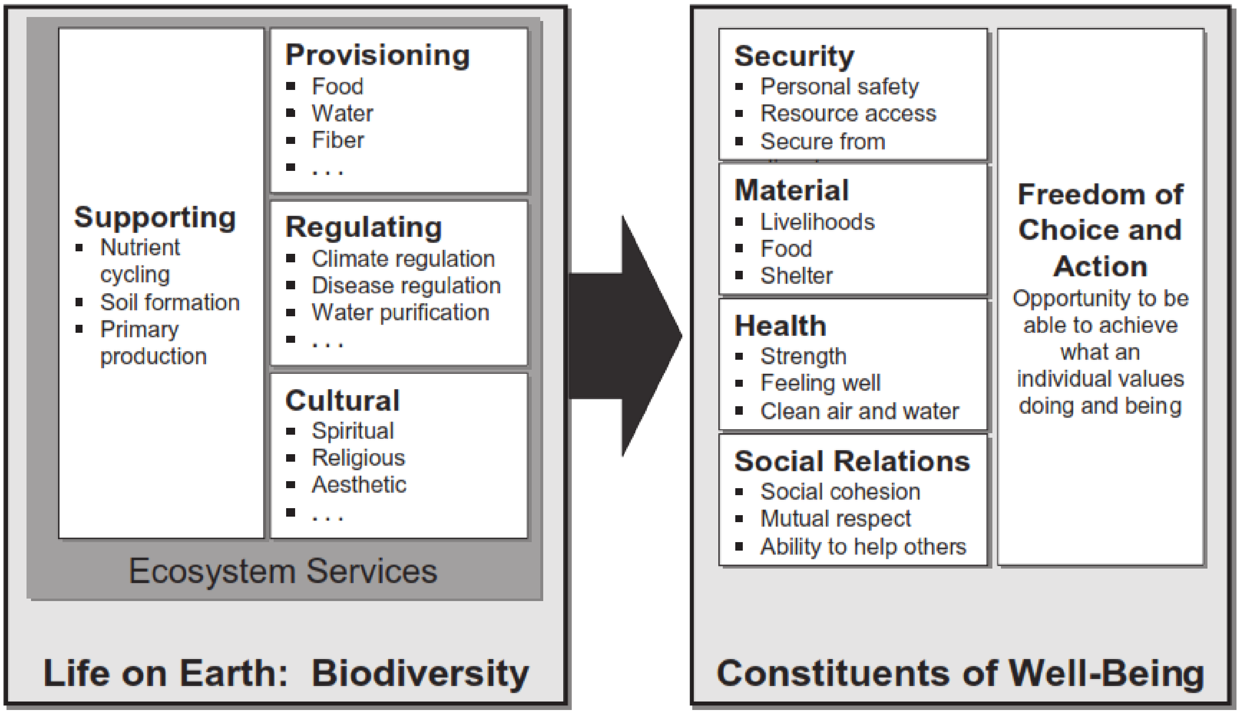
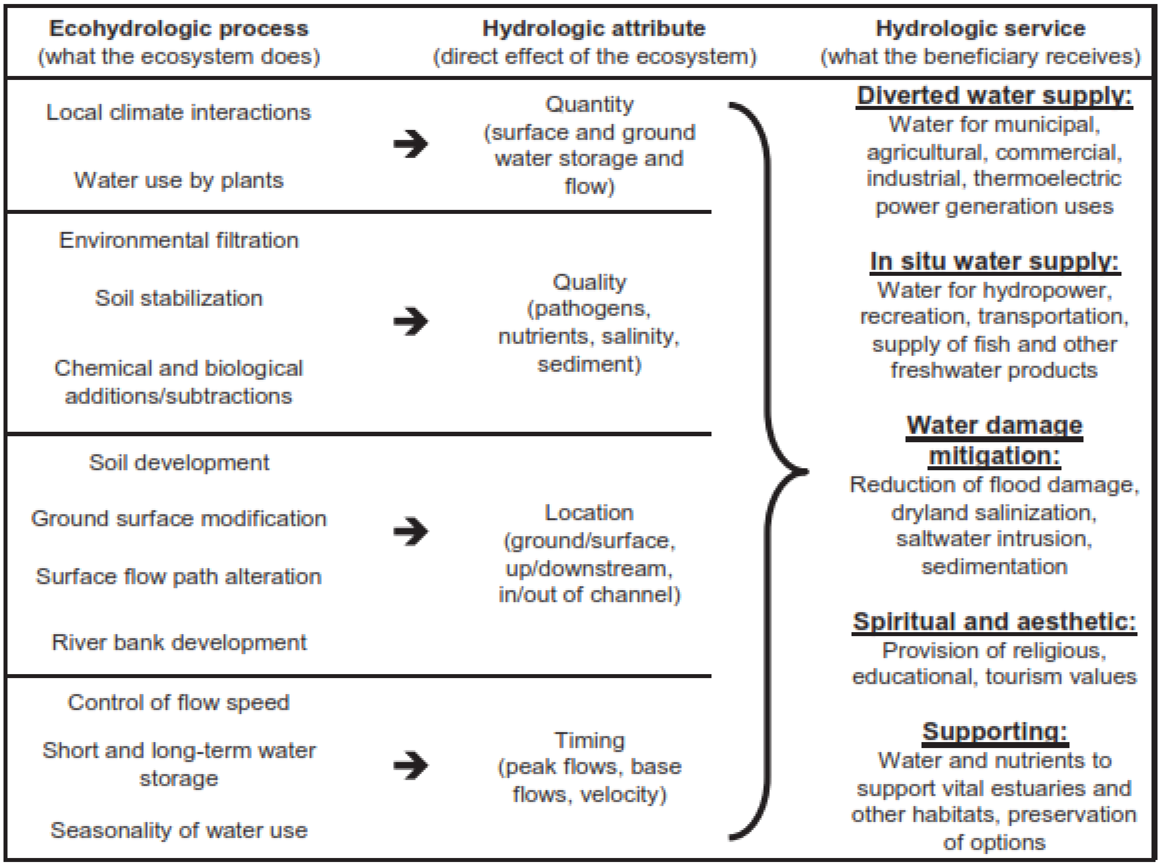


Figure 3: Millennium Ecosystem Assessment classification scheme.
Source: Bruaman et al., 2007.

Motivated by the Millennium Ecosystem Assessment classification scheme, Bruaman *et al.* (2007) developed a framework to incorporate hydrologic ecosystem services. These water related services include the mitigation of flood damage or the provision of clean water and depends on the amount, timing, location, and quality of water (Guswa *et al.*, 2014). The hydrologic services provide a number of benefits which are broadly grouped into five categories; extractive water supply, in situ water supply, water damage mitigation, spiritual and aesthetic, and supporting. Figure 4 is an illustration of the relationship of hydrologic ecosystem processes to hydrologic services.



Ecohydrologic process (what the ecosystem does)		**Hydrologic attribute** (direct effect of the ecosystem)	**Hydrologic service** (what the beneficiary receives)
Local climate interactions Water use by plants	➔	Quantity (surface and ground water storage and flow)	**Diverted water supply:** Water for municipal, agricultural, commercial, industrial, thermoelectric power generation uses **In situ water supply:** Water for hydropower, recreation, transportation, supply of fish and other freshwater products **Water damage mitigation:** Reduction of flood damage, dryland salinization, saltwater intrusion, sedimentation **Spiritual and aesthetic:** Provision of religious, educational, tourism values **Supporting:** Water and nutrients to support vital estuaries and other habitats, preservation of options
Environmental filtration Soil stabilization Chemical and biological additions/subtractions	➔	Quality (pathogens, nutrients, salinity, sediment)	
Soil development Ground surface modification Surface flow path alteration River bank development	➔	Location (ground/surface, up/downstream, in/out of channel)	
Control of flow speed Short and long-term water storage Seasonality of water use	➔	Timing (peak flows, base flows, velocity)	

Figure 4: Relationship of hydrologic ecosystem processes to hydrologic services.
Source: Bruaman et al., 2007.

Based on these two framework approaches, the Millennium Ecosystem Assessment classification scheme and the Bruaman framework, Murieta & Chiabai, (2015) summarized them into one approach (as in Figure 5) and this serves as the backbone of this study. These services are interrelated in dynamic and complex ways (Guswa *et al.*, 2014); here we see that the discharge (a hydrologic attribute) is a function of hydropower generation which is under in situ water supply (hydrologic service). The eco-hydrologic processes can be considered as the foundation for providing water for hydropower production. Understanding their functioning and relationships requires approaches spanning diverse fields of inquiry as these characteristics are affected by complex interactions among climate, geology and topography, along with land cover, land management, and other human modifications of the landscape.

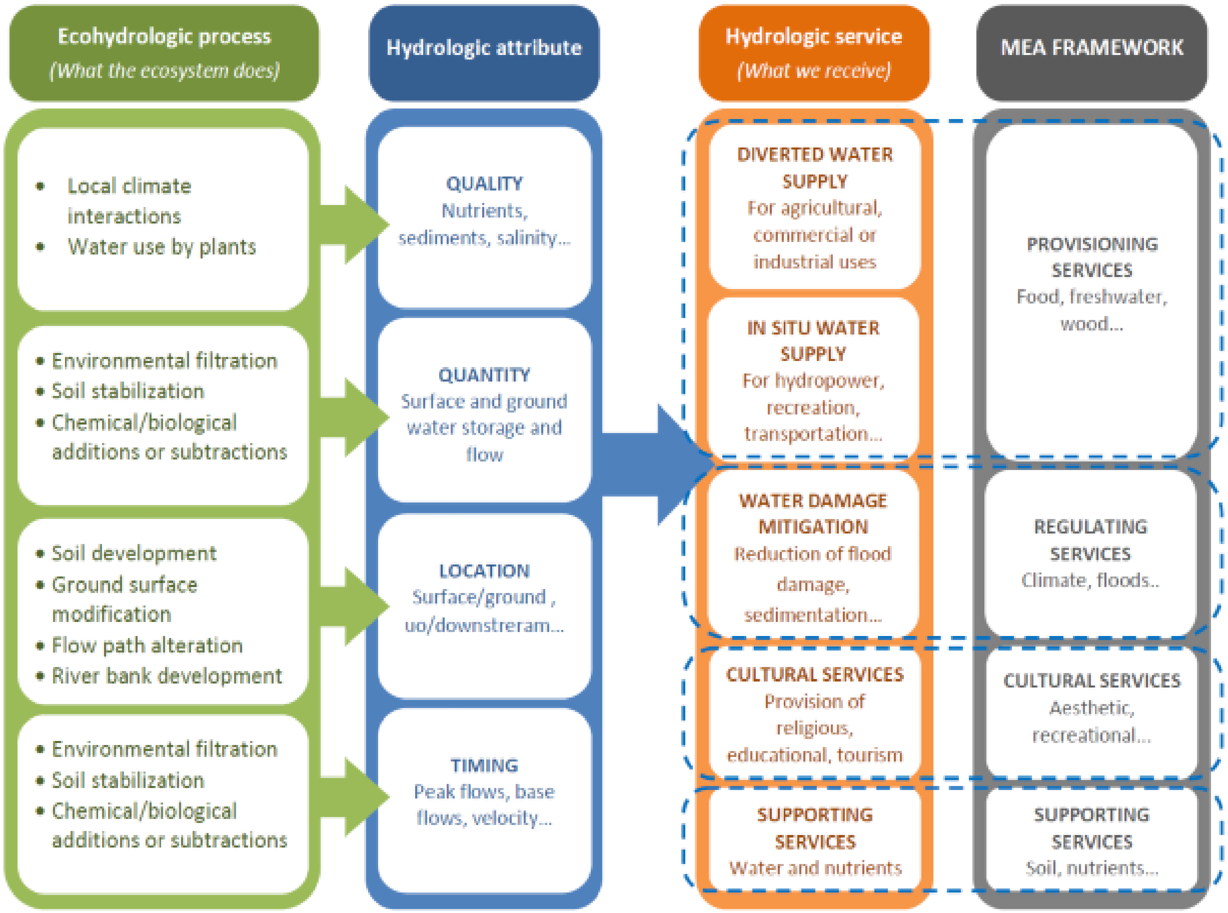


Figure 5: Relationship between Millennium Ecosystem Assessment general framework and Brauman approach, which shows the complex connection between hydrologic ecosystem services and processes.
Source: Murieta & Chiabai, 2015.

Therefore, agriculture, forestry and land use will affect discharge. However, this study mainly focused on climate change and how it will particularly affect the precipitation and flow regime.

The impacts are inevitable since the alteration of rainfall and temperature patterns will affect hydropower generation with run-of-river power plants being more vulnerable to climate change impacts than storage facilities (Kumar *et al*., 2011). This should be a concern for a sustainable socio-economic development of a nation like Malawi, where energy sector is heavily dependent on hydropower and therefore water and energy policies need to be more closely coordinated. Our approach to this study is summarized in the flow chart depicted in Figure 6.

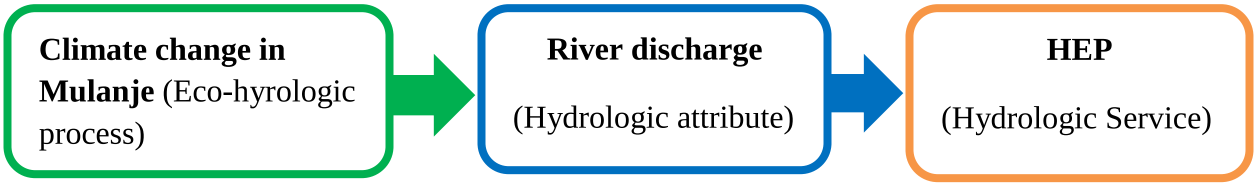


Figure 6: Conceptual Research Scheme.

2.6 Global and Regional Studies on Climate Change and Hydropower

Currently, hydropower accounts for close to 16 % of the world's total power supply and is the world's most dominant (86 %) source of renewable electrical energy (Hamududu & Killingtveit, 2012). The key resource for hydropower generation is runoff, which is dependent on precipitation. The future global climate is uncertain and hence changes in temperature and precipitation due to climate change will have an impact on river catchments runoff thus posing some risks for the hydropower generation sector (Mulumba, Afullo & Ijumba, 2012)

Hamududu and Killingtveit (2012) evaluated the changes in global hydropower generation resulting from predicted changes in climate. The study used an ensemble of simulations of regional patterns of changes in runoff, computed from global circulation models (GCM) simulations with 12 different models. Based on these runoff changes, hydropower generation was estimated by relating the runoff changes to hydropower generation potential through geographical information system (GIS), based on 2005 hydropower generation. The countries/states were used as computational units to reduce the complexities of the analysis. The results indicated that there are large variations of changes (increases/decreases) in hydropower generation across regions and even within regions. Globally, hydropower generation is predicted to change very little by the year 2050 for the hydropower system in operation today. However, there are many regions where runoff and hydropower generation will increase due to increasing precipitation, but also many regions where there will be a decrease. Therefore, it is necessary to carry out basin level detailed assessment for local impacts which may differ from the country based values.

The East and Southern African region has climate that is highly variable, unreliable and unpredictable (Hamududu & Killingtveit, 2006). Both of them attempted to evaluate the potential impacts of climate change on future water resources and specifically hydropower production of Eastern and Southern Africa. The MAGICC/SCENGEN and the CSAG visualizations were employed to get insight of future climate picture for the region. The CSAG employed the station data (14 GCMs) while MAGICC/SCEGEN (20 GCMs) used grids to aggregate the climate variables. The resulting runoff for the year 2050 was then used to evaluate the likely changes in hydropower production. The results indicated a decrease of hydropower production in Southern African systems while there is increase in the upper Eastern African systems. The combined future hydropower production for Eastern and Southern Africa however indicated a decrease compared to the 2006 levels as most of the hydropower production systems are located in the southern part of the region where projections showed a decreased trend. However, the situation could change if East Africa increases its hydropower production capacity.

Similarly, Malley (2011) conducted a study to analyze the link of climate change to water shortages for hydropower generation in the Mtera reservoir (Tanzania), which supply 50 % of the hydropower to the national grid. Literature survey, records collection and analyses and observations were research tools used. Regression analysis of variations in the amounts of rainfall revealed that 64 % of increasing variability in rainfall over the years in the watersheds described declining water levels in Mtera dam. The study also found out that climate change was the main driver of water shortages for hydro-power generation. This suggests a need for national adaptation strategies to water supply shortages.

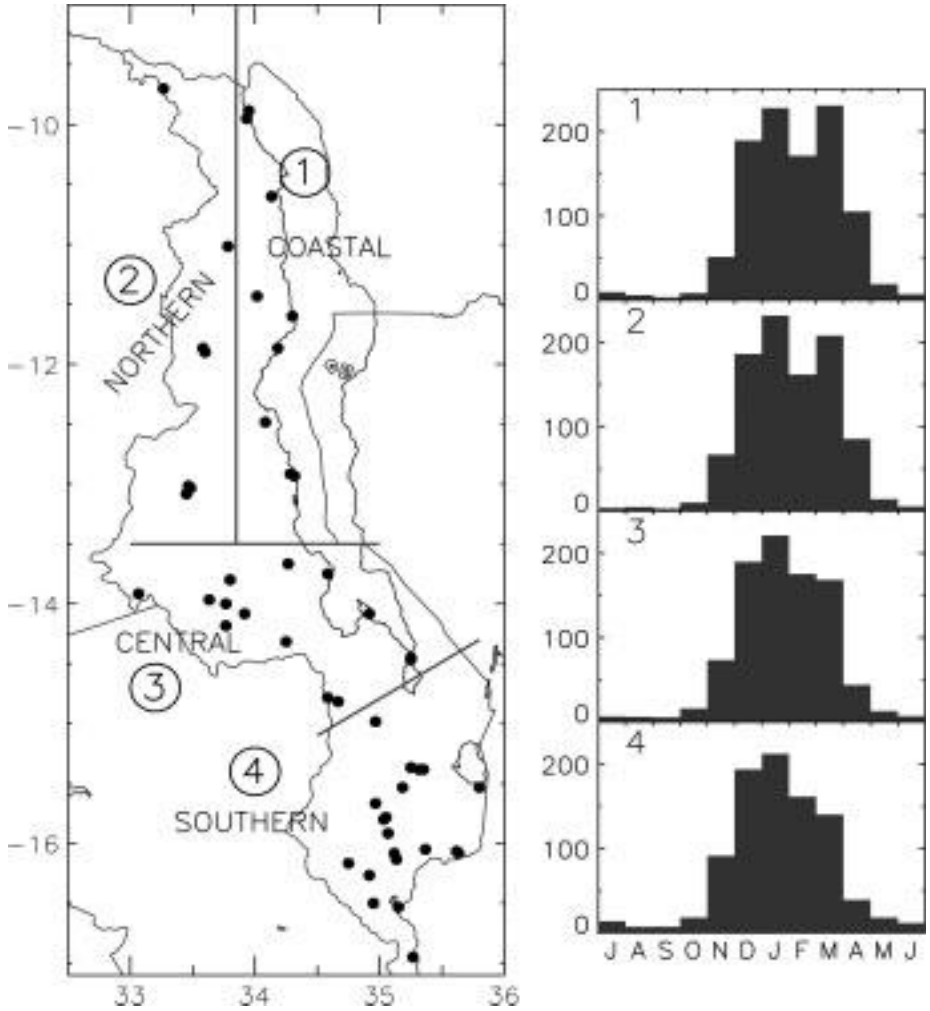
Evidence from these studies clearly shows that changes in temperature and precipitations due to climate change will affect rivers catchments discharge as well as hydropower generation. However, the rapid population growth and industrialization in the developing countries will lead to high demand for power. Since hydropower is renewable energy, Africa has an imperious obligation to maximize its production and distribution in order to satisfy the increasing demand, and therefore meet the Sustainable Development Goals. In general, these global and region studies have shown hydropower is vulnerable to climate change. The impacts will differ from region to region and Africa is not an exception. Hence, the impacts of climate change on Malawi needs to be evaluated in order to move towards adaptation measures as well as their effective implementation that would constitute a significant benchmark for the maximization of hydropower generation capacity and consequently satisfying the ever growing energy demand for sustainable economic development in Malawi.

2.7 Malawi Studies on Climate Change and Hydropower

Literature on the study of climate change and variability specifically on hydropower in Malawi is almost non-existent at all-time scales. Consequently this study will serve to fill for that gap. However, McSweeney, New & Lizcano (2011) in a UNDP Climate Change Country Profiles for Malawi report that the mean annual temperature has increased by 0.9 °C between 1960 and 2006, an average rate of 0.21 °C per decade. They ascertain that increase in temperature has been most rapid in the rainy summer (December to February) and lowest in hottest season (September to November). Year to year variability in rainfall is very high in Malawi, thus long-term trends are difficult to identify. In 2006, wet-season (December to February) rainfall over Malawi was markedly low, possibly causing a decreasing trend in December to February rainfall; however, evidence does not reveal consistent decreases. The GCMs projections of future climate indicate that the mean annual temperature will increase by 1.1 to 3.0 °C by the 2060's, and by 1.5 to 5.0 °C by the 2090's. All projections indicate substantial increases in the frequency of days and nights that are considered 'hot' in current climate. Annually, projections indicate that 'hot' days will occur more often. Projections of mean rainfall do not indicate substantial changes in annual rainfall. The range of projections from different models is large and straddles both negative and positive changes (-13 % to +32 %). Seasonally, the projections tend towards decreases in dry season rainfall (June to August) and (September to October), and increases in wet season rainfall (December to February) and (March to May).

Similarly, Ngongondo *et al*. (2011) conducted a study to evaluate spatial and temporal characteristics of rainfall in Malawi, a data scarce region, between 1960 and 2006. Rainfall variables and indicators from rainfall readings at 42 stations in Malawi, excluding Lake Malawi, were analyzed at monthly, seasonal and annual scales. Spatial rainfall variability was investigated using the spatial correlation function. Temporal trends were analyzed using Mann–Kendall and linear regression methods. Heterogeneity of monthly rainfall was investigated using the precipitation concentration index (PCI). The results showed that (1) most stations revealed statistically non-significant decreasing rainfall trends for annual, seasonal, monthly and the individual months from March to December at the 5 % significance level. The months of January and February (the highest rainfall months), however, had overall positive but statistically non-significant trends countrywide, suggesting more concentration of the seasonal rainfall around these months. (2) Spatial analysis results showed a complex rainfall pattern countrywide with annual mean of 1095 mm centered to the south of the country and mean inter-annual variability of 26 %. (3) Spatial correlation amongst stations was highest only within the first 20 km, typical of areas with strong small-scale climatic influence. (4) The country was further characterized by unstable monthly rainfall regimes, with all PCIs more than 10. (5) An increase in inter-annual rainfall variability was found. Therefore, an understanding of temporal and spatial characteristics of rainfall is central to water resources planning and management especially with evidence of climate change and variability in recent years.

On the other hand, the study by Nicholson, Klotter *&* Chavula (2013) revealed that the rainfall regime in 75 weather stations throughout Malawi is not homogeneous. Through correlating the stations from one another, the country was divided into four regions by combining the stations as illustrated in Figure 7. The results indicated that the rainy season generally commences in late October or early November and runs through early April and maximum rainfall occurs in January in three of the four regions (2, 3 and 4). Overall, rainfall has generally been below normal during the last two decades in regions 1 and 2. A major implication of the results was that the factors governing inter-annual variability may be quite different for the early and late rainy seasons and global climate change might affect these regions differently.



(a) **(b)**

Figure 7: (a): homogeneous rainfall regions of Malawi and the stations within them. (b): The typical seasonal cycle of rainfall (mm per month) in each.

Source: Nicholson *et al.*, 2013.

In the quest of forecasting climate change pattern for Bolero Agriculture Extension Planning Area in Malawi Singini, Tembo and Banda (2015) concluded that the maximum temperature will increase by 1.6 °C from 27.7 °C in 1982 to 29.3 °C in 2030. The temperature data used to project this temperature increase was from 1982 to 2013 and the study used Univariate Autoregressive Integrated Moving Average to model and forecast temperature variability. This increase in temperature would have a negative impact on agricultural livelihood options in the area (Bolero). From Nicholson *et al*. (2013), Bolero falls in region 2 and as attested by them, the regions are not homogeneous and thus the climate for region 2 is different from region 4 (where the hydropower is located). Therefore, this further calls for reasons to investigate the change in climate for Mulanje (in region 4) in order to reveal the impact it will have on hydropower.

In its Initial National Communication of Malawi prepared in fulfilment of her commitments under the United Nations Framework Convention on Climate Change (UNFCCC) of 2002, climate projections from models were used to represent three basins for the vulnerability assessments on water resources namely, South Rukuru, Bua and Linthipe river basins. Two GCM models, the HadCM2 and CSIRO-TR were selected for scenarios generation for the years 2020 to 2100. The HadCM2 model underestimated rainfall, predicting a decline in rainfall by 1 to 18 %, thus giving a dry scenario. By contrast CSIRO-TR overestimates rainfall suggesting an increase in the amount of rainfall of 6 to 22 % leading to wet scenarios. Runoff projections were estimated using the watball model with inputs from the two scenario generations. The following projected results were obtained for the years 2020, 2075 and 2100. (1) Both models predict that temperatures of all basins will increase by 0.6 °C. (2) For precipitation CSIRO-TR projected an increase in the amount of rainfall by 6 to 22 % whereas HadCM2 predicts a decline from -1 to 18%. (3) Watbal predicted that runoff will change by -1 to 44 % and -8 to 81 % using HadCM2 and CSIRO-TR models respectively. (4) Annual availability of water resources in the study basins may not be vulnerable to climate change; and (5) Analysis of the water balance shows that evapotranspiration exceeds annual rainfall. This result implied that the excess water used for evapotranspiration is obtained from the ground water (MoNRE, 2002).

Evidence shows that the quantity of surface water resources are usually more abundant during the rainy season than the dry season. Under these circumstances, the sectors that are expected to exert high water demand are domestic needs, irrigated agriculture, hydropower generation, and industrial production. Therefore, changes in river hydrology due to climate change will have an impact on hydropower generation.

2.8 Malawi's Climate Baseline and Projected Climate Change

2.8.1 Climate Baseline

Malawi is a land-locked and densely populated country in Sub-Saharan Africa, lying in the southern end of the Great East African Rift Valley. It lies between latitudes 09025'S and 17008'S and longitudes 32040'E and 35055'E. The total area is 118 484 km^2 of which 20 % is covered by water mainly Lake Malawi. The country is bordered by Mozambique to the east, south and west; Tanzania lies to the north; and Zambia to the north-west. Its topography is varied; the Great Rift Valley that covers Lake Malawi runs from north to south with elevations ranging from 800-1200 meters, but with highland peaks as high as 3000 meters above sea level (McSweeney *et al*., 2011). The country's climate is tropical but is significantly moderated by the effects of Lake Malawi, high altitudes and proximity to the influence of westerly frontal systems which move eastwards around the South African coast influences the temperatures to be relatively cool (MoNRE, 2002). The climate has two distract seasons, the rainy season from November to April and the dry season from May to October. However, the dry season is subdivided into two parts namely cool and wet (May to August) and hot and dry (September to October).

As reported in its Second National Communication of Malawi prepared in fulfilment of her commitments under the United Nations Framework Convention on Climate Change (UNFCCC) of 2011, Malawi has experienced extreme weather events over the last few decades, ranging from droughts (1991/92) to floods (1996/97) and flush floods (2000/01). This shows that Malawi is vulnerable to climate change because of its heavily reliance on natural resources mainly soils, water, fisheries from inland lakes and fuel wood from forests. The Malawi Vulnerability Assessment recognizes two climate change response options: mitigation and adaptation. UNFCCC (2009) defines mitigation as efforts to reduce/prevent emission of greenhouse gases (GHGs) or to enhance their removal from the atmosphere by sinks. While adaptation to climate change refers to adjustments in human and natural systems in response to actual or expected climatic variation, with a view to moderating harm or exploiting beneficial opportunities (IPCC, 2001b). Adaptation was the focus of this study.

Precipitation. A detailed rainfall climatology for Malawi by Nicholson *et al*. (2013) reveals that Malawi is a region with a strong rainfall maximum in the austral autumn along the western shore of Lake Malawi. The mean annual rainfall in Malawi ranges between 725 mm in low-lying marginal rainfall areas such as the Shire Valley and some areas along the Lakeshore Plain, to over 2500 mm on high altitude plateaus, such as Viphya and Nyika plateau (Action Plan, n.d.). Its distribution is influenced by topography (orographic effects) and proximity to the lake. The Inter-Tropical Convergence Zone (ITCZ) and the Congo Air Mass or Zaire Air Boundary are known main rain-bearing systems that bring rainfall to the country. Sometimes, easterly waves, anti-cyclones and occasionally tropical cyclones also influences the climate of Malawi. A deficiency in rainfall may occur if these systems are not active in a season.

USAID (2013) reports that the rain shadow areas, such as the Shire Valley, the western parts of the Shire Highlands, Lake Chilwa Plain, and the north-western parts of the Viphya and Nyika plateaus, receive the lowest total annual rainfall. High altitude plateaus, such as Mulanje, Thyolo, Nyika, Misuku and Viphya plateaus, and some areas along the Lakeshore Plain, such as the Nkhata Bay lowlands and north Karonga receive the highest total annual rainfall. The rains typically peak in December/January and end in March or, at times, in April. Mean monthly averages of total rainfall range from under 50 mm to over 400 mm. Humidity ranges from 50 % to 87 % for the drier months of September/October and wetter months of January/February, respectively.

***Temperature*.** The mean annual minimum and maximum temperatures for Malawi ranges from 12 °C to 32 °C (Malawi Meteorological Services, 2006). Usually, lowest temperatures happen in months of June or July, and highest at the end of October or early November. The highest mean temperatures are recorded in the Shire Valley (25 °C to 26 °C) and some areas along the Lakeshore (23 °C to 25 °C). The lowest mean air temperatures (13 °C to 15 °C) are recorded over high altitude areas such as the Mulanje, Zomba and Dedza mountains, Shire highlands, Nyika and Viphya, plateaus. Occasionally, frost has been recorded in some hilly and high altitude areas of the country. The 1980s recorded some of the highest surface air temperatures in recent years, closely followed by the 2000s, raising fears in many quarters that climate is already changing at a rate that is faster than at any other time in the past (USAID, 2013). These changing climatic conditions have normally been associated with the effects of the El Niño.

2.8.2 Projected Climate Change

Scientist use Global Circulation Models (GCMs) to project future climate changes under plausible future climate change scenarios to inform decision makers on future climate. GCMs comprise of simplified but systematically rigorous mathematical representations of atmospheric, oceanic, and continental processes and interactions. Climate change scenarios represent possible expressions of what may happen in the future, especially as a result of increased GHG concentrations, and selected to provide spatially compatible, mutually consistent, coherent, systematic, freely available and physically plausible descriptions of future climate.

Precipitation. Projected precipitation shows inconsistence among different models, with some models projecting increase and others projecting decrease in rainfall (MoNRE, 2002; McSweeney *et al*., 2011). The projections tend to decrease in dry season rainfall (June, July, August and September, October, November), and increases in wet season rainfall (December, January, February and March, April, May) (McSweeney *et al*., 2011). The general trend is that the mean monthly rainfall will decrease with time with the highest percentage decrease predicted for the year 2020 (MoNRE, 2011). The rainfall change is predicted to be worse in the Lower Shire Valley (-4.8% annual rainfall change); around Lake Chilwa, Bvumbwe, Makoka and Liwonde National Park (-3.5% annual rainfall change), with little change for most parts of the northern Malawi.

Projections for Malawi for the 2020 to 2040 period are mainly consistent and show an enhancement of rainfall during the months of December through February, followed by an early cessation (USAID, 2013). Projections were also consistent for the period of 2040 to 2060 with an over-all decrease in monthly rainfall in the early parts of the rainy season compared to those found from the historical climate analysis. The USAID (2013) further reports that both 2020 to 2040 and 2040 to 2060 period, projections show drier conditions during November and December respectively. Evidence also show less rainfall in April, suggesting that an early cessation will continue to occur after the 2020 to 2040 period. A report by Action Aid (2006) confirms these changes in precipitation are already happen as farmers have perceived change in the rainy season, making agriculture decisions regarding planting more difficult and less reliable.

Temperature. Generally, all GCMs results predict significant increase in temperature, forecasting slightly warmer winters and hotter summers. Temperature projections for 2020 to 2040 period, the maximum monthly mean temperature indicated the lowest increases in maximum temperature likely to take place during January and February, with changes of between of 0.6 °C to 1.15°C and 0.75 °C to 1.5 °C (USAID, 2013). Furthermore, the early summer months of October and November were projected to be warmer, with an increase of between 1.75 °C to 2.5 °C for 2040 to 2060 period. Furthermore, strongest warming is projected to occur for the period 2040 to 2060 as compared to 2020 to 2040 period during the months of October and November. Hence, the analysis gave indications that the heat spells would be of longer duration during these periods. A report by Action Aid (2006) confirms that farmers have seen increase in temperatures over the years.

2.9 Overview of Malawi's Electric Generation Profile

Nearly all of Malawi's electricity is provided by hydropower from a cascaded group of interconnected hydroelectric power plants located on the Shire River and a mini-hydro on the Wovwe River, which constitute the interconnected system. Total installed capacity of these hydropower plants is 351 MW. Some thermal power plants serve as stand-by for the interconnected system: a 15 MW gas turbine in Blantyre and a 1.1 MW diesel power plant in Mzuzu. However, these thermal power plants have not been in use for a long time. Therefore, the total present installed capacity, exclusive of stand-by thermal plants, is about 351 MW. The breakdown of the present generation installed system is shown in Table 1.

Table 1: Generation Installed Capacity

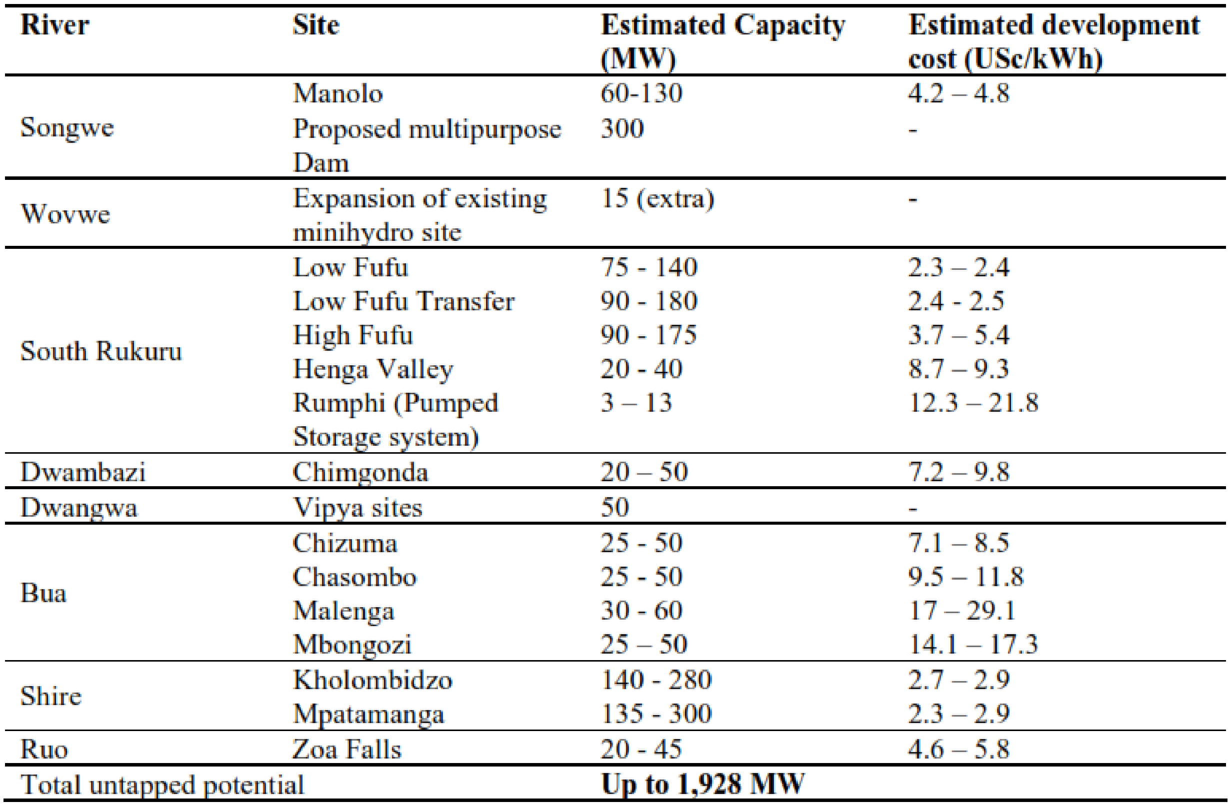
Nkula A	❖ 3 units at 8 MW each, installed in 1966
Nkula B	❖ 3 units at 20 MW each, installed in 1980
	❖ 1 unit at 20 MW, installed in 1986
	❖ 1 unit at 20 MW, installed in 1992
Tedzani I	❖ 2 units at 10 MW each, installed in 1973
Tedzani II	❖ 2 units at 10 MW each, installed in 1977
Tedzani III	❖ 2 units at 25 MW each, installed in 1996
Wovwe Small Hydro	❖ 3 units at 1.5 MW each, installed in 1995
Kapichira Phase I	❖ 2 units at 64 MW each, installed in 2000

Source: MERA

Taulo *et al.* (2015) reports that the projected electricity demand was 598 MW in 2015 and it will edge up further to 874 MW in 2020. In addition, Changes of power demand scenarios in Malawi coupled with tremendous environmental degradation within the past years has severely and negatively affected the operation of the existing power generation plants and their efficiency, which are hydro-based (Ojukwu, Cheikhrouhou *&* Kanonda, 2013; Kaunda and Mtalo, 2013).

This has forced the government to re-examine its power development options in the short and medium term. The hydropower resources of Malawi have not been precisely evaluated, but the potential of a number of major rivers and sites have been identified. Untapped potential hydro resources in Malawi are given in Table 2, while the actual location of the site is shown in Figure 8. Most of the studies were done in 2003 and 2004 under the Malawi Rural Electrification Programme (MAREP) Master plan development.

Table 2: Untapped Hydro Sites and estimated development costs



River	Site	Estimated Capacity (MW)	Estimated development cost (USc/kWh)
Songwe	Manolo	60-130	4.2 – 4.8
	Proposed multipurpose Dam	300	-
Wovwe	Expansion of existing minihydro site	15 (extra)	-
South Rukuru	Low Fufu	75 - 140	2.3 – 2.4
	Low Fufu Transfer	90 - 180	2.4 - 2.5
	High Fufu	90 - 175	3.7 – 5.4
	Henga Valley	20 - 40	8.7 – 9.3
	Rumphi (Pumped Storage system)	3 – 13	12.3 – 21.8
Dwambazi	Chimgonda	20 – 50	7.2 – 9.8
Dwangwa	Vipya sites	50	-
Bua	Chizuma	25 - 50	7.1 – 8.5
	Chasombo	25 - 50	9.5 – 11.8
	Malenga	30 - 60	17 – 29.1
	Mbongozi	25 – 50	14.1 – 17.3
Shire	Kholombidzo	140 - 280	2.7 – 2.9
	Mpatamanga	135 - 300	2.3 – 2.9
Ruo	Zoa Falls	20 - 45	4.6 – 5.8
Total untapped potential		**Up to 1,928 MW**	

Source: Kaunda and Mtalo, 2013.

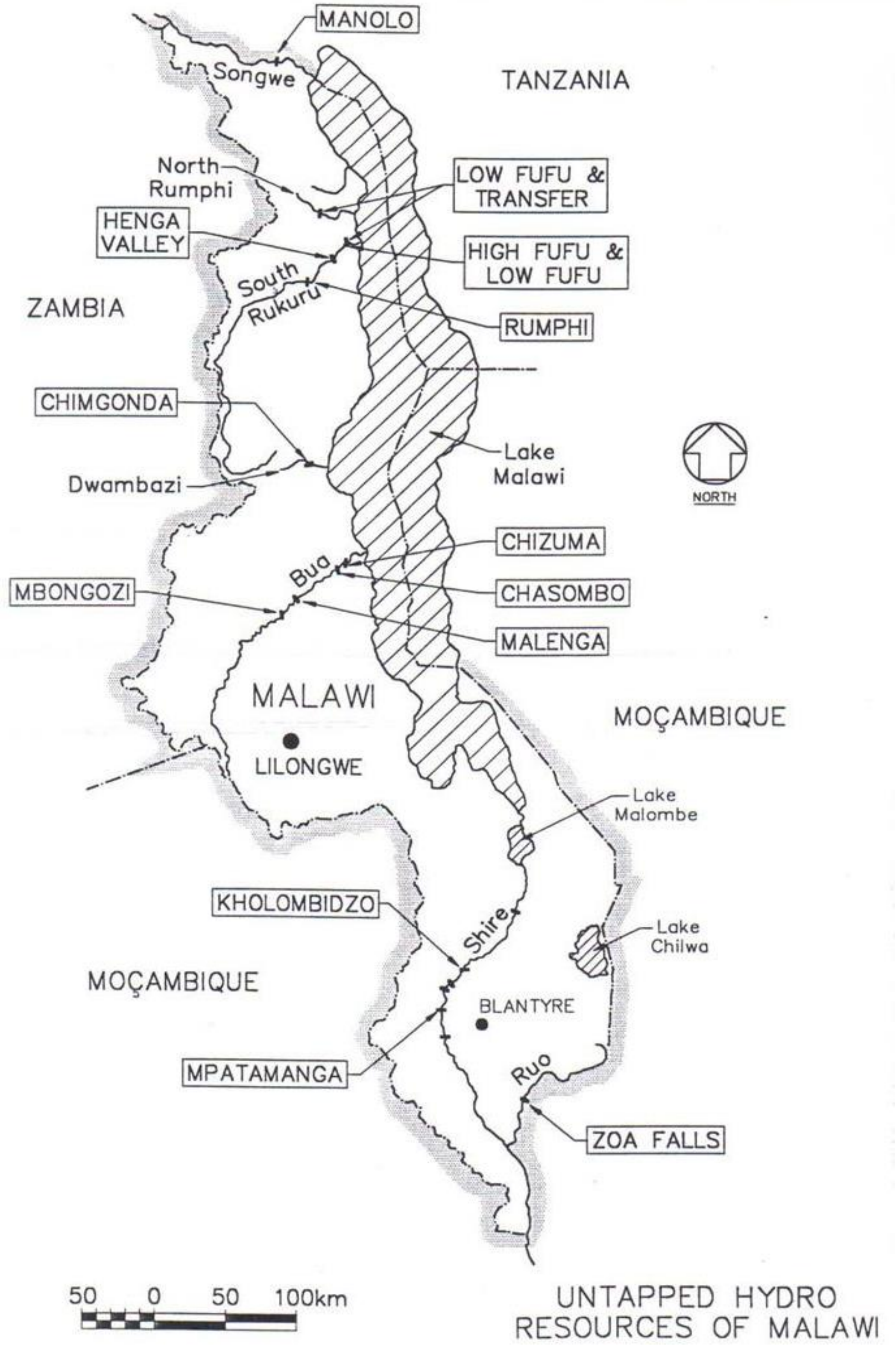


Figure 8: Untapped Hydro Resources of Malawi
Source: MERA

Several efforts are underway to improve the energy predicaments Malawi is facing. In 2011 the Millennium Challenge Corporation (MCC) and World Bank signed agreements with the Government of Malawi (GoM) to fund several projects in order to improve the current energy system. The MCC has financed the development of an Integrated Resource Plan project which comprehensively assessed the status of the sector, defined priority areas of attention and feasibility studies required for the power sector infrastructure rehabilitation, as well as helped to prioritize sector development options and support for the sector reforms (Ojukwu, Cheikhrouhou & Kanonda, 2013). The MCC is also providing USD 350.70 million compact which is focusing on addressing the rehabilitation of key generation, transmission and distribution assets throughout the country.

On the other hand, the World Bank provided a loan of about USD 84.70 million for the development of the Energy Sector Support Project to increase the reliability and quality of electricity supply in the major load centres (Ojukwu *et al.*, 2013). The project has four main components which include; conducting generation and transmission feasibility studies, electricity network strengthening and expansion, capacity building and technical assistance and finally, demand side management and energy efficiency measures. In addition, the Electricity Supply Corporation of Malawi (ESCOM) is running a project to interconnect its power system with the Southern African Power Pool (SAPP) through interconnection with Mozambique's power system (Liu, Masera & Esser, 2013).

2.10 Conclusion

This chapter has established that the country depends heavily on hydropower for its generation of electricity and all of them are run of river type facilities. Run of river facilities directly depend on discharge of the river; increase discharge results in more electric power being produced and reduced discharge results in decreased production. The global studies on climate change effects on hydropower revealed the potential increase and a decrease in hydropower generation that will depend on regional climatology. One of the regional studies (Mtera reservoir, Tanzania) showed that the neighboring country to Malawi is facing a decline in hydropower generation which is being attributed to climate change. However, the climatology within Malawi greatly varies from place to place because it is highly influenced by topography (orographic effects) and proximity to the lake (Lake Malawi). This may have different impacts on generation profile of hydropower facilities within the country. Furthermore, the non-existence (to the researcher’s knowledge) of climate change studies on hydropower in Malawi serves the basis for the researcher to assess the impact of climate change on Lujeri micro-hydro generation. The next chapter, methodology, will highlight the methods and materials used to conduct this study.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter presents the methods that were used to achieve the study objectives. Generally, the study analyzed the weather time series (air temperature and precipitation) and hydrological (discharge) data in relationship to energy generation.

3.2 Data Collection

To achieve the research objectives, several data such as historical discharge rates, monthly and seasonal air temperature and precipitation data was collected for analysis.

3.2.1 Precipitation and Temperature data.

To assess the recent trend patterns in Mulanje district, the historic temperature and precipitation data for the district was collected (Appendix 1 and 2). The utilized data in these study was kindly provided by the Department of Climate Change and Meteorological Services (DCCMS). Pre-quality analyses of the data were done by DCCMS and thus were assumed to be of high quality. The mean monthly minimum temperature and mean monthly maximum temperature data as well as the monthly and seasonal precipitation for the past 52 years (1959 to 2011) from Mimosa station was analysed to infer for any changes in climate.

3.2.2 River Discharge data.

The study analysed discharge data from year 1959 to 1991 (Appendix 3). This was due to the fact that they were more missing values from the years after 1991 as fewer resources were channelled in capturing of this data. The Ruo River hydrological discharge data from station 14C2 was collected from Water Department in the Ministry of Agriculture, Irrigation and Water Development. Pre-quality analyses of the data were also done by Department and thus were assumed to be of high quality.

3.2.3 Power generated data.

The study also required historical data of power generated from the power plant in order to analyze the changes in power output with respect to changes in climate. However, this data was unavailable because the owners of the plant do not regularly keep records of monthly average data on the amount of power generated from the plant. Nevertheless, hydropower generation is a function of net rated head (m), discharge (m^3/s) and machine efficiencies (Hamududu & Killingtveit, 2012) and therefore the potential power generated was estimated according to the following power equation:

$$P\ (W) = \rho g \eta Q H \qquad [1]$$

Where:

P = the power output (W),
ρ = the density of water (1000 kg/m^3),
g = acceleration due to gravity (9.81 m/s^2),
η = the turbine efficiency (%),
Q = the discharge rate (m^3/s),
H = the head (m).

Substituting for ρ and g in [1] gives:

$$P\ (kW) = 9.81\, \eta Q H \qquad [2]$$

3.3 Data Analysis

The data collected was categorized into separate variable as required by the study objectives. The data was logically interpreted along with simple tables, charts and graphs. XLSTAT 2016 was used for Mann-Kendall (MK) statistical test, Microsoft excel 2013 was used for the regression analysis and finally, Statistical Package for Social Science (SPSS) version 18 was used for the correlation analysis test.

3.3.1 The recent trend of climate changes taking place in Mulanje.

The precipitation and temperature data was used to analyze the changes in climate in Mulanje district over the years. To begin with, the precipitation data was analyzed in respect to changes in rainfall distribution, average annual rainfall as well as changes in seasonal rainfall distribution. Ordinary least squares (OLS) regression analysis was used to determine marginal changes in the climatological time series data. The coefficients (marginal change) of these regression equations were used to estimate the future weather conditions. The mathematical equations for calculating the regression analysis is given in equation 3 as follows:

$$y' = a + bx \qquad [3]$$

Where:

$y' =$ the predicted precipitation/temperature from x

$a =$ the y'intercept and is given by

$$a = \frac{(\sum y)(\sum x^2) - (\sum x)(\sum xy)}{n(\sum x^2) - (\sum x)^2}$$

$b =$ the slope of the line (marginal change) and is given by

$$b = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2}$$

$y =$ Dependent variable (precipitation / temperature)

$x =$ Independent variable (time)

$n =$ The sample size.

The MK test was also used to detect if any statistical significant trends exist in the climatological time series data. This test, MK, is a powerful non-parametric method tool for analyzing long time series data such as precipitation, temperature and discharge. Under the null hypothesis (H_0), the assumption is that there is no trend in the data and the alternative hypothesis (H_1) carries the assumption that there is an increasing or decreasing trend over time. The mathematical computation for the MK test statistics S, Var (S) and the standard test statistic Z_S were calculated as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(\text{Tj} - \text{Ti}) \qquad [4]$$

$$sign(\text{Tj} - \text{Ti}) = \begin{cases} 1 & if \ \text{Tj} - \text{Ti} > 0 \\ 0 & if \ \text{Tj} - \text{Ti} = 0 \\ -1 & if \ \text{Tj} - \text{Ti} < 0 \end{cases} \qquad [5]$$

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum t_i(i)(i-1)(2i+5)}{18} \qquad [6]$$

$$Z_s = \begin{cases} \frac{s-1}{\sigma} & for \;\; S > 0 \\ 0 & for \;\; S = 0 \\ \frac{s+1}{\sigma} & for \;\; S < 0 \end{cases} \qquad [7]$$

where T_j and T_i are the actual time series observation data, n is the period of the time series data, t_i denotes the number of ties up to sample i. The test statistic Z_S follows normal distribution and was used as a measure of significance of trend. Positive and negative values of Z_S signifies an increase and decreasing trend respectively. A significance level α is used to test the null hypothesis (increase or decreasing) trend exist. If Z_S is greater than $Z_{\alpha/2}$, the null hypothesis is rejected implying that the trend is statistically significant. The chosen significance level for this study was 1.96 for p-value of 0.05. However, before running a MK trend test, autocorrelation was considered to remove the serial dependence of the time series data that would cause problems in testing of data and interpretation of results, according to the method proposed by Yue and Wang (2004).

3.3.2 The factors influencing discharge rates of Ruo River.

The discharge data was first analyzed for trend test using the MK equations [4], [5], [6] and [7]. To establish if any relationship existed between discharge and precipitation as well between temperature and discharge, the Pearson product moment correlation was used using SPSS. The correlation analysis used the formula presented in equation [8] below:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2]\,[n(\sum y^2) - (\sum y)^2]}} \qquad [8]$$

Where:

$x =$ Independent variable (precipitation / temperature)

$y =$ Dependent variable (discharge rates)

$n =$ The number of data pairs

In addition, the influence of temperature and precipitation on annual average discharge from 1960 to 1990 was investigated further by using multiple regression analysis as given in equation [9]:

$$y' = a + b_1 x_1 + b_2 x_2 \qquad [9]$$

Where:

y' = the discharge

a = the y'intercept

b_1 = the slope of the line (marginal change) of x_1

b_2 = the slope of the line (marginal change) of x_2

x_1 = Temperature

x_2 = Precipitation

3.3.3 Power analysis.

The estimated potential power generated was analyzed using simple graphs in order to evaluate changes in the annual average power generated. The regression equation [3] was used to project the future generated power.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of the data analyzed as per the methods explained in the methodology chapter (data analysis section). Section 4.2 presents changes in recent climatic trends (with respect to temperature and rainfall) over Mulanje district. The impact of the changes in temperature and rainfall on river discharge is discussed in section 4.3. The last section 4.4 discusses the impact of temperature, rainfall and discharge on power generated.

4.2 Recent Climate Trends

4.2.1 Precipitation

This subsection first presents the changes in rainfall distribution followed by changes in average annual rainfall. The third subsection discusses on seasonal rainfall distribution and finally the changes in number of non-rainy days occurring in Mulanje.

4.2.1.1 Rainfall Distribution

The 52 years' data of monthly and seasonal rainfall from 1959 to 2011 at Mimosa station in Mulanje district was analyzed for changes in rainfall distribution, and results of the analysis are given in Figure 9. The results showed that about 85 % of the rainfall occurs during rainy season (November to April), 11 % during the cool and wet season (May to August) and finally, 4 % during the hot and dry season (September to October). Therefore, the results indicate that the water levels for Ruo River accumulates more during the rainy season and the water levels will be dropping as less rainfall will be received during the cold and wet season as well as during the hot and dry season.

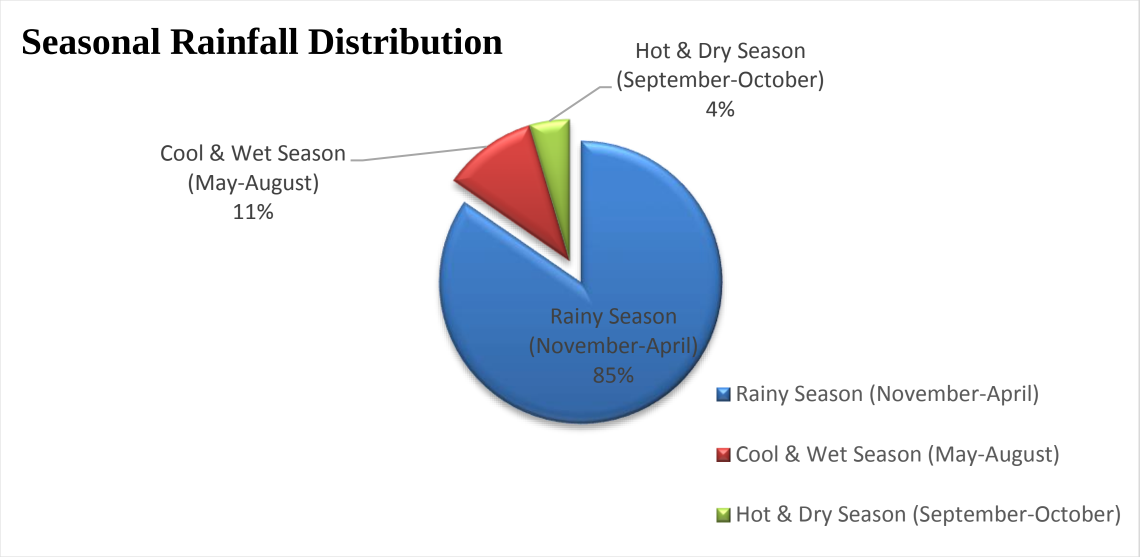


Figure 9: Seasonal Rainfall Distribution in Mulanje

The mean daily rainfall distribution in Mulanje district for the same period (1959 to 2011) is shown in Figure 10, and shows that precipitation in Mulanje starts to peak from the 279th day, which is in October, and is highest between the 341th to 80th days in the year, which is the period during November to March (rainy season in Malawi). These results are in agreement with most of the studies done on Malawi about the onset, duration and end of rainy season, that is, it begins late October or November and continues until March or April. (Action Aid, 2006; Kaunda & Mtalo, 2013; Magrath & Sukali, 2009; MoNRE, 2002; MoNRE, 2011; Nicholson *et al*., 2013; USAID, 2013; Vincent *et al*., 2014).

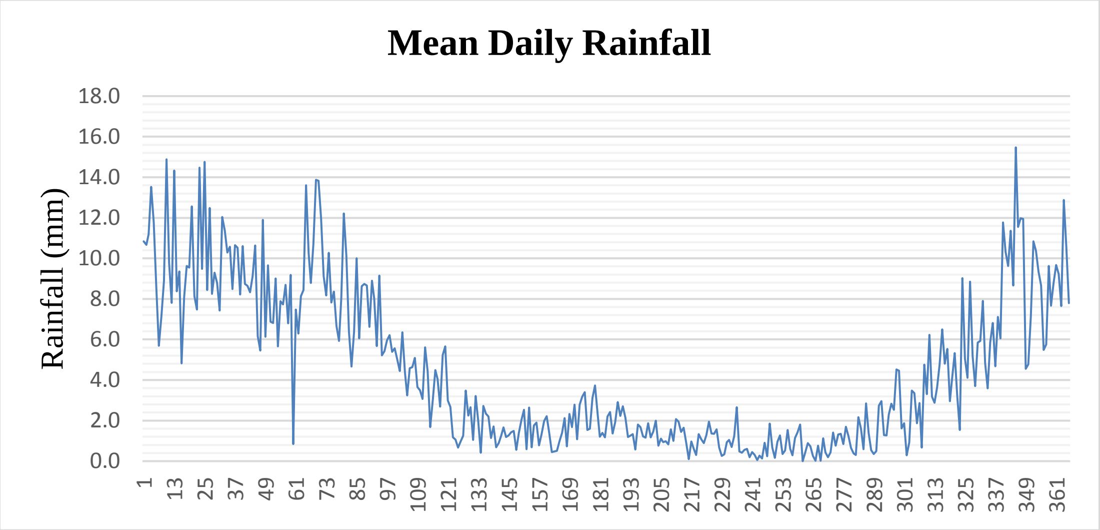


Figure 10: Daily Rainfall Distribution in Mulanje

4.2.1.2 Annual Rainfall Variation

As it has been alluded to earlier, projected precipitation shows inconsistence among different GCMs, with some models projecting an increase, while others project a decrease in rainfall. However, the average annual rainfall data for period 1959 to 2011 (52 years) used in this study showed that the average annual rainfall of Mulanje is decreasing at a rate of about 2.97 mm per year (Figure 11). This is in agreement with the observation by MoNRE (2011), which shows a general decrease in the mean monthly rainfall with time. From this analysis, the maximum occurrence of rainfall occurred in 1962/63 and 1988/89 season with total annual precipitation of 2346.1 mm and 2356.5 mm respectively while the minimum rainfall of 811.2 mm was recorded in 1991/92 season. It was these rainy season, 1991/92, when Malawi experienced severe drought across all regions of the country. It was also observed from the results that the average rainfall is 1602.1 mm for the 52 year period representing an average of about 133.5 mm of precipitation per month. However, Vincent *et al*. (2014) reports that the amount of rainfall in southern Malawi is between 150 mm and 300 mm per month and hence that for Mulanje is below this range. Bulckens (2013) also observed a decrease in rainfall in Mulanje district from an average of 2000 mm in 1960 to about 1500 mm in 2012. This clearly shows that there is a decline in annual rainfall distribution for period 1959 to 2011 and more analysis needs to be done to see whether this trend will continue.

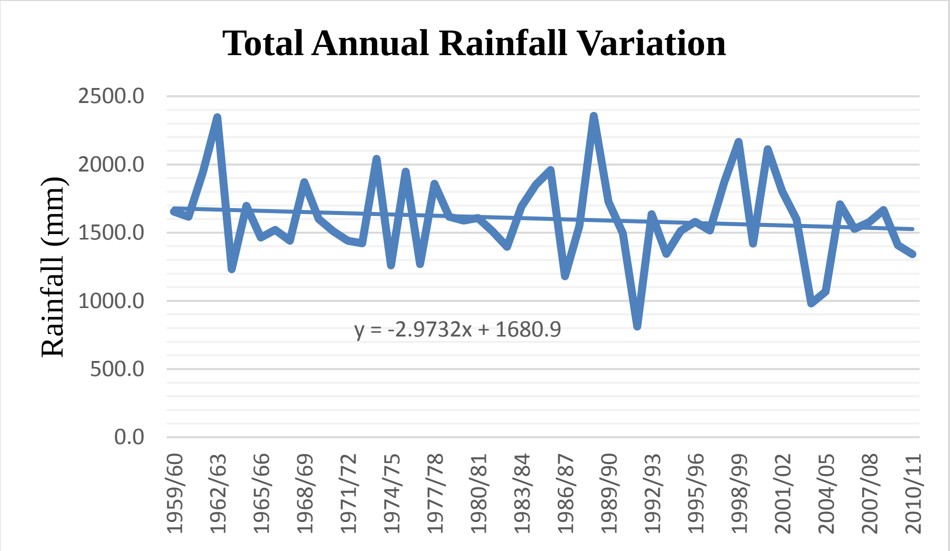
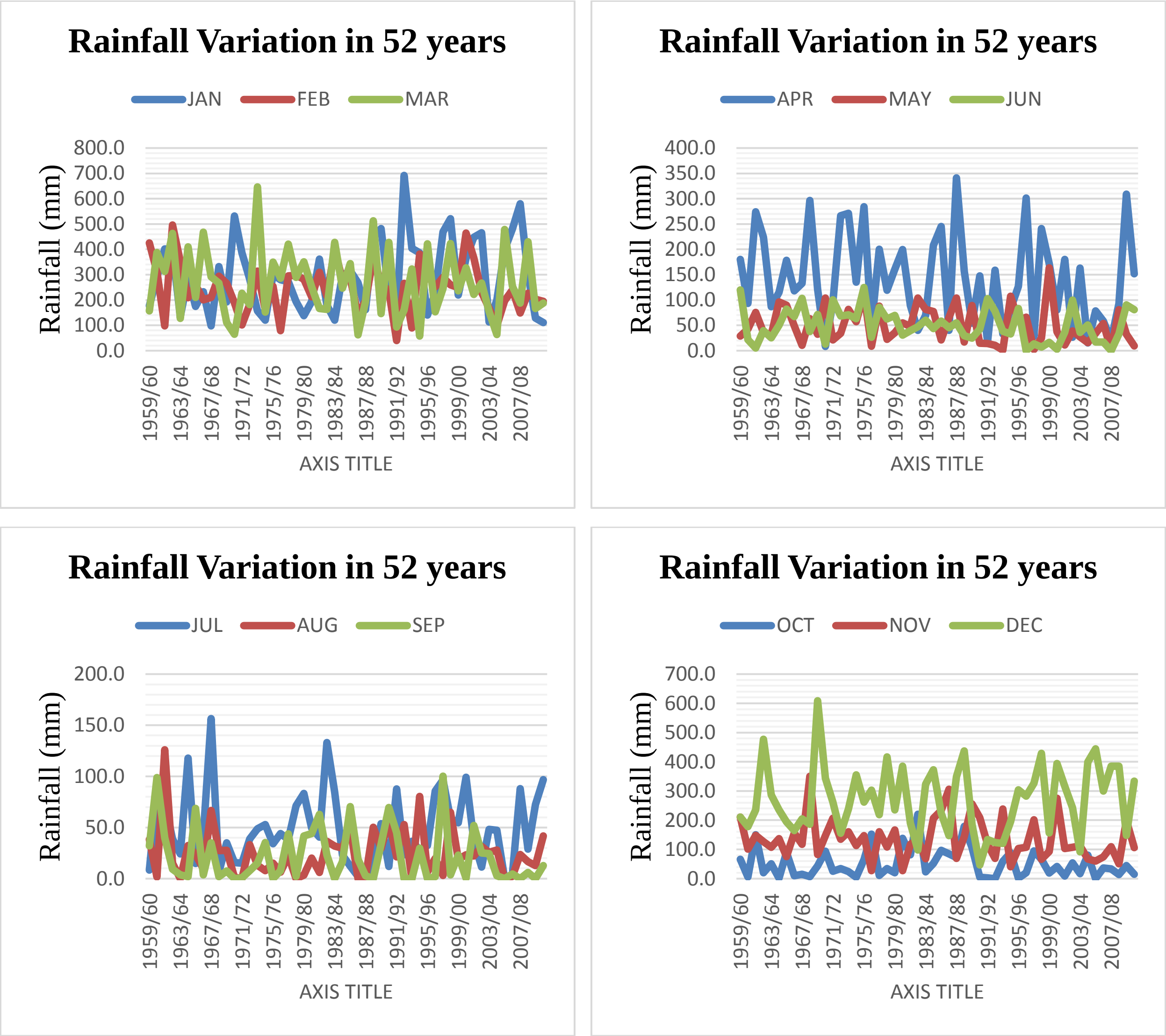


Figure 11: Total Annual Rainfall Variation in Mulanje

Figure 12 shows the rainfall variation for individual months for the 1959 to 2011 period. It was observed that the minimum average annual rainfall occurs in the month of September (21.7 mm) followed by August (24.6 mm) and the maximum average rainfall is in January (292.9 mm), December (270 mm), March (268.8 mm) and February (247.3 mm).


Rainfall Variation in 52 years

Rainfall Variation in 52 years

Rainfall Variation in 52 years

Rainfall Variation in 52 years

Figure 12: Rainfall Variations for Individual Month for 52 years

In order to detect if the trends in the precipitation were significant, the MK test was applied on a monthly scale for the entire period from 1959 to 2011 (52 years). The summary results of non-parametric MK test for trend analysis of data are presented in Table 3. The results for monthly trend tests showed a mix of positive and negative trends with January, July, August and

December depicting a positive trend and the rest of the months of the year showing negative trend. The increasing trend in precipitation was statistically significant for January (*p* = 0.005). Statistically significant negative trend were detected in the months of February, March, April, May, June September and November; no significant trends were found for the other months. The significant decrease of precipitation in November confirms the observation by many studies that the rains are shifting towards December (Action Aid, 2006; Magrath & Sukali, 2009; USAID, 2013).

Table 3: MK tests results for precipitation in monthly time series

Variable	Kendalls tau	S	Var (S)	P-value (Two-tailed)	Alpha	Interpretation	Trend
JUL	0.04	57	2156.3	0.228	0.05	Accept	NST
AUG	0.02	28	2677.9	0.602	0.05	Accept	NST
SEP	-0.12	-156	3494	0.009	0.05	Reject	Decreasing
OCT	-0.05	-72	5697.5	0.347	0.05	Accept	NST
NOV	-0.15	-201	2113.2	<0.0001	0.05	Reject	Decreasing
DEC	0.09	104	3743	0.09	0.05	Accept	NST
JAN	0.11	143	2593.4	0.005	0.05	Reject	Increasing
FEB	-0.12	-164	3309.1	0.005	0.05	Reject	Decreasing
MAR	-0.07	-92	584.2	0.000	0.05	Reject	Decreasing
APR	-0.15	-199	761.4	<0.0001	0.05	Reject	Decreasing
MAY	-0.16	-206	1627.8	< 0.0001	0.05	Reject	Decreasing
JUN	-0.18	-244	2188.2	<0.0001	0.05	Reject	Decreasing

NST = No Significant Trend

4.2.1.3 Seasonal rainfall variation

The hot and dry season precedes the rainy season. Total rainfall data for about 61 days for September and October for 52 year period (1959 to 2011) was analysed. The hot and dry season total annual rainfall variation results together with the non-rainy days in Mulanje are shown in Figure 13. The observation was that the season total annual rainfall is decreasing by about 0.60 mm per year in the district. The UNDP climate change profile on Malawi done by McSweeney *et al*. (2011) also showed that the projections in rainfall tend to decrease in September, October and November. In addition, the number of non-rainy days as depicted in Figure 13 (b), are showing a mild increasing within the season.

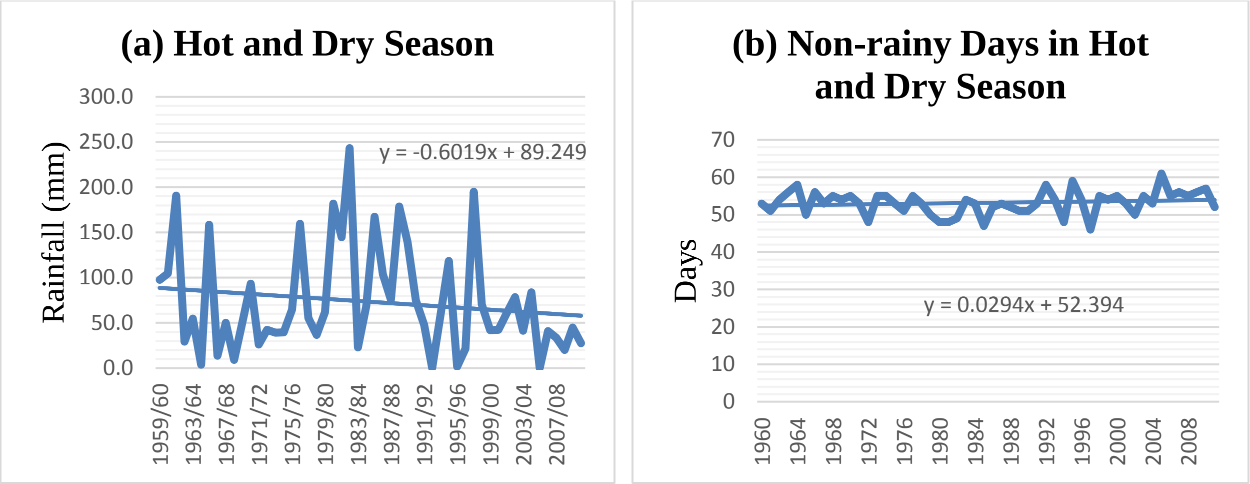


Figure 13: Hot and Dry Season (September-October) Rainfall Distribution

The total annual rainfall distribution and non-rainy days during the rainy season (November to April) were also analysed as shown in Figure 14 (a) and (b) respectively. It was observed that the rainy season total annual rainfall showed a decrease in trend of about 1.36 mm per year. This was also attested by Ngongondo *et al.* (2011) where most rainfall stations over Malawi revealed statistically non-significant decreasing rainfall trends for annual and seasonal rainfall at the 5 % significance level. The decrease in amount of precipitation within the season is also accompanied by an increase in the number of non-rainy days at a rate of 0.43 days per year. Participatory Rural Assessment (PRA) exercise have reported that villagers are experiencing late onset of the rains and an earlier cessation from what they consider “normal rainy seasonal” and making agricultural decisions regarding planting more difficult and less reliable (Action Aid, 2006; Magrath & Sukali, 2009; USAID, 2013). Generally, projections for Malawi as a whole are mainly consistent which suggest a later onset of rainy season and shows an enhancement of rainfall during the months of December through February, followed by an early cessation (McSweeney *et al*., 2011; MoNRE, 2002; MoNRE, 2011; Nicholson *et al*., 2013; USAID, 2013).

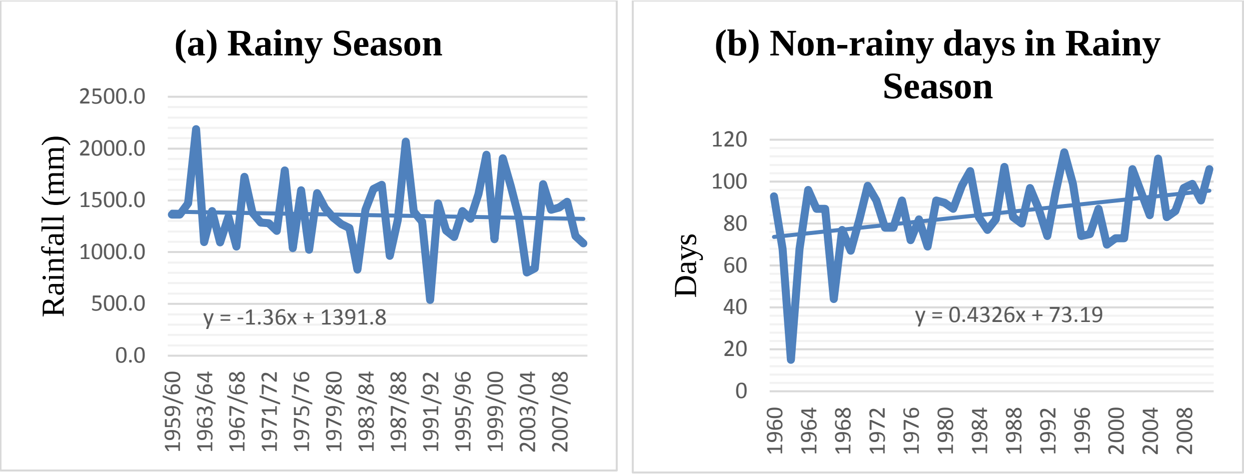


Figure 14: Rainy Season (November-April) Rainfall Distribution

Similar to hot and dry season, the trend of the cool and wet season (May to August) total seasonal rainfall is decreasing by about 1.01 mm per year, with an increasing number of non-rainy days as shown in Figure 15 (a) and (b) respectively. Rainfall projections for the austral winter months (June, July and August) tend to decrease from June to August becoming exceedingly dry over most of Malawi, with seasonal rainfall in the order of 10 mm to 25 mm (McSweeney *et al*., 2011; Nicholson *et al*., 2013). These trends, therefore, needs to be analyzed further to evaluate if the changes are significant in the district in seasonal time series.

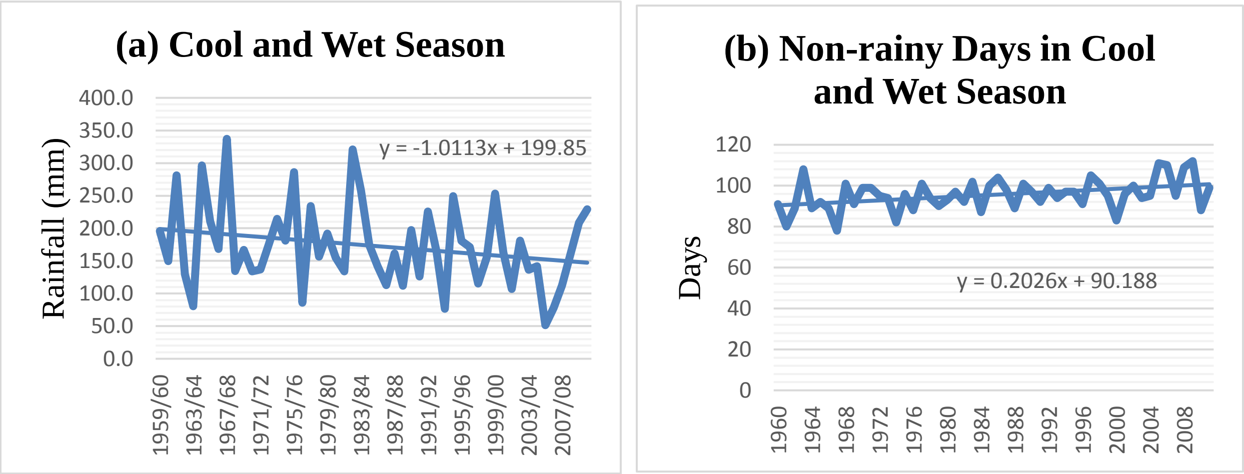


Figure 15: Cool and Wet Season (May-August) Rainfall Distribution

Hence, the MK test was also used to detect trends in seasonal precipitation between 1959 and 2011 period and the results are given in Table 4. The results revealed that all seasons showed a decreasing trend. Thought not statistically significant, a negative precipitation trend was detected for rainy season as well as hot and dry season and that the decrease in precipitation for cool and wet season was statistically significant.

Table 4: MK tests results for precipitation in seasonal time series

Variable	Kendalls tau	S	Var (S)	P-value (Two-tailed)	Alpha	Interpretation	Trend
Rainy	-0.01	-18	1027.3	0.596	0.05	Accept	NST
Cool & Wet	-0.14	-183	1474.5	<0.0001	0.05	Reject	Decreasing
Hot & Dry	-0.10	-129	6305.8	0.107	0.05	Accept	NST

NST = No Significant Trend

4.2.2 Temperature

The temperature data from 1960 to 2010 was also analyzed. Figure 16 shows that both mean annual minimum temperature and mean annual maximum temperature for Mulanje is increasing by about 0.03 and 0.04 °C every year respectively. Phiri *et al*. (2004) also observed that mean temperatures in the lower Shire had increased by 2.3 % while mean maximum temperatures had increased by 2 % between 1970 and 2002. Meanwhile, for the period 1960 to 2006, McSweeney *et al*. (2011) observed that mean annual temperature increased by 0.9 °C, an average of 0.21 °C per decade and also projections indicate that hot days will occur more often annually. The observation from the temperature analysis done here shows consistency with the GCMs which is also in conformity with temperature projections for the whole country. This increase in temperature has also been perceived by villagers in a PRA study (Magrath & Sukali, 2009; USAID, 2013) and the results highlighted warming temperatures as one of the most visible impacts of climate change in Malawi.

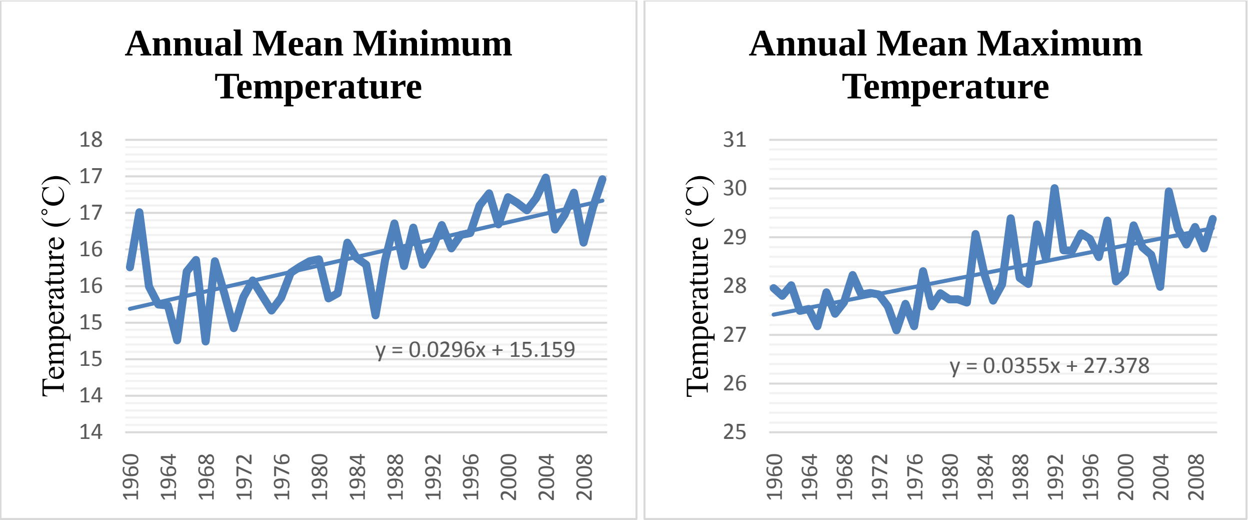


Figure 16: Annual Mean Minimum and Maximum Temperature

On running the MK test on mean monthly and mean maximum temperature data to detect if there was a trend in the 50 years period, the following results in Table 5 were obtained. The results indicated that there was significant increasing trend for both mean annual minimum and maximum temperature. Therefore, further impacts associated with the increasing temperature in Mulanje district should be looked upon in greater detailed.

Table 5: MK tests results for temperature in annual time series

Variable	Kendall's tau	S	Var(S)	p-value (Two-tailed)	alpha	Interpretation	Trend
MEAN ANNUAL MINIMUM TEMPERATURE	0.59	753	6709.5	< 0.0001	0.05	Reject	Increasing
MEAN ANNUAL MAXIMUM TEMPERATURE	0.52	658	4078.1	< 0.0001	0.05	Reject	Increasing

4.3 Discharge Analysis

4.3.1 Monthly Discharge and Annual Discharge

The Ruo River hydrological data from 1959 to 1991 (station 14C2) was collected and analysed. The study was limited in using hydrological data within this period because of unavailability of the data for the years after 1991. On plotting a linear trend line for the 32 years data, the annual mean discharge indicates that the Ruo discharge is decreasing at a rate of 0.10 m^3/s every year as shown in Figure 17. This results is in alignment with the annual rainfall distribution which has also indicated a decreasing trend over the years. It was also observed that the mean annual minimum discharge was 8.17 m^3/s and occurred in 1982/83 rainy season. The year 1982/83 rainy season precedes the drought that occurred in 1981/82 season which had affected many areas in Malawi (MoNRE, 2011). It has also been noted that the quantity of surface water resources in Malawi's river systems is highly dependent on runoff from rainfall and thus water resources are usually more abundant during the rainy season than the dry season (MoNRE, 2002). However, while attributing that data collection on the rivers' flowing from the Mulanje Mountain is inadequate, Nangoma (2008) observed that the rivers runoffs are no longer reliable and depict flow irregularity. If the decreasing trend of Ruo discharge is to go on it will have a negative impact on life activities that depends on and thus the trend needs to be researched further.

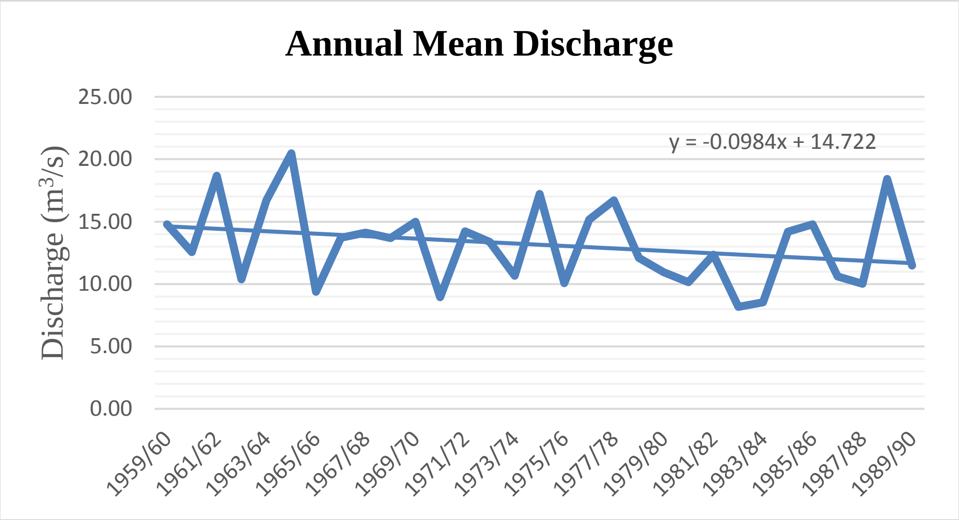


Figure 17: Annual Mean Discharge of Ruo River

On the other hand, a mix of decrease and increase trend were obtained when the MK test was run to detect trend in monthly discharge of Ruo River. The results indicated that there was a positive trend in discharge in the months of January, February, March, April and December at 5 % significance level and all these months correspond to the rainy season. The increase in trend was statistically significant for February, March and April. The results also indicated a statistically significant negative trend in discharge for the rest of the months of the year apart from May. The MK tests results for discharge in monthly time series are shown in Table 6. Therefore, it is of immense importance based on these results to look further on the impacts such as ecological, economical as well as social that would result if the decreasing discharge trends are to continue in future.

Table 6: MK tests results for discharge in monthly time series

Variable	Kendall's tau	S	Var(S)	p-value (Two-tailed)	alpha	Interpretation	Trend
NOV	-0.27	-136	849.7	< 0.0001	0.05	Reject	Decreasing
DEC	0.07	36	3334.1	0.544	0.05	Accept	NST
JAN	0.22	108	5081.8	0.133	0.05	Accept	NST
FEB	0.36	178	3434.6	0.003	0.05	Reject	Increasing
MAR	0.40	200	1819.8	< 0.0001	0.05	Reject	Increasing
APR	0.29	144	557.4	< 0.0001	0.05	Reject	Increasing
MAY	-0.07	-36	2354.3	0.471	0.05	Accept	NST
JUN	-0.21	-106	1936.1	0.017	0.05	Reject	Decreasing
JUL	-0.30	-148	2531.2	0.003	0.05	Reject	Decreasing
AUG	-0.36	-178	1708.9	< 0.0001	0.05	Reject	Decreasing
SEP	-0.54	-270	3040.7	< 0.0001	0.05	Reject	Decreasing
OCT	-0.45	-224	1623.1	< 0.0001	0.05	Reject	Decreasing

NST = No Significant Trend

4.3.2 Rainfall and Discharge Relationship

One factor that affects discharge is the amount of rainfall. The relationship between the mean annual rainfall and mean annual discharge was investigated using Pearson product-moment correlation coefficient for 1959 to 1991 period. It was assumed that the sample is of normality, linearity and homoscedasticity. Therefore, preliminary analyses were performed to ensure no violation of the assumption of normality, linearity and homoscedasticity. The results indicated a small, positive correlation between the rainfall and discharge, with $r = 0.093$, $n = 32$, $p = 0.55$. These results therefore show that as the amount of rainfall will be increasing, it will be associated with increase in the amount of river discharge and vice versa. However, the increase is not statistically significant as p-value is greater than 0.05 and the relationship between the variables was observed to be minimal. Hence, the results strongly suggest that other variables other than rainfall, have major influence on discharge.

4.3.3 Temperature and Discharge Relationship

Similarly, temperature is another factor that affects discharge. Temperature is proportional to evaporation: the higher the temperature the higher the rate of evaporation. Hence, the hydrological regimes of any specific watershed is directly affected as rate of evaporation changes (Mohammed, 2013). To understand the relationship between temperature and discharge, the mean monthly maximum temperature and mean monthly discharge was investigated using Pearson product-moment correlation coefficient from 1960 to 1991. It was also assumed that the sample is of normality, linearity and homoscedasticity. Therefore, preliminary analyses were performed to ensure no violation of the assumption of normality, linearity and homoscedasticity. It was observed from the results that there was a large, positive correlation between the temperature and discharge, with $r = -0.642$, $n = 31$, $p = 0.0001$. The relationship between these two variables is statistically significant as p-value is less than 0.05. This means that with any increase in temperature it will be associated with decrease in the amount of river discharge as temperature will increase evaporation. As it has been projected that temperature is increasing in the area, this will lead to further reduction in discharge.

4.3.4 Relationship of Temperature and Rainfall on Discharge

A multiple regression was conducted to see how the influence of temperature and rainfall predicted the river discharge for the 31 years period (1960 to 1991). Using the enter method, the results revealed that temperature and rainfall explained a significant amount of the variance in the value of sales made per week ($F(2, 41) = 14.92$, $p = 0.0001$, $R^2 = 0.41$, $R^2 Adjusted = 0.39$). The analysis also revealed that rainfall levels did not significantly predict the value of discharge for the entire period ($\beta = -0.10$, $t(31) = -0.801$, $p = 0.43$), however temperature levels did significantly predict value of discharge for the entire period ($\beta = -0.67$, $t(31) = -5.41$, $p < 0.0001$). This means that temperature changes will greatly affect the Ruo River discharge rates, with increasing temperatures resulting in decreasing discharge which will result in less hydropower being produced. The overall multiple regression equation was as follows:

$$Discharge = 156.22 - 5.08x_1 - 0.02x_2 \qquad [10]$$

4.4 Power Generated

Power generated by a hydropower facility largely depends on discharge, water head and the efficiency of the turbine. However, the fluctuations in the quantity and timing of river discharge, which is affected by seasonal and quantitative changes in precipitation and evaporation, affects much the production of hydroelectric power. This study was limited in using estimated potential power output because the owners of the plant do not regularly keep records of energy generated data. Therefore, this study adopted equation [2] to estimate the potential power generated from the plant using observed monthly average discharge rates (data from 1959 to 1991). The machines at the plant are all Pelton turbines which have a world reputation of reaching efficiencies of about 90 %. Still, old installation of the machines and inadequacy in maintenance of hydropower station could drastically affect the efficiencies of these turbines. Similarly, several losses are also encountered during the conversion of potential and kinetic energy of water to electricity but typically hydropower turbines efficiencies range between 60 % and 90 % (Meijer *et al*., 2012). Hence, an average efficiency of 70 % was assumed in this study to show a more realistic first impression of potential hydropower. From the plant data, it was established that it has a net rated head of 365 m (for Ruo 1 and 2) and 355 m (for Ruo 3).

Hence, by using equation [2], the potential power that can be generated from the plant was calculated, and the results are shown in Figure 18. The trend for the annual distribution of potential generated power was also established. The results indicate that annually, the power generated will be decreasing by around 0.26 MW and this will have a negative impact on the operations of Lujeri Tea Estate. However, the actual power generated may likely be lower than the estimated results found in this analysis due to inadequate maintenances of the machines and that they were installed in early 1930’s thus their efficiencies have dropped with time. It was also observed that the pattern for this estimated potential power is analogous to Figure 18 since the annual mean discharge were used in the calculations. Therefore, the MK tests results for monthly discharge will play a greater role in the power that will be generated in future.

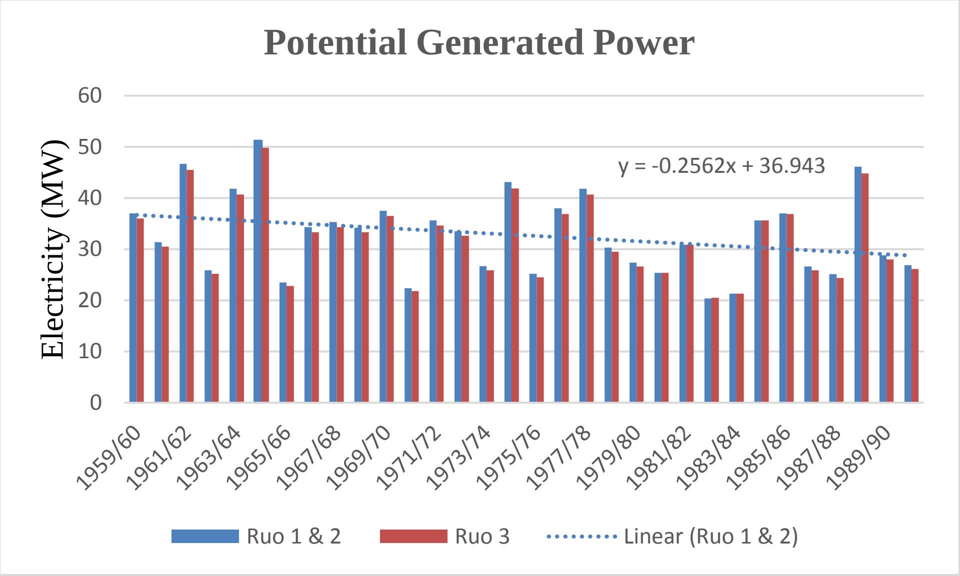


Figure 18: Estimated Potential Generated Power from Ruo 1, 2 and 3

4.5 Discussion

It is obvious that discharge is the main variable that affects power generated by hydropower plants. Consequently, the discharge is also affected by precipitation and temperature and later on climate change. The annual rainfall variation analysis showed a general decreasing trend with time. However, this annual rainfall change is not significant on the annual discharge. Hence, this could mean that there is no significant change in the annual hydroelectricity generated. Nevertheless, the analysis on the potential generated power revealed that there is a significant decrease in power annually. This is mainly attributed by the change in temperature. The relationship between the two variables (temperature and discharge) is significantly negatively correlated. The warmer temperatures will lead to increased evaporation in the rivers and in turn reduce discharge. This pose a worrisome future as the projections for both mean annual minimum and maximum temperature have showed a significantly increasing trend.

The trend test has shown an increase in discharge from December to April and the increase was significant for months February to April. These months correspond to the rainy season period and as expected, the discharge will be high during this period due to the rains being received. This increase in discharge rate will in-turn lead to more electricity being generated during the rainy season period. The power generated would begin to decrease from May to November as the trend was negative in these months. The negative trend was also statistically significant from

June to November. This period falls in both cool and wet as well as hot and dry season. During the site visitation, it was also observed that the plant was forced to shut down due to minimum discharges flowing in the river in some months of hot and dry season. Similar to the results found by Ngongondo *et al.* (2011), all seasons revealed a decreasing rainfall trend. Though not statistically significant in the rainy season as well as hot and dry season, however, the trend was statistically negative for cool and wet. Therefore, the trend of precipitation in all seasons is in alignment with trend results of discharge.

The trend in precipitation in monthly time series was significantly negative for November and February-April and a positive trend was observed for December and January. The period from November to April is in the rainy season hence the decreasing trend in precipitation in the months of November and February-April shows that the rainy season is indeed decreasing. This will have a negative impact on the hydropower generation as this will lead to decreasing discharge levels. However, the months of December to March are the highest rainfall months suggesting more concentration of the seasonal rainfall around these months. The heavy rainfall in short time interval signifies that high discharge rates will also be available within a short time period and less during the other seasons, particularly the hot and dry. Also, the more amount of rainfall concentrated within these months may lead to increasing floods which could damage hydropower stations. Therefore, the adoption of hydropower generation with storage facilities rather than just run-of-river power plants should be encourage so that the water that accumulates during the rainy season should provide a minimum discharge rates throughout the year for generation of electricity.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5 Conclusion

The research study was conducted to assess the impact of climate change on micro-hydropower generation with a focus on Lujeri micro-hydropower scheme in Mulanje district. The study involved collection of hydrological (river discharge) from 1959 to 1991 and weather time series (air temperature and rainfall) data from 1959 to 1991. The data was logically interpreted using Statistical Package for Social Science (SPSS), XLSTAT and Microsoft Excel. In general, there was conformity in the results obtained from the Mann-Kendall test, regression and correlation analysis for the time period.

The evidence shows that there is some changes in the trend of temperature, precipitation and discharge of the district in the 52 years period (1959 – 2011) analyzed in different months. The precipitation and temperature data showed consistence with the climate baseline and projected climate change. The data indicated that the annual rainfall variation is decreasing with time at the rate of about 2.97 mm per year. It also showed that the rainy season amount of precipitation is decreasing at 1.36 per year. The MK test gave a mix of positive and negative trends for the monthly precipitation. Only the month of January showed a positive significant trend while February, March, April, May, June September, and November had a significant negative trend. All three seasons showed decreasing trend in precipitation and the negative trend was statistically significant for cool and wet season. Similarly, temperature has been and can be predicted to be rising in the years to come (by about 0.04 °C every year) which can lead to high evapotranspiration hence less discharge. On running the MK test for temperature, the results indicate that there is significant increasing trend for both mean monthly and mean maximum temperature.

The annual mean discharge indicates that Ruo River discharge levels are decreasing at a rate of 0.10 m^3/s every year. This was further supported by the annual rainfall distribution which has also indicated a decreasing trend over the years in Mulanje. Further analysis on MK test revealed that there was a positive trend in discharge in the months of January, February, March, April and December. The increase in trend was significant for February, March and April. The results also indicated a statistically significant negative trend in discharge for the rest of the months of the year apart from May. There was also a small, positive correlation between rainfall and discharge, r = 0.09, but the increase in discharge due to rainfall is not statistically significant. On the other hand, the relationship between temperature and discharge showed a large, negative correlation (r = - 0.64) and the relationship was significant. The results of the study do not deny climate change is happening. The study, therefore, offers remarkable insights and new perspective for policy makers and planners in helping them take proactive measures in the context of climate change.

5.1 Recommendation

The results obtained in this research study are essential to hydropower plants for planning and management purposes. Based on the findings, a number of recommendations are proposed as follows:

- Construction of dam-based hydropower plants facilities to store enough water for power generation as rains will come in a short period of time.
- Standby alternative sources of energy should be kept in place to supplement the shortage of hydropower due to reduced river discharge in some months of the year.
- Storage mechanism of the produced power when the hydroelectric facilities are producing maximum power should be exploited as the stored power could be used in times when the production will be less.
- Better early warning system that could help reduce vulnerability of extreme climate events should be used.
- A detailed flood risk assessment in the study area should be conducted as analysis have revealed that more rainfall will be received in a shortest time interval.
- Although hydropower feasibility studies conduct historical discharge data analysis, it usually does not include a range of possible future discharge projections for the upcoming century. Hence, hydropower feasibility studies should include component of climate change to avoid installing hydropower stations that may not generate the anticipated power in future.

- Awareness campaigns should be conducted to sensitize authorities on the importance of hydrological data so that proper funding should be channeled towards capturing of such data.
- More statistical and mathematical modeling should be conducted to address the growing concerns of climate change and use of more possible variables that would affect discharge like agriculture, forestry and land use which may lead to siltation of rivers.

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Appendices

Appendix 1: Mean Monthly Maximum Temperature (°C) for Mimosa

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1960	29.1	29.4	27.6	27.0	25.9	23.5	22.4	27.1	28.6	31.7	32.4	30.8	**28.0**
1961	29.1	28.9	28.9	28.3	27.6	25.3	23.1	24.3	28.8	31.2	29.2	28.9	**27.8**
1962	28.6	29.5	27.5	27.6	23.4	25.9	23.2	26.5	29.6	32.6	32.0	29.8	**28.0**
1963	28.1	27.2	27.1	26.7	24.6	23.4	24.6	26.2	29.7	32.0	30.5	29.8	**27.5**
1964	28.9	29.3	29.3	27.3	24.7	24.1	21.5	24.7	28.2	32.6	31.4	28.4	**27.5**
1965	29.0	28.9	27.1	27.4	24.4	23.1	23.6	26.2	27.8	28.3	30.5	29.8	**27.2**
1966	29.3	29.1	28.1	27.1	26.1	23.5	23.6	26.1	29.2	31.0	30.7	30.7	**27.9**
1967	29.8	29.3	28.5	27.7	26.0	25.1	21.6	23.8	27.1	31.0	30.2	29.1	**27.4**
1968	30.2	28.9	26.6	27.0	26.5	22.7	24.1	27.0	28.7	32.5	28.6	29.2	**27.7**
1969	29.2	29.3	29.0	27.7	25.6	25.3	24.0	25.9	28.9	33.0	32.0	28.8	**28.2**
1970	29.3	28.6	28.2	26.6	26.6	23.6	24.8	26.2	30.8	29.5	30.5	29.2	**27.8**
1971	28.0	28.1	28.7	29.0	25.1	23.0	24.0	27.6	29.4	31.5	30.2	29.7	**27.9**
1972	29.2	28.2	28.5	27.8	26.1	23.3	23.1	26.0	29.8	30.7	29.7	31.5	**27.8**
1973	29.3	29.3	29.8	25.6	26.1	22.8	22.8	25.0	29.9	32.0	29.7	28.7	**27.6**
1974	28.9	28.1	28.0	25.8	24.1	23.3	22.2	26.2	27.5	30.7	31.6	28.7	**27.1**
1975	29.3	28.8	27.7	27.2	26.7	23.4	24.1	25.1	29.0	29.5	30.7	30.1	**27.6**
1976	28.9	28.9	28.5	26.0	23.7	22.9	22.9	23.6	28.1	29.3	32.7	30.6	**27.2**
1977	29.4	30.2	28.3	27.3	27.7	25.0	23.0	25.2	29.7	32.2	31.1	30.6	**28.3**
1978	29.5	29.7	28.5	27.0	26.1	23.0	22.3	27.1	29.9	31.6	29.5	26.8	**27.6**
1979	29.3	29.2	28.3	27.7	25.7	23.3	23.2	26.2	29.6	32.4	30.7	28.6	**27.9**
1980	29.6	30.5	28.1	27.8	26.3	22.3	21.8	25.0	29.2	30.2	32.9	29.0	**27.7**
1981	30.6	29.2	28.3	26.6	24.7	23.7	23.1	26.6	29.2	28.8	32.6	29.3	**27.7**
1982	29.5	28.9	28.9	28.0	25.1	25.0	23.6	26.0	27.1	29.0	30.1	30.7	**27.7**
1983	30.6	29.2	30.6	29.7	28.8	26.7	25.2	24.5	29.1	30.3	34.1	30.0	**29.1**
1984	29.7	28.8	28.7	27.9	27.1	24.6	25.1	25.8	30.5	31.7	29.6	29.3	**28.2**
1985	29.8	28.4	29.0	27.1	26.0	23.9	24.4	25.7	29.0	30.6	29.4	29.1	**27.7**
1986	28.9	29.4	29.1	28.4	27.0	24.1	24.2	27.7	29.3	29.8	29.5	29.0	**28.0**
1987	29.0	30.7	30.9	29.1	28.2	24.6	25.2	28.0	31.5	29.8	33.4	32.3	**29.4**
1988	30.9	29.1	29.4	29.3	25.7	25.1	25.2	25.6	29.5	30.4	28.8	29.0	**28.2**
1989	29.2	28.5	28.5	27.0	26.0	24.8	25.0	27.1	28.5	30.8	31.6	29.5	**28.0**
1990	29.6	29.8	30.0	30.6	27.2	27.2	26.6	26.4	28.0	31.7	31.8	32.3	**29.3**
1991	30.3	30.5	28.6	27.1	27.1	24.6	24.7	26.3	30.8	31.7	31.3	29.7	**28.6**
1992	31.4	31.7	31.3	30.3	27.8	26.2	24.7	26.6	30.9	33.8	32.8	32.6	**30.0**
1993	29.0	29.8	30.6	28.8	28.6	25.2	24.3	25.4	29.9	30.6	31.3	31.3	**28.7**

1994	30.2	29.1	28.5	28.5	27.8	24.9	24.2	26.1	30.0	29.6	34.5	31.3	**28.7**
1995	27.9	28.0	30.5	28.8	27.0	24.5	25.4	27.9	30.9	34.8	33.5	29.8	**29.1**
1996	30.8	29.3	27.3	26.5	26.3	24.4	24.1	27.4	31.0	35.4	34.9	30.2	**29.0**
1997	30.4	27.6	30.8	27.8	25.9	27.8	23.5	27.9	29.1	29.4	32.9	30.0	**28.6**
1998	29.7	29.9	30.7	28.9	28.6	26.3	25.4	26.1	30.1	32.5	32.9	31.0	**29.3**
1999	29.6	28.1	28.9	26.8	26.7	25.2	23.9	25.4	29.1	29.3	32.3	31.7	**28.1**
2000	30.3	30.6	29.9	28.3	26.0	25.3	23.1	24.8	30.3	31.6	29.9	29.1	**28.3**
2001	28.4	29.5	29.4	29.0	27.1	25.7	25.1	28.6	30.6	31.9	33.9	31.7	**29.2**
2002	30.1	29.9	29.6	28.2	27.0	24.6	27.5	27.1	29.6	31.9	30.2	29.9	**28.8**
2003	29.2	29.9	29.6	27.0	26.5	23.5	23.6	26.3	29.5	32.2	32.9	33.4	**28.6**
2004	31.0	28.7	29.3	27.1	23.9	23.5	25.0	28.0	28.9	30.2	30.4	29.9	**28.0**
2005	29.7	30.1	29.8	30.9	28.7	26.2	24.2	28.7	30.1	33.7	35.0	32.1	**29.9**
2006	30.4	29.2	29.8	28.0	28.5	26.4	24.9	28.0	28.6	34.0	31.7	30.9	**29.2**
2007	27.9	30.4	28.2	29.7	26.6	26.0	24.9	27.4	29.9	32.7	32.6	30.0	**28.9**
2008	29.7	29.6	29.5	28.2	28.2	25.1	25.6	26.5	31.3	33.9	34.3	28.6	**29.2**
2009	30.8	30.1	27.9	28.2	27.6	25.5	22.9	26.3	30.0	31.7	32.0	32.2	**28.8**
2010	32.4	30.0	29.8	29.4	28.4	24.3	24.1	24.9	30.2	33.7	34.1	31.2	**29.4**

Appendix 2: Mean Monthly Minimum Temperature (°C) for Mimosa

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1960	17.8	18.7	17.8	16.2	14.1	13.4	11.2	11.7	14.4	16.6	17.8	19.4	**15.8**
1961	19.3	18.3	19.6	18.3	14.8	13.2	13.5	12.8	14.8	16.9	18.0	18.6	**16.5**
1962	17.8	18.4	18.1	17.7	13.4	9.4	11.6	12.6	13.2	16.0	18.5	19.2	**15.5**
1963	18.6	18.8	18.0	16.8	13.1	11.1	10.7	10.2	13.1	16.4	17.6	18.6	**15.3**
1964	19.3	19.1	17.6	15.4	13.3	11.0	10.1	11.6	12.4	16.5	18.0	18.5	**15.2**
1965	18.8	17.8	18.1	15.2	12.7	9.8	10.1	11.7	12.9	14.2	17.8	18.0	**14.8**
1966	19.1	19.1	18.1	16.3	13.2	13.1	12.0	12.8	14.1	14.8	17.1	18.7	**15.7**
1967	19.4	18.9	19.1	16.9	14.9	12.7	11.6	12.6	13.6	16.7	16.9	17.0	**15.9**
1968	18.8	18.5	17.4	15.3	12.5	9.2	10.1	10.5	12.7	16.0	17.2	18.7	**14.7**
1969	19.1	18.8	18.3	17.5	13.4	10.9	11.5	12.2	13.3	18.2	17.7	19.2	**15.8**
1970	18.6	18.8	16.6	15.6	12.8	12.3	10.6	12.4	14.1	16.0	18.4	18.5	**15.4**
1971	18.7	18.1	17.2	16.5	13.0	11.3	10.5	10.3	12.8	15.3	17.2	18.2	**14.9**
1972	18.4	18.8	17.9	17.2	14.8	9.7	11.3	10.7	14.1	16.2	16.3	18.8	**15.4**
1973	19.4	18.6	18.5	17.3	12.7	11.7	10.9	11.1	13.3	17.2	17.7	18.5	**15.6**
1974	18.4	18.7	18.2	16.4	14.4	10.8	11.7	11.6	12.6	15.2	17.8	18.6	**15.4**
1975	18.1	17.9	17.7	16.6	12.7	12.5	10.3	12.1	13.1	15.1	17.2	18.7	**15.2**
1976	18.6	18.5	18.7	17.2	13.6	11.7	9.3	10.3	14.0	15.4	18.2	18.6	**15.3**
1977	19.0	19.6	18.8	16.0	13.1	9.7	11.7	12.2	14.5	16.9	17.8	18.9	**15.7**
1978	19.3	19.3	19.0	17.2	13.0	11.3	10.1	11.7	14.2	17.4	18.1	18.6	**15.8**
1979	17.2	18.6	20.0	15.8	13.1	12.0	11.8	12.5	14.8	17.5	18.5	18.3	**15.8**
1980	17.9	19.2	18.2	17.3	12.5	11.3	12.1	12.2	14.8	16.4	19.1	19.4	**15.9**
1981	19.1	19.5	18.1	16.2	12.9	11.2	10.4	11.5	13.6	15.1	18.3	18.1	**15.3**
1982	19.1	19.1	18.1	16.4	13.2	11.8	11.7	11.8	12.7	15.9	16.8	18.2	**15.4**
1983	19.1	19.2	19.4	17.3	15.1	13.4	12.5	11.7	13.4	14.7	18.8	18.5	**16.1**
1984	18.3	18.8	18.5	16.0	14.4	12.3	12.4	11.2	14.4	16.6	18.4	19.3	**15.9**
1985	19.4	19.0	18.9	16.3	13.2	10.9	11.4	12.4	14.9	16.5	17.2	19.4	**15.8**
1986	19.3	18.6	12.9	17.7	13.4	11.1	10.3	10.5	14.1	17.3	17.4	18.6	**15.1**
1987	18.7	18.8	18.1	15.9	14.4	10.9	10.4	13.5	15.1	15.9	18.6	20.0	**15.9**
1988	19.5	19.6	19.7	18.3	15.0	12.3	12.3	12.8	14.3	17.5	16.4	18.6	**16.4**
1989	18.8	19.0	18.7	16.7	13.7	11.7	11.5	12.0	14.2	16.3	17.9	18.8	**15.8**
1990	19.2	18.8	17.3	17.7	15.8	12.7	11.4	12.5	14.0	17.3	19.5	19.4	**16.3**
1991	19.9	19.8	19.4	16.9	11.7	11.9	11.6	12.3	14.1	16.0	17.6	18.3	**15.8**
1992	19.0	18.5	18.7	16.4	12.5	12.5	11.5	12.7	14.0	17.1	18.7	20.7	**16.0**
1993	19.2	19.4	18.4	18.2	14.3	12.6	12.5	12.1	14.3	17.5	18.4	19.1	**16.3**
1994	19.5	18.6	17.4	16.1	12.9	12.0	13.8	12.6	14.0	16.5	20.5	18.3	**16.0**

1995	19.6	17.9	18.3	16.0	15.5	11.2	11.6	14.2	14.1	18.4	18.6	19.0	**16.2**
1996	19.5	19.7	18.8	17.3	14.9	12.7	10.6	11.9	14.7	16.2	19.5	18.9	**16.2**
1997	20.0	19.4	19.9	16.8	12.5	12.3	12.9	12.4	16.3	17.2	19.5	20.0	**16.6**
1998	21.0	20.0	20.1	17.3	13.5	12.4	12.1	13.4	14.6	17.6	19.8	19.4	**16.8**
1999	20.1	19.8	19.0	17.5	13.5	12.1	12.8	13.0	14.4	16.0	18.7	19.1	**16.3**
2000	20.0	19.8	19.0	17.7	14.6	14.0	13.0	13.1	14.8	16.3	19.0	19.3	**16.7**
2001	19.8	20.1	19.3	17.1	14.7	12.1	11.9	13.1	14.8	16.5	19.7	20.5	**16.6**
2002	19.8	19.0	18.6	16.6	15.4	12.7	12.4	14.4	15.5	17.8	17.4	19.0	**16.5**
2003	19.6	19.9	19.7	16.9	14.2	13.5	13.2	11.9	15.1	16.5	19.1	20.9	**16.7**
2004	20.3	20.0	20.0	18.1	15.1	12.5	11.6	12.6	14.9	20.4	18.6	19.9	**17.0**
2005	20.2	19.3	18.5	15.5	13.1	12.0	12.7	12.8	14.8	17.2	18.9	20.4	**16.3**
2006	19.9	20.2	19.4	17.4	12.3	12.2	12.5	12.5	14.0	18.0	19.1	20.2	**16.5**
2007	20.0	19.5	19.2	17.4	15.8	12.5	12.6	12.4	15.2	17.8	19.2	19.8	**16.8**
2008	20.0	18.0	17.6	14.8	13.0	12.1	12.3	12.9	15.4	17.9	19.4	19.8	**16.1**
2009	20.0	20.0	19.3	18.1	14.7	12.3	12.2	12.2	14.5	17.7	17.9	20.1	**16.6**
2010	20.5	20.5	18.3	19.1	15.0	13.3	13.2	14.1	14.0	17.0	19.4	19.3	**17.0**

Appendix 3: Monthly and Seasonal Rainfall Totals (mm) for Mimosa

SEASON	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	TOTAL
1959/60	8.4	38.4	32.0	65.8	211.1	211.1	177.3	424.9	157.0	180.1	29.0	119.9	**1654.8**
1960/61	84.1	1.5	98.8	5.8	101.3	178.1	290.1	311.9	387.9	93.2	42.4	21.6	**1616.7**
1961/62	74.2	126.0	40.1	150.6	148.6	235.0	402.1	97.8	312.7	274.3	75.7	5.3	**1942.4**
1962/63	38.9	15.0	9.4	19.8	127.0	477.5	399.3	496.1	463.6	224.0	36.1	39.4	**2346.1**
1963/64	24.1	0.0	3.6	51.1	107.2	287.0	135.0	352.6	127.8	86.6	31.2	25.4	**1231.6**
1964/65	117.9	32.5	2.0	1.8	137.4	235.7	289.6	208.8	410.0	115.1	96.0	50.0	**1696.8**
1965/66	14.7	23.6	68.8	89.9	75.9	194.8	175.0	259.6	210.3	178.6	89.7	82.3	**1463.2**
1966/67	42.7	9.7	3.6	9.9	156.0	164.1	232.4	200.4	468.4	118.1	49.0	67.1	**1521.4**
1967/68	156.5	66.5	35.1	15.0	117.3	204.2	98.0	210.8	291.6	132.6	10.7	103.4	**1441.7**
1968/69	6.4	27.4	2.0	6.9	350.3	186.4	332.2	294.1	267.0	296.4	63.2	37.6	**1869.9**
1969/70	35.1	27.7	7.4	43.4	82.8	608.8	193.0	265.4	111.3	121.2	32.5	71.6	**1600.2**
1970/71	15.7	1.5	0.0	93.5	147.6	343.7	531.9	188.7	64.3	8.4	103.9	12.7	**1511.9**
1971/72	15.2	0.0	0.8	25.1	206.2	261.6	386.6	101.9	226.3	95.5	21.3	100.3	**1440.8**
1972/73	38.9	33.3	7.9	34.3	134.9	155.4	282.2	183.6	182.1	266.7	34.5	68.3	**1422.1**
1973/74	48.8	13.2	15.2	23.9	160.5	238.5	156.5	314.7	646.4	271.3	81.3	71.1	**2041.4**
1974/75	52.8	7.9	35.3	4.3	113.3	355.3	120.1	162.3	152.4	135.1	57.4	63.0	**1259.2**
1975/76	34.0	15.0	0.0	64.8	146.8	262.1	300.2	254.0	349.8	284.2	112.3	124.7	**1947.9**
1976/77	44.2	6.4	7.9	151.9	27.4	302.8	279.7	79.0	285.8	48.3	8.6	26.7	**1268.7**
1977/78	38.1	22.4	43.9	11.4	160.5	219.2	272.8	295.1	420.6	200.2	88.1	85.6	**1857.9**
1978/79	71.4	0.0	2.3	34.5	108.0	416.3	193.5	298.2	289.1	119.4	22.6	62.5	**1617.8**
1979/80	83.3	3.3	41.7	20.3	166.9	235.7	138.2	282.7	351.3	160.8	35.6	69.6	**1589.4**
1980/81	49.4	20.1	44.0	137.9	27.3	385.2	194.1	212.6	252.1	199.5	54.7	30.7	**1607.6**
1981/82	40.5	5.9	62.7	82.1	117.1	190.2	361.0	309.3	166.9	89.0	48.0	39.4	**1512.1**
1982/83	133.2	36.6	23.0	220.3	135.2	98.3	179.7	215.3	162.5	40.1	104.0	47.3	**1395.5**
1983/84	84.6	31.8	0.0	22.7	68.0	323.4	121.0	400.9	427.1	69.9	81.3	60.2	**1690.9**
1984/85	23.0	29.7	16.7	51.7	206.6	372.1	297.6	277.7	247.4	207.7	77.4	43.9	**1851.5**
1985/86	12.2	50.0	70.3	97.2	233.5	224.3	315.6	286.4	344.2	245.4	21.2	58.3	**1958.6**
1986/87	2.1	0.0	19.0	84.5	306.1	147.2	267.6	140.5	63.0	40.1	65.5	45.2	**1180.8**
1987/88	2.1	0.7	2.9	72.8	68.9	348.5	161.6	197.0	193.5	341.0	103.9	54.7	**1547.6**
1988/89	15.2	50.2	0.0	178.6	143.4	436.7	447.7	368.1	512.8	157.2	17.2	29.4	**2356.5**
1989/90	53.9	29.5	33.5	106.0	255.9	186.6	481.6	266.1	146.8	54.2	89.2	24.5	**1727.8**
1990/91	11.9	57.0	69.6	5.2	208.8	46.8	226.5	236.4	427.3	147.6	14.5	42.7	**1494.3**
1991/92	87.6	21.4	44.9	2.6	117.5	133.4	136.3	40.1	92.8	17.7	14.1	102.8	**811.2**
1992/93	23.2	52.9	0.0	0.0	69.3	123.8	691.8	266.2	160.7	159.1	10.3	78.2	**1635.5**
1993/94	36.6	0.0	0.0	58.7	238.7	120.7	404.2	90.2	322.7	32.8	1.4	38.4	**1344.4**
1994/95	28.2	80.5	29.8	88.7	41.1	195.5	386.6	381.2	57.8	82.7	107.5	32.9	**1512.5**
1995/96	32.4	6.6	0	1.5	103.2	303.8	140.2	300.5	422.3	126.8	58.4	83.2	**1578.9**

1996/97	85.6	19.8	1.8	19.8	106.7	282.3	226.7	251.8	153.3	301	66.1	0.0	**1514.9**
1997/98	96.6	3.2	100.2	95.0	201.5	326.9	469.4	289.0	245.7	28.1	2.3	13.4	**1871.3**
1998/99	58.7	65.0	3.8	66.5	66.1	429.0	521.3	259.4	423.4	240.9	24.5	7.3	**2165.9**
1999/00	54.5	18.8	22.9	19.2	92.9	155.9	220.1	248.7	236.1	171.6	163.5	16.5	**1420.7**
2000/01	99.2	23.2	0.4	41.9	275.7	394.0	365.3	463.8	327.2	80.5	37.3	2.8	**2111.3**
2001/02	37.2	22.0	51.9	9.0	102.6	316.7	447.6	366.6	222.6	180.4	11.2	36.7	**1804.5**
2002/03	11.2	31.5	25.1	53.5	107.0	242.1	465.3	229.9	267.4	26.8	38.8	99.5	**1598.1**
2003/04	48.3	25.6	24.6	16.9	112.0	92.3	113.9	167.3	154.3	163.1	26.9	35.7	**980.9**
2004/05	47.3	28.1	2.7	81.0	66.8	399.0	199.9	99.0	63.3	15.2	15.6	50.9	**1068.8**
2005/06	0.0	0.0	0.0	0.0	59.6	443.8	398.7	197.5	478.1	78.7	34.3	17.2	**1707.9**
2006/07	4.4	2.3	4.6	36.4	74.3	299.6	481.0	240.2	254.5	58.5	53.9	17.3	**1527.0**
2007/08	88.0	23.5	0.0	33.5	109.1	384.4	580.3	148.5	187.2	20.4	1.1	0.0	**1576.0**
2008/09	29.0	16.5	6.0	13.9	50.9	384.4	301.8	227.0	430.1	92.8	80.9	33.0	**1666.3**
2009/10	72.6	12.9	0.0	44.7	199.4	147.9	128.4	202.7	166.6	309.1	32.4	90.5	**1407.2**
2010/11	96.9	41.9	12.8	14.7	106.6	333.4	111.2	195	188	151.6	9.4	80.9	**1342.4**

Appendix 4: Ruo River Discharge Data from Station 14C2 (m^3/s)

SEASON	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTAL
1959/60	34.648	30.662	22.534	6.999	11.535	18.718	5.174	10.305	2.788	3.133	8.193	22.837	**177.5**
1960/61	18.415	28.581	17.461	8.469	6.128	11.130	12.738	6.581	5.877	11.020	10.264	13.871	**150.5**
1961/62	22.975	24.410	15.190	6.192	3.975	2.476	1.753	1.729	2.553	17.399	75.203	50.355	**224.2**
1962/63	20.087	11.152	5.077	7.021	1.774	1.372	0.881	1.957	24.724	23.083	15.672	11.658	**124.5**
1963/64	5.753	5.432	16.377	6.834	2.947	0.905	5.372	16.910	31.705	22.403	65.333	20.620	**200.6**
1964/65	19.148	11.544	4.090	3.819	14.923	14.044	20.166	50.103	43.200	36.201	21.764	6.676	**245.7**
1965/66	8.991	6.044	2.578	1.948	0.969	2.642	13.184	11.629	21.678	21.906	10.818	10.255	**112.6**
1966/67	18.386	14.743	7.435	3.083	5.535	16.567	12.528	22.424	40.868	12.270	5.272	5.418	**164.5**
1967/68	3.588	2.232	1.712	1.720	18.039	15.920	28.897	35.182	25.319	19.906	9.764	7.075	**169.4**
1968/69	5.924	3.924	2.372	1.350	8.997	30.895	23.743	29.839	18.923	23.329	5.739	9.086	**164.1**
1969/70	3.972	1.880	3.351	5.155	11.971	17.688	61.686	33.467	20.337	5.946	10.543	3.731	**179.7**
1970/71	2.020	1.059	0.808	0.539	4.961	16.095	20.502	15.709	15.835	14.919	4.821	10.190	**107.5**
1971/72	6.692	5.400	5.185	2.675	8.746	12.545	15.901	16.555	51.825	28.468	8.575	8.100	**170.7**
1972/73	6.054	4.331	2.691	1.458	4.935	17.733	16.230	25.757	29.413	28.981	15.048	7.881	**160.5**
1973/74	15.463	4.443	3.416	2.181	1.481	16.152	11.852	12.695	22.406	16.103	12.115	9.729	**128.0**
1974/75	6.147	3.079	2.949	6.678	4.594	25.594	25.444	26.100	34.339	37.402	15.717	18.474	**206.5**
1975/76	9.220	5.979	2.506	5.470	2.838	10.885	19.272	14.509	20.694	22.016	3.832	3.668	**120.9**
1976/77	2.707	2.975	1.585	0.609	3.037	12.917	25.094	20.959	52.625	39.084	6.396	13.937	**181.9**
1977/78	8.904	2.225	1.238	2.349	5.997	42.834	25.894	32.224	46.073	7.166	9.071	16.380	**200.4**
1978/79	2.224	6.492	1.445	9.839	14.612	12.818	23.003	30.687	19.443	8.298	6.791	9.588	**145.2**
1979/80	6.817	3.341	3.580	7.947	17.979	20.376	21.672	17.826	12.278	7.570	5.536	6.319	**131.2**
1980/81	0.436	15.022	6.51	6.054	21.345	27.934	20.341	4.965	5.112	6.842	4.281	3.049	**121.9**
1981/82	1.171	16.666	17.230	32.894	24.548	22.450	15.703	3.093	5.216	4.853	2.412	1.846	**148.1**
1982/83	20.082	14.940	8.046	19.658	17.262	3.524	3.925	1.221	5.320	2.864	0.544	0.643	**98.0**
1983/84	0.334	2.517	12.882	17.999	26.039	18.875	8.924	9.290	2.280	1.778	0.664	0.735	**102.3**
1984/85	6.448	19.188	20.964	26.068	34.815	34.226	7.629	6.363	4.262	4.148	2.504	3.772	**170.4**
1985/86	9.803	19.507	29.686	21.367	18.337	45.025	10.572	7.521	3.570	2.020	2.408	7.483	**177.3**
1986/87	14.006	25.611	26.766	13.839	8.857	6.928	6.195	8.177	2.083	3.578	0.944	10.373	**127.4**
1987/88	1.496	10.662	16.489	20.079	12.942	15.455	17.659	7.457	3.699	6.352	1.395	6.526	**120.2**
1988/89	11.925	24.644	24.462	26.707	66.653	27.919	8.182	9.701	6.536	6.618	4.300	3.360	**221.0**
1989/90	11.561	24.877	24.254	20.29	11.555	14.191	10.017	3.872	3.7	6.94	5.035	1.527	**137.8**
1990/91	3.321	4.518	23.286	12.204	31.743	21.229	5.194	7.488	9.060	5.002	3.153	2.457	**128.7**