CHARACTERISTICS OF TRENDS AND RELATIONSHIPS AMONG CLIMATE VARIABLES IN ZAMBIA

BY

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DISCLAIMER

This work has not previously been submitted for a degree or diploma in any University. To the best of my knowledge and belief, the dissertation contains no material previously published or written by another person except where due reference is made in the dissertation itself.

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APPROVAL

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ABSTRACT

This study embarked on trend analysis to understand the relationship that exists in weather, precipitation and river flow using time series data. The study area was the entire country of Zambia. Secondary hydrological and weather data used was representative of the six catchment areas of the country and the three agro-ecological zones. Weather records were obtained from SWAT- soil, an internet based software that stores daily meteorological data across the globe from 1979 to 2009 were temperature was extracted and used as reference for weather data. For stream flows, 40 hydrological gauge data sets were acquired from DWA for the same period across the country. The hydrological data sets were then classified into clusters using the five indicators of hydrologic alterations namely; the frequency of flows, the magnitude of flows, the duration of flows, the timing of flows and the rates of change in flows. The metrics for these indicators of hydrologic alterations were obtained using time series analysis (TSA) in river analysis package (RAP). Stream-flows of each station were grouped in three clusters according to precipitation patterns in agro-ecological zones and according to the area each stream drained. These clusters were used together with the corresponding temperature data sets for trend analyses and linear regressions. It was found that firstly, there was an upward trend in temperature across the clusters for the temporal window period of the study. Secondly, temperature is a predictor of precipitation and discharge in streams across the country based on the P values (0.10 – 0.50) and r^2 values (0.008 – 0.336) obtained from regression and trend analysis. This was observed in 39 hydrological and meteorological gauge stations used. Thirdly, temperature predicts stream-flow in rivers with large catchment areas (>40,000km^2) across all agro-ecological zones and perennial rivers in Agro-ecological zone III. It was further found that temperature does not predict stream-flow of ephemeral streams based on the P values (>0.50) obtained on temperature-discharge relationship of these streams. Based on the findings, it is concluded that temperature has been increasing with time and that it predicts precipitation negatively across the agro-ecological zones in Zambia. Climate variables are characteristic of increasing or decreasing trend in Zambia.

DEDICATION

I dedicate this work to my family for their patience and prayers. My wife and kids, I love you. My brothers and sisters thanks for encouraging me to push on. Dad thanks for being there for us. Mom I miss you so much.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
ARI	Average recurrence intervals
BFI	Base flow index
C1	Cluster one
C2	Cluster two
C3	Cluster 3
DWA	Department of Water Affairs
GRZ	Government of the Republic of Zambia
Cv	Coefficient of variance
ENSO	ElNino Southern Oscillation
FAO	Food and agriculture organization
GIS	Geographical information systems
HFSpl	High flow spell
HFSplDur.	High flow spell duration
IPCC	Inter-panel for climate change
ITCZ	Inter-tropic convergence zone
Jul.DMax	Julian date maximum
Jul.DMin	Julian date minimum
LFSpl	Low flow spell
LFSplDur.	Low flow spell duration
MDF	Mean daily flow/runoff
FMARI	Flood magnitude average recurrence intervals
MDG	Millennium development goals
NCCRS	National climate change response strategy
RAP	River analysis package
TSM	Time series management
WARMA	Water Resources Management Authority
ZMD	Zambia Meteorological Department

CHAPTER ONE: INTRODUCTION

1.1 Background

This study explored the response of precipitation and runoff to climate variability and change in Zambia with temperature as the main driver. The aim of this research was to model the relationships between climate variability and change, precipitation and stream flow.
Climate variability, which embraces the intermittent changes in long term weather patterns, augments seasonality (IPCC, 2014). While this is the case for climate variability, climate change induces permanent changes to long term weather patterns. Climate change has become a significant challenge globally. Critical studies and analyses undertaken have provided overwhelming evidence that has compelled the need to look at climate change as a calamity that has largely impacted on developing nations (Johnson *et al*., 2010). Projections indicate that the impact will manifest in food security, biodiversity and human health, all of which are a function of water resources (Johnson *et al*., 2010; Scheffran & Battaglini, 2011). Unpredictable rainfall patterns which are an attribute to climate change will affect rain-fed agricultural yields and prospectively lead to increased food insecurity in under developed regions (Falkner, *et al* 2010). For survival, communities settled in these regions will tend to exploit other avenues such as fishing, deforestation, blocking of naturally flowing river channels to harness the water resource, and increased pressure on biodiversity of ecosystems. This human footprint will result in environmental degradation (Ward & Stanford, 1995). Over the years, there has been an increase in the frequency of natural disasters which have led to loss of lives, damage to property and degradation of the environment (Mwape, 2009). Most of these disasters have been a result of extreme weather patterns. To mitigate this, governments of such regions must thrive to invest in climate change adaptation plans. The core of such plans must hinge on elucidating the relationships among climate change scenarios, precipitation and runoff (Smith & Olesen, 2010). If such relationships exist, then a yardstick on which to base informed decisions on water use plans would be provided. Elucidating this relationship, therefore, relies on research.

Climate change is a reality in Zambia (Jain, 2007). The country being part of the underdeveloped regions, government must take centre stage in developing climate change adaptation plans based on scientific evidence. With respect to the forgoing water reforms, incorporation of climate variability and change research is imminent. The purpose of this research was to establish relationships that may exist between climate change, rainfall patterns and river flow using trend analyses of historical data and inferring the results on future scenarios. The Zambian government has made headway by developing the National Climate Change Response Strategy (NCCRS) under the Ministry of Tourism, Environment and Natural Resources (GRZ, 2008). The strategic plan in this government paper dwells much on adaptation options based on the past climate change scenario such as prolonged droughts in the southern part of the country that have negatively impacted on tourism and the energy sector. It has not scientifically tied the cause and effect of climate change on the water resources. Whether climate variability and change is responsible for these prolonged droughts on the southern part of the country is mere speculation.

1.2 Statement of the problem

The problem that this study sought to address is the prediction of future climate scenarios. Climate change is a challenge that we have to live with. Predictions made thus far, in various literature reviews, point to a future that will have extreme climate conditions such as increased diurnal temperatures and precipitation events. The effects will manifest in all sectors of economic importance. Crop yields are expected to decrease in food insecure regions such as Zambia, exacerbating impacts on global food security. However, the scale of these extreme climate conditions is not known so as to inform the level of preparedness. The pressing challenge of responding to existing food security issues combined with the additional stress from climate change means that action will be required to implement strategies to adapt to the impacts of climate change to enhance food security.

The major issue for all nations in the fight against climate change is to build economies that are resilient to the effects. Zambia needs to understand the intricacies that exist between precipitation, run-off and temperature. This can only be achieved by the use of time series data for at least a minimum of 30 years of consistency. Once this understanding is known, adaptation strategies can then be derived

This research sought to observe the response of precipitation and stream flow to temperature in Zambia with the hope to devise adaptation strategies based on past scenarios to infer on the future in order to enhance a resilient economic growth. To do so, the study employed trend analysis based on the changes in precipitation, flow regimes and temperatures over time

1.3 Aim of the study

The aim of this study was to model the relationships between climate variability and change as determined by temperature, precipitation and stream flow in Zambia.

1.4 Objectives

This study was guided by the formulated general and specific objectives

1.4.1 General objective

The general objective of this research study was to determine how precipitation and river flow respond to average temperature changes in Zambia.

1.4.2 Specific Objectives

The study had two specific objectives

i. To characterize the climate variables in Zambia over time.
ii. To determine the response of precipitation and streamflow to average temperature changes in Zambia over time
iii. To establish the relationship between precipitation and streamflow to temperature changes in Zambia.

1.5 Hypothesis

The research only had one hypothesis.

i. There is a linear relationship between climate variability represented by temperature, precipitation and stream flow.

1.6 Justification

The justification of this research was adding value to the bank of climate variability and change literature in Zambia for development purposes. Since climate has taken centre stage in the environmental discussions globally in the recent past due to climate change, there is need to have as much research as possible on the menace and its associations so as to find solutions that could help us create an economic wealth resilient to its effects. The information that the research would provide could help water managers and those in the agricultural fraternity to plan their activities. Furthermore, other interested scholars could take a leaf from issues and gaps from this study that could prompt further research

1.7 Organization of the dissertation

The study undertaken followed this order: This chapter has outlined how the problem was formulated, provided the research aim, research question and hypothesis, and, finally, the aims of this dissertation. Chapter two discusses the relevant literature on the topic and outlines the gap to be filled with this research. Chapter Three sets out an understanding of the study area and its general characteristics. Chapter Four discusses the methodology used in the research during data collection, analysis and presentation. Chapter Five presents the results obtained after applying the methodology. Chapter Six provides a general discussion of the findings, while Chapter Seven gives recommendations and provides the conclusion of the study.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter highlights the literature that is available so far on climate variability and its impacts on the socio-economic activities at global regional and national scale.

2.2 Climate variability and change at global scale

Water is a finite resource and its availability, at the right time, is dependent on climate variability. Any permanent change to the natural climate variability will infer climate change. Anthropogenic activity is the major cause of permanent change to natural climate variability. Carbon emissions from this activity have continually exacerbated climate change. The IPCC report of 2007 as quoted in DaMatta *et al*., (2010), indicates that, as the earth moved from the ice ages over the past 800, 000 years, atmospheric carbon (CO_2) changed between 180ppm (glacial periods) and 280ppm (inter-glacial periods). There has been a steady increase of atmospheric carbon from the 280ppm of pre-industrial levels to 384ppm in 2009 and mean temperature has increased by 0.76^{o}C over the same period. Projections to the end of this century suggest that atmospheric carbon will top 700ppm or more whereas global temperature will increase by 1.8 – 4.0^{o}C depending on the greenhouse emission scenarios. Overwhelming evidence suggests that these permanent changes will alter precipitation patterns (Batima *et al*., 2007). As if that is not enough, IPCC (2010) asserts that any climate change outside the natural variability of the recent climate regime will profoundly induce a change in the rainfall patterns. This will, in the long run, induce change in the river flow patterns of a particular catchment.

Climate change has been globally professed as being caused by anthropogenic activities (Falkner *et al*., 2010; Scheffran & Battaglini, 2011; Smith & Olesen, 2010). The carbon emitted from socio-economic activities such as industrial processes, livestock and agricultural activities and deforestation is responsible for the warming of the atmosphere. The warming in turn induces climate change variability that is outside the naturally patterned climate enjoyed over a long period of time (Keogh *et al*., 2011; Nursey-Bray, 2010). This change in climate manifests in extreme rainfall patterns such as drought and flood conditions at the least expected times, shifts in the hydrological cycles, and raised diurnal temperatures due to elevated day time temperature records (Australian-Government, 2012; Ernst & van Riemsdijk, 2013). These manifestations have adverse effects on biodiversity of various ecosystems, which have developed their lifetime processes through the natural climate variability over years of their existence (Bloom, 2010). Scheffran & Battaglini (2011) assert that, in its 2007 fourth assessment report, the IPCC addressed serious risks associated with climate change that could undermine the living conditions of people across the world. In its deliberations, it informed that vulnerable systems would include water resources, agriculture, health settlements, energy and the economy. Because of such manifestations due to induced climate variability, socio-economic activities will shift and find what period of the year they can optimize benefits using the period that will give the most available water resources. This shift will create stress in ecosystems as some of the shifts in anthropogenic activities will imply construction of dams to harness the required amounts of water to attain economic benefits.

Other changes will imply shift of economic activities to river bank water abstraction for domestic uses and deforestation as survival strategies in vulnerable poor communities (Olsen & Fenhann, 2008). Such activities will affect the river channel geomorphology negatively and will lead to depletion of riparian vegetation that protects the river continuum (Arthington, 2011). River channels will be exposed to the atmosphere and with increased day time temperatures, evaporation will tend to increase to a level where even those streams of lower order that have recorded perennial flows will become non perennial in the long run. Such pressure on the water resources will alter the natural flow regime of lower order river networks and this effect will trickle down to large rivers usually of higher order (Poff *et al*., 1997).

2.3 Climate variability and change in Zambia

Over the last three decades, the frequency of extreme climate events such as high surface temperatures, floods and droughts has increased over the entire globe. Although such extreme events are attributed to climate variability, they also signal that the earth is going through long term climate changes in mean temperature and rainfall patterns (Jain, 2007). Zambia has experienced an increase in drought frequency and intensity in the last 20 years. The droughts of 1991 92, 1994 95 and 1997 98 worsened the quality of life for vulnerable groups such as subsistence farmers (Muchinda, 2001).

Although the country Zambia has a tropical climate, temperatures remain relatively cool throughout the year due to the high altitudes of the East African Plateau (Christensen *et al*. 2007) The highest seasonal temperatures are reached in the hot, dry season (22-27°C), and coolest in the winter months (15-20°C). The hot summer months are very dry, receiving almost no rainfall between June and August. The wet season rainfalls are controlled by the passage of the tropical rain belt (also known as the Inter-Tropical Conversion Zone, ITCZ) which oscillates between the northern and southern tropics over the course of a year, bringing rain between October and April of 150-300mm per month. Variations in the movements of the ITCZ can cause large variations in the rainfall received from one year to the next. Rainfall in Zambia is also strongly influenced by the El Niño Southern Oscillation (ENSO), which causes further inter-annual variability. El Niño conditions (warm phase) bring drier than average conditions in the wet summer months in the southern half of the country, whilst the north of the country simultaneously experiences significantly wetter-than average conditions (Christensen *et al*. 2007). The reverse pattern occurs with La Niña (cold phase) episodes, with dry conditions in the north and wet conditions in the south. Zambia was one of the countries in Africa most severely affected by the 1997/1998 El Niño event, suffering flooding due to abnormally persistent and heavy rainfall in the north, as well as near-drought conditions in the south.

2.3.1 Recent Climate Trends

Studies conducted have shown recent climate trends in temperature and precipitation.

2.3.1.1 Temperature

Studies conducted show that mean annual temperature has increased by 1.3°C since 1960, an average rate of 0.29°C per decade. The rate of increase is most rapid in the winter, at 0.34°C per decade. Daily temperature observations show significantly increasing trends in the frequency hot days and nights in all seasons. The average number of ‘hot’ days per year in Zambia has increased by 43 (an additional 11.8% of days) between 1960 and 2003. The rate of increase is seen most strongly when the average number of hot days has increased by 5.2 days per month over this period. The average number of ‘hot’ nights per year increased by 43 (an additional 11.6% of nights) between 1960 and 2003. The rate of increase is seen most strongly in December, January and February when the average number of hot nights has increased by 5.3 days per month (an additional 17.2% of December, January and February nights) over this period. The frequency of cold days and nights has decreased significantly since 1960 in all seasons. The average number of ‘cold ‘days per year has decreased by 22 (6 percent of days) between 1960 and 2003. The rate of decrease is similar in all seasons. The average number of ‘cold’ nights per year has decreased by 35 (9.7 percent of days). This rate of decrease is most rapid in March, April and May when the average number of cold nights has decreased by 3.5 nights per month (11.2 percent of March, April and May nights) over this period (Christensen *et al*. 2007).

2.3.1.2 Precipitation

Mean annual rainfall over Zambia has decreased by an average rate of 1.9mm per month (2.3 percent) per decade since 1960. This annual decrease is largely due to decreases in December, January and February rainfall, which has decreased by 7.1mm per month (3.5 percent) per decade. Daily precipitation observations show some indication of reductions in the contribution of heavy events to total rainfall, and the magnitude of maximum 1- and 5-day rainfalls, but none of these trends are statistically significant (Christensen *et al*. 2007).

2.3.2 Projections of Future Climate

Furthermore, studies have made projections in future climate in terms of temperatures and precipitation

2.3.2.1 Temperature

The mean annual temperature is projected to increase by 1.2 to 3.4°C by the 2060s, and 1.6 to 5.5°C by the 2090s. The range of projections by the 2090s under any one emissions scenario is 1.5- 2.5°C. The projected rate of warming is a little more rapid in the southern and western regions of Zambia than the northern and eastern regions (Christensen *et al*. 2007). 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 are projected to occur on 15-29 percent of days by the 2060s, and 16-49 percent of days by the 2090s. Days considered ‘hot’ by current climate standards for their season are projected to occur 22-80 percent of days by the 2090s. Nights that are considered ‘hot’ for the annual climate of 1970-99 are projected to increase more quickly that hot days, occurring on 26-54 percent of nights by the 2060s and 30-80 percent of nights by the 2090s. Nights that are considered hot for each season by 1970-99 standards are projected to increase most rapidly in DJF, occurring on 30- 99 percent of nights in every season by the 2090s.

All projections indicate decreases in the frequency of days and nights that are considered ‘cold’ in current climate. These events are expected to become exceedingly rare, occurring on maximum of 1-4 percent of days in the year, and potentially not at all by the 2090s in many of the projections. Cold nights decrease in frequency more rapidly than cold days (Christensen *et al*. 2007).

2.3.2.2 Precipitation

Projections of mean rainfall do not indicate large changes in annual rainfall. Seasonally, the range of projections from different models is large, but ensemble indicate decreases in SON rainfall (-39 to +14 percent by 2090) and increases in DJF rainfall (-11 to +15 percent), particularly in the north-east of the country. The proportion of total rainfall that falls in heavy events is projected to increase annually, but mainly in December, January, February and March, April and May. Projections indicate that maximum 1- and 5-day rainfalls may increase in magnitude in these months (Christensen *et al*. 2007).

2.4 Impacts of human activities

Zambia has many areas of remarkable human foot prints (Mukanda, 1998). Nearly each agro-ecological zone and catchment has designated areas were human activity such as farming, fishing, river channeling for city landscaping and many more activities that may have negative impacts on the environment at large (Uhlendahl *et al*., 2011). However, there are also areas reserved specifically for preservation of nature. In these areas, no human activity is allowed. Restricted areas from any human activity will usually have rivers flowing freely and naturally. Forest reserves, game management areas and national parks are some of the areas that are a heritage for nature. Forest sheds along river channels protect river flows from alterations. River channel connectivity in such sheds would usually exhibit natural flows.

2.5 Research gaps

Most of the research presentations indicate that climate variability in Zambia is mostly driven by the ITCZ, the LaNino and the ElNino and this variability has induced a permanent upward change in average temperatures over time. However, these presentations have not illustrated how different variables such as precipitation, stream flows and temperature within the climatic scenarios are interacting during these transformations

CHAPTER THREE: STUDY AREA

3.1 Location

The landlocked Republic of Zambia is located on the Southern part of Africa and surrounded by eight other countries, the democratic republic of Congo on the Northern side, Angola on the North-Western, Namibia, Botswana and Zimbabwe on the Southern side, Mozambique and Malawi on the Eastern side, Tanzania on the North-Eastern side. The country covers an area of 752 610 km^2 and geographically sits between latitude 8^o15’ and 18^o7’ south of the Equator and longitude 22^o to 34^o east of the Greenwich meridian (GRZ, 2008).

3.2 Physical characteristics

The physical characteristics of the country can be explained in the following terms

3.2.1 Climate

Although lying in a tropical region, because of the high altitude, much of the country enjoys a subtropical climate characterized by two main seasons:

i. The cool and hot dry season from May to October with average temperature variations of between 16^oC and 21^oC. This season is further subdivided into midwinter which is a period between May and July and exhibiting average temperatures of up to 16^oC. Dry summer is another subdivision which is a period between August and October with average temperatures between 30^oc and 40^oc (Mukanda, 1998).
ii. The wet season between November and April which is characterised by rainfall with January and February having the highest rainfall peaks and, therefore, making these two months the wettest (Mukanda, 1998).

3.2.2 Topography

Zmabia is a generally level to undulating plateau with slopes rarely exceeding 3-5% except for the Zambezi, Luangwa and Muchinga valley escarpments which are mountainous and rocky (GRZ, 2008). The main drainage system is comprised of the Zambezi, the Kafue, the Luangwa, the Luapula and the Chambeshi Rivers and Lake Tanganyika. On a much broader perspective, the entire country is drained by two basins, the Zambezi and the Congo River basins (GRZ, 2008).

3.2.3 Precipitation

The annual average rainfall Zambia receives ranges between 600mm and 1500mm (Mukanda, 1998). Based on the rainfall received, it is zoned into three Agro-ecological regions as shown in Figure 1.

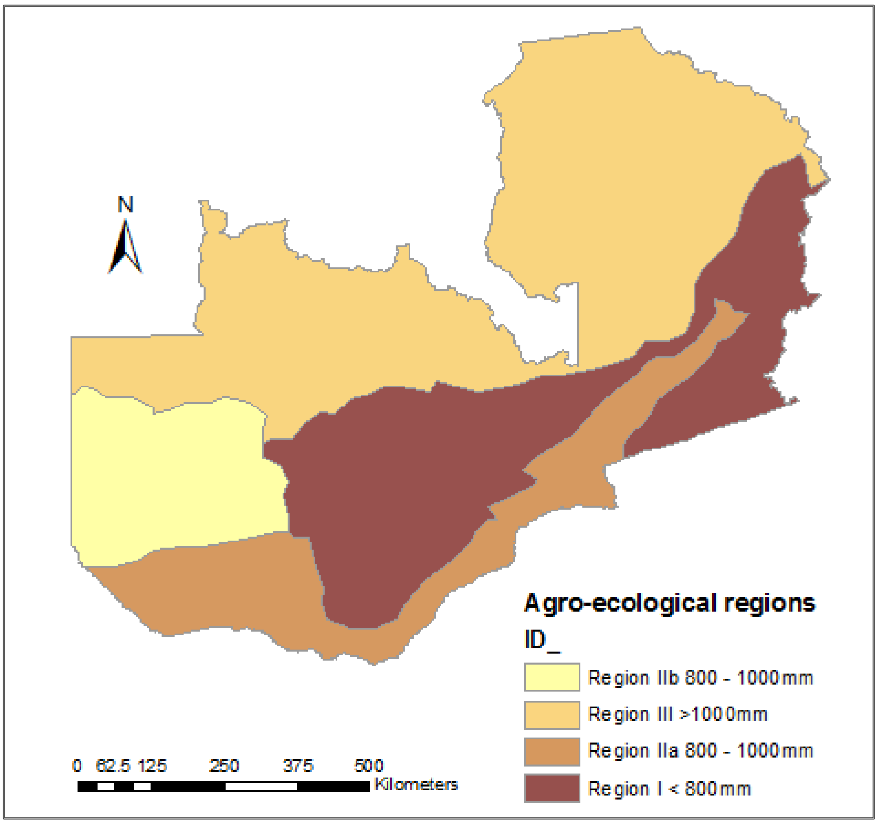

Figure 1: Map of Zambia showing boundaries of agro-ecological regions.

i. Agro-ecological region I

This region receives an annual average rainfall of between 600mm and 800mm and covers the semi-arid areas of the southern part of the country that include the Luangwa and Zambezi catchments. The region is characterized by high temperatures and high evaporative losses with short rain-fed agricultural period due to poor rainfall patterns (Mukanda, 1998). The vegetation cover is mostly that of Minga (thorny bushes) woodlands and savannah grassland (Mukanda, 1998).

ii. Agro-ecological region II

With average annual rainfall between 800mm and 1000mm, this region has more Agricultural activities. Both rain-fed and irrigation-fed agriculture are practiced in the region. The type of vegetation is Miombo (indigenous trees that form a larger portion of Zambia's forestry) woodlands and savannah grasslands in sub-regions of the northern part towards Agro-ecological region III and Minga woodlands (thorny bushes) in sub-regions of the southern part towards Agro-ecological region I (Mukanda, 1998). Most of the Kafue and part of the Zambezi catchments are covered by this region (Uhlendahl *et al*., 2011).

iii. Agro-ecological region III

This region covers the Luapula, the Chambishi and the Tanganyika catchment areas receiving between 1000mm and 1500mm of annual average rainfall. The region is characterized with plains and wetlands mostly Miombo woodlands and savannah grasslands type of vegetation and with fishing as the main activity (Mukanda, 1998).

3.2.4 Hydrology

On a larger scale, Zambia is drained by two major river basins; the Congo basin which has its headwaters in the Northern part draining the entire area into democratic republic of Congo and Tanzania into the Atlantic Ocean. The Zambezi basin drains the rest of the country into the Indian Ocean. The two river basins form six sub-basins within the country's boundaries called catchments (Figure 2).

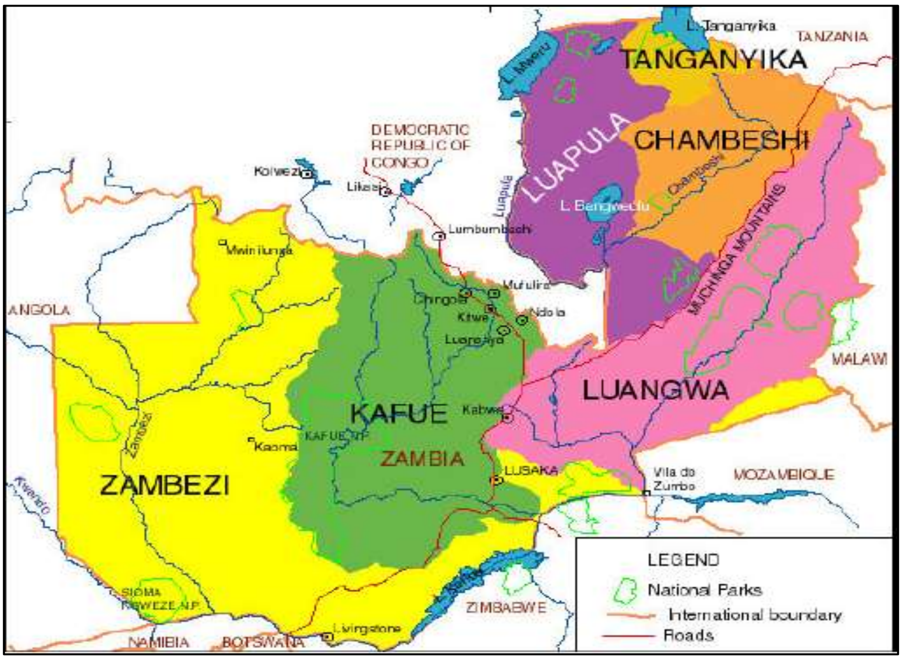

Figure 2: Map of Zambia showing the six catchments and their drainage pattern. Source: GRZ (2008).

i. The Zambezi River Catchment

This catchment is drained by the Zambezi River whose source is in the north-western part of the country. The river drains the western and the southern parts before it exits the country's political boundaries into Mozambique and finally flows into the Indian Ocean (Uhlendahl *et* *al*., 2011). It drains a total area of 268 235 km^2 of Zambia and stretches about 1700 km from the source up to the political boundary where it exits into Mozambique (Hughes *et al*., 1992). Three quarters of the catchment area is in the Agro-ecological region III, while a quarter is under region II. The main activity in this region is farming and fishing. The vegetation type is Miombo and Minga woodlands and savannah grasslands (Mukanda, 1998).

ii. The Luangwa River Catchment

The Luangwa catchment covers an area of about 140 000 km^2 and most of this area lies in the Luangwa valley (Hughes *et al*., 1992). The entire catchment is drained by the Luangwa River. The river covers a distance of 850 km from its source in the north-western part of the Nyika plateau in Malawi up to its confluence with the Zambezi River at the political boundaries of Zambia and Mozambique (Hughes *et al*., 1992). The catchment valley contains five national parks and seven game management areas, and as such, it has very few settlements. These features make the river systems of this catchment area the most uncontrolled of all the river systems in the country's catchments.

iii. The Kafue River Catchment

A larger portion of the Kafue catchment is covered by Agro-ecological zone II receiving between 800mm and 1,000mm of annual average rainfall per annum, while a smaller portion on the northern part of the catchment falls in Agro-ecological zone III receiving up to 1,500mm of average annual rainfall (Mukanda, 1998). The abundant vegetation cover in this catchment is the Miombo woodlands with many portions of the Savannah grasslands (Mukanda, 1998). The Kafue catchment is drained by the Kafue River which is a second order river system. The River meanders over a distance of 1,300 kilometres from its source on the Northern part of the catchment in the political boundary of the Republic of Zambia and the Democratic Republic of Congo up to its confluence with the Zambezi River on the southern part of the catchment on the political border with Zimbabwe. It drains a total area of 144, 388 square kilometers (Hughes *et al*., 1992).

iv. The Chambeshi River Catchment

The main drainage of this catchment is the Chambishi River which is a third order river flowing through the catchment a distance of 560 km from the source to the point where it offloads the water into the Bangweulu wetlands. The catchment is situated in the northern part of the country covering an area of 144,358km^2 (Hughes *et al*., 1992). The area is under

Agro-ecological region III with Miombo woodlands and savannah grasslands as the main vegetation cover and farming and fishing as the main activity (Mukanda, 1998).

v. The Luapula River Catchment

This catchment is located in the northern part of the country and is entirely covered by the Agro-ecological zone III which receives an annual average rainfall range of between 1,200mm and 1500mm (Mukanda, 1998). It is drained by the Luapula River which is a tributary of the Congo River that drains into the Atlantic Ocean. As the Chambishi River flows into the Lake Bangweulu, it comes out as the Luapula River and flows for about 615 km, draining an area of 156, 995 km^2, into Lake Mweru on the northern part of the catchment and exits the lake into the Democratic Republic of Congo as the Lualaba River (Hughes *et al*., 1992). The catchment is dominated by the Miombo woodlands and savannah grasslands with many Dambos (natural and permanent wetlands due to a rise in the water tables) here and there (Mukanda, 1998).

vi. The Lake Tanganyika catchment

This catchment covers an area of 15, 856 km^2 in Agro-ecological region III on the northern part of the country receiving an annual average rainfall of between 1,100mm and 1,500mm (Mukanda, 1998). The main watershed draining the area is Lake Tanganyika which is a shared water resource between the Republic of Zambia, the Republic of Tanzania and Burundi and only stretches about 250 km into the political boundaries of Zambia (Hughes *et al*., 1992).

CHAPTER FOUR: METHODOLOGY

4.1 Introduction

This chapter outlines the type of data collected and the techniques used in collecting it. It further outlines how the data was screened and prepared for analysis. It also gives an account of the methods used in screening and analysing the data.

4.2 Types of data

Time series secondary data of hydrology, precipitation and temperature were used in this study.

4.2.1 Hydrological data

Hydrological data of mean daily discharge of at least between 40 and 30 years of record from a total of 60 gauge stations with 10 stations from each catchment was obtained from the offices of the regional heads of Department of Water Affairs across the six catchments. These data sets were selected from a list of minimally altered gauges of stream and river flows. To ensure selection of gauges from near natural flowing rivers, shape files for forest reserves, game management areas and national parks were obtained from the Zambia Wildlife Authority.

4.2.2 River analysis package RAP

River analysis package (RAP) filled the gaps present in the discharge data sets by linear interpolation via the gap diagnostic window on the time series management (TSM). It further generated the metrics using time series analysis TSA. The metrics were used to group the rivers into clusters with similar characteristics based on known seasonal environmental and weather variability.

4.2.2.1 Gap diagnostic

The data was screened for gaps using the river analysis package software RAP (Marsh, 2003), where eight (8) data sets were dropped due to large single gaps. In a research to classify natural flow regimes at continental scale, Kennard *et al*. (2010) generated hydrological metrics that informed them of variations in different flow categories from data sets with up to 30 days of missing record of flow as the longest gap in all their datasets. The rule of thumb is that the less days of missing record you have as longest gaps in your data sets the more accurate the metrics obtained. However, for the case of the data sets used in this study, this rule of thumb could not apply otherwise all the data sets could not qualify. The longest single gap obtained for analysis was up to 398 days of missing record for the 52 data sets the criteria selected from initial 60. The other data sets had to be disqualified because they were giving outrageous days of missing data as single gaps. River analysis package was capable of performing gap diagnostic that allows checking for the length of single gaps and the total number of gaps in a data set (Marsh, 2003). The length of each data set was then reviewed to ensure it was overlapping.

To ensure meaningful and consistent generation of physical hydrological metrics upon which classification can be based, Kennard *et al*. (2010) suggested that estimation of hydrological metrics based on at least 15 years of discharge record was suitable for use in hydrologic classification analyses that aim to characterize spatial variation in hydrologic regimes, provided that the discharge records were contained within a discrete temporal window of preferably > 50 percent overlap between records. The study settled for a period of record between 1970 and 2012 because the data sets overlapped overwhelmingly at this interval. Within this interval, a period of within 30 years of daily flow record was chosen starting from 1st of October, 1979 to 31st of September, 2009 as the period of reference. This meant that any data set with this period of daily flow record was assigned 100 percent overlap weighting. Based on this criteria, a total of 40 data sets out of 53 was selected as having met the requirements with 10 data sets having 90 percent overlap weighting, 13 data sets with 88 percent overlap weighting, seven data sets with 81.3 percent overlap weighting, three data sets with 75 percent of overlap weighting, two data sets with 70 percent overlap weighting, four data sets with 64 percent overlap weighting and only one data set had 50 percent of overlap weighting. The research then only remained with 40 data sets from the initial 60 that had been targeted to be used.

4.2.2.2 Hydrological metrics

Five hydrological metric groups that influence the ecological integrity in both direct and indirect ways include; magnitude, frequency, timing, duration and rate of change in flow events (Poff *et al*., 1997). Within the five groups, numerous metrics can be used to describe relevant components of hydrological flow regimes. Taking a leaf from the research study undertaken by Olden & Poff, (2003) on hydrological metrics and their abilities to describe relevant components of hydrological flow regimes quantified on 420 stream gauges of the continent of the United States of America, this study used the Indicators of Hydrological Alteration IHA software package and qualified 66 hydrological metrics from 171 to be adequate in describing important hydrological flow regimes. From this perspective, from these, 29 metrics were chosen for the purpose of this research, out of the 66 metrics across the five groups of hydrological metrics to describe the flows of the rivers from the six main river drainage catchments of Zambia.

4.2.3 Types of hydrological parameters

The five hydrological parameters from which the indicators of hydrologic alterations were derived are magnitude of flow events, frequency of extreme flow events, timing of extreme flow events, duration of extreme flow events, and rates of change in flow events. These are described below.

4.2.3.1 Magnitude

The magnitude of a flow event is the volumetric amount of water passing a particular area or position in a river system within a specified time frame. This is usually interpreted as the measure of the availability or suitability of a habitat and its attributes within a position of the river system in relation with the wetland or riparian plant rooting zone in an aquatic system (Richter *et al*, 1996). In the research, magnitude was defined by metrics namely; total annual runoff for each station divided by the catchment area of the river to define the down weighted mean daily flow, the coefficient of variance (cv) of the mean daily flow, base flow index and its coefficient of variance, low flow discharge at both 1st and 10th percentile, high flow discharge at both the 90th and the 99th percentile and flood magnitude at 1, 2, 10 and 15 years average recurrence interval (ARI). All the parameters are informants of annual flow variability and availability of the resource at a particular point in time. The coefficients of variance will inform the variations that will exist inter-annually and therefore will provide an expression for contingency.

4.2.3.2 Frequency

The frequency of a flow event describes how often certain extreme conditions such as droughts or floods occur and have an influence on the mortality or reproduction patterns of various aquatic species in the river system (Richter *et al*., 1996). In this research frequency was defined by the number of low flow spells at both 1st and 10th percentile and their respective coefficients of variance, number of high flow spells at both 90th and 99th percentile with their respective coefficients of variance.

4.2.3.3 Timing

Timing is the time of the year within which extreme conditions such as drought and floods occur. This will inform whether the influence of such conditions on the flow events within their occurrence can provide life time requirements for certain species life-cycles (Richter *et al*., 1996). Timing of extreme events metrics were generated from moving average in RAP (Marsh, 2003). Four metrics were taken, Julian date maximum and minimum and their respective coefficients of variance.

4.2.3.4 Duration

Duration is how long the flow events associated with extreme conditions such as droughts and floods last. This will have an influence on the completion of particular species' life-cycles (Richter *et al*., 1996). In this physical characteristic, 10 metrics were developed. These were; average number of zero flow days and its coefficient of variance denoted by No.0Qs and CvNo.0Qs respectively, High and Low flow spell duration at 99th, 90th 10th and 1st percentile with their coefficients of variance 99th and 90th, 10th and 1st percentiles, respectively, low flow spell duration 10th and 1st percentiles and coefficients of variance with respective percentiles.

4.2.3.5 Rate of change in flow events

This is the rate at which the flow events increase or decrease in magnitude. This will determine the resilience and lifetime patterns such as reproduction, migration and hibernation developed by species assemblages within a particular river system (Richter *et al*., 1996). In this category, four metrics were picked; the rate of rise in flow events , the coefficient of variance for the rate of rise in flow events, the rate of fall in flow events with its coefficient of variance respectively.

4.2.4 Hierarchical classification

Hierarchical analysis was used in Primer to obtain three parsimonious clusters of river flow were presented in form of a dendrogram. Three clusters formed parsimoniously at a Euclidean distance of about 2.6 where membership of the clusters followed an agro-ecological trend which each cluster membership bearing at least some characteristics of average rainfall conditions

4.2.5 Precipitation and temperature data

Precipitation and temperature data were obtained from various stations across the country using SWAT SOIL climate database, an internet based software that, among other things, captures and stores daily climate data via satellite. With over 500 recording points across the country, selection of data for the study was based on the GIS mapping system. This helped to obtain climate data sets as close as possible to the data sets for stream flow from the gauging points (Figure 3). The criteria on the choice of the stations from where the data was collected, was based on the catchment and agro-ecological zone delineation. With the six catchments in place, six stations, at most, were selected from each catchment. In this study, temperature was set as the main parameter that could influence changes and variability in precipitation and stream flow. For details of the stations that tied with hydrometric stations, see Appendix 2**.**

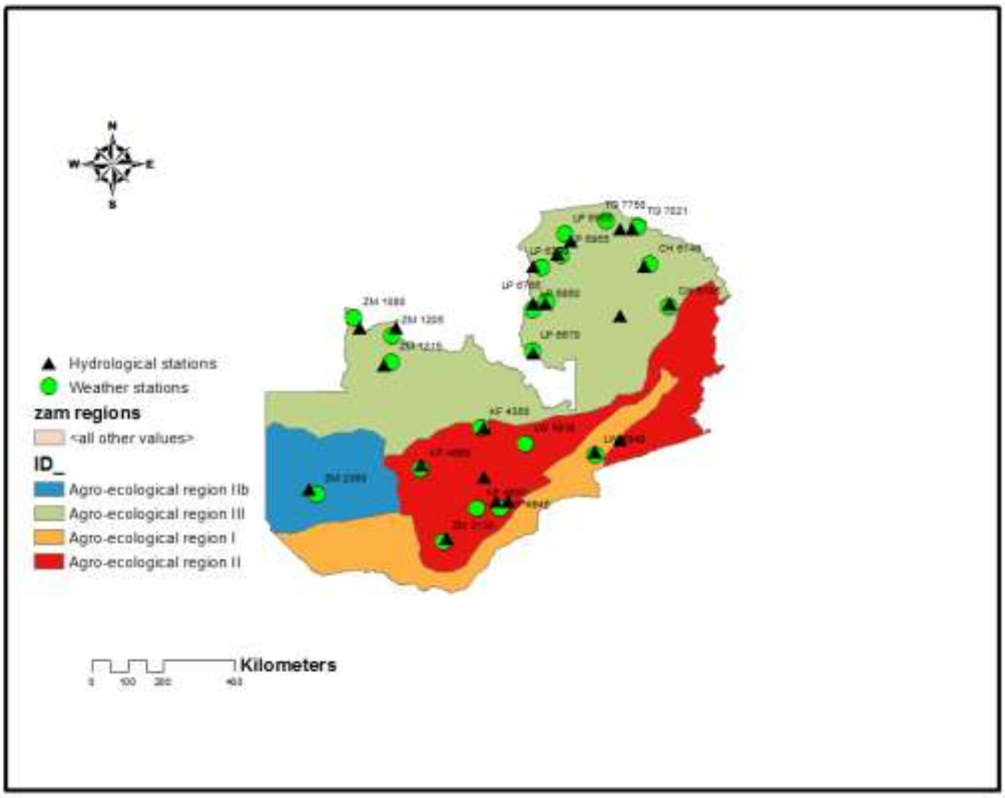

Figure 3: Map showing points of hydrological and meteorological gauge points across Zambia

To assert the response of precipitation and stream flow to climate variability (temperature in the case of this study), trend analysis was performed using spreadsheets in excel. The ***P*** value from linear regression was then used at 95 percent confidence level to determine the strength of the linearity between temperature against precipitation and river flow.

CHAPTER FIVE: ANALYSIS AND RESULTS

5.1 Introduction

This chapter highlights the techniques that the study used to analyze the collected data. It further presents the results obtained from the analysis.

5.2 Analysis

The techniques and analyses of data and results obtained showed the following observations:

5.2.1 Determination of Hydrological parameters

The five hydrological parameters of magnitude, frequency, timing, duration and rate of change in flow events were determined as described in section 4.2.3. Table 1 summarizes the metrics derived from each hydrological parameter.

Table 1: Summary of the metrics that were used for this research as generated from the river analysis package

Magnitude	**Frequency**	**Duration**	**Timing**	**Rate of change in flow events**
Mean daily flow (MDF)	Low flow spell (LFSpl) 1st and 10th percentile	Low flow spell duration (LFSplDur) 1st and 10th percentile	Julian date maximum (JulDMax)	Rate of rise in flow events (RiseRate)
CV mean daily flow	CV low flow spell 1st and 10th percentile	CV low flow spell duration 1st and 10th percentile	CV Julian date maximum	CV rate of rise in flow events
Base flow index (BFI)	High flow spell (HFSpl) 90th and 99th percentile	High flow spell duration (HFSplDur) 90th and 99th percentile	Julian date Minimum (JulDMin)	Rate of fall in flow events (FallRate)
CV base flow index	CV high flow spell 90th and 99th percentile	CV high flow spell duration 90th and 99th percentile	CV Julian date minimum	CV rate of fall in flow events
Low flow discharge 1st and 10th percentile (LFQ)		Number of zero flow days (No0Q)		
High flow discharge (HFQ) 90th and 99th percentile		CV number of zero flow days		
Flood magnitude (FM) 1, 2 10, 15 year ARI				

Source: RAP (2003).

Cluster 1 - C_1 Agro-ecological region III, II and I

Based on the Euclidean distance of dissimilarity seen on the dendrogram, membership of this cluster comprised of rivers characterized by large catchment areas (more than 40,000km^2) draining across two or more agro-ecological zones (Figure 4 and Table 2).

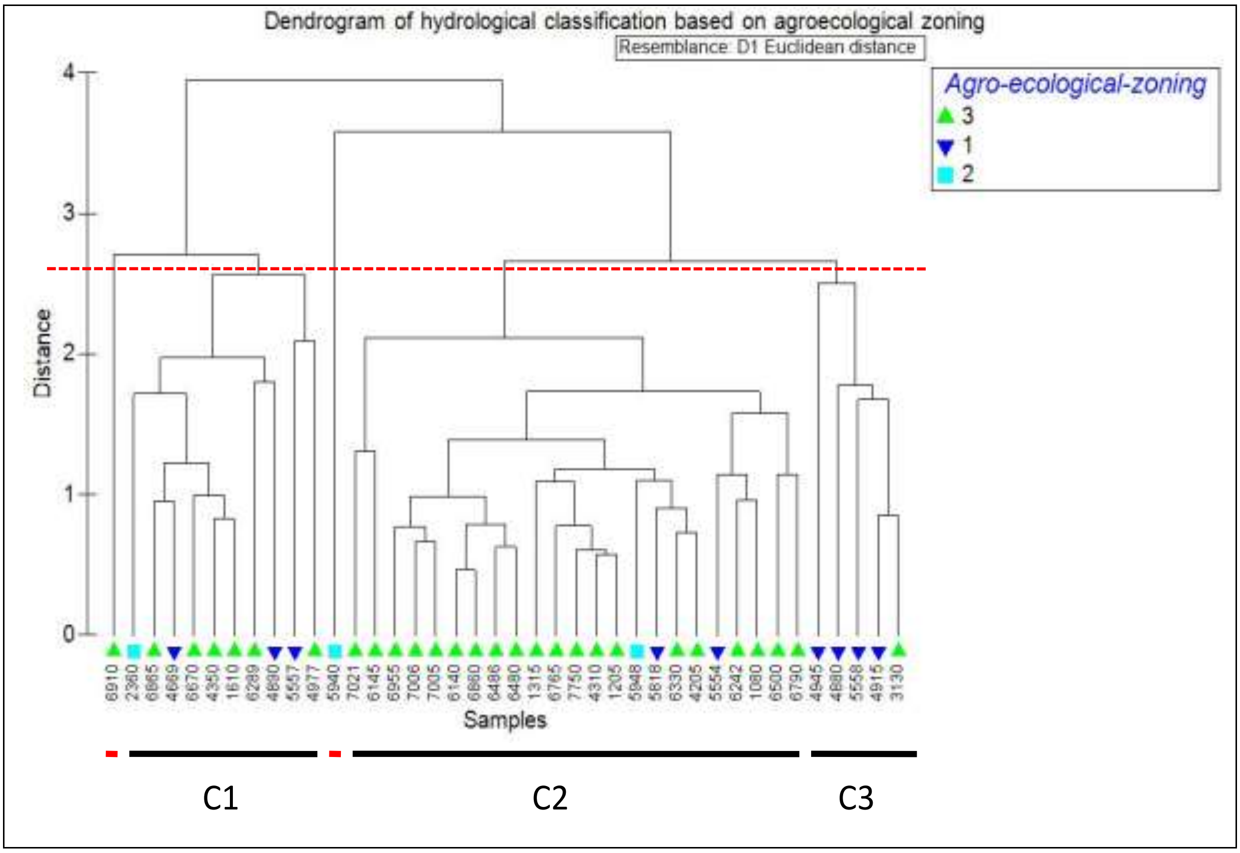

Figure 4: Dendrogram showing cluster groupings at Euclidean distance of 2.6 generated from Primer

Table 2: Summary of River stations in cluster C1

No	Name of River and location	Station number
1	Kataba River at Siandi Bridge	2360
2	Kalungwishi River at chimpempe	6865
3	Kafue River at Hook Bridge	4669
4	Luapula River at Chembe ferry	6670
5	Kafue River at Chilenga	4350
6	Kabompo River at Manyinga Bridge	1610
7	Chambishi River at the Pontoon	6289
8	Kafue River at Nyimba	4890
9	Msipazi River at Chadidza Bridge	5557
10	Kafue River at Kasaka	4977

Cluster 2 – C_2 Agro-ecological region III

Membership of cluster 2 comprised of 87 percent of rivers belonging to agro-ecological region III, all with perennial flow characteristics. They have drainage catchment areas almost 12 times less than those in cluster 1 (Figure 5 and Table 3).

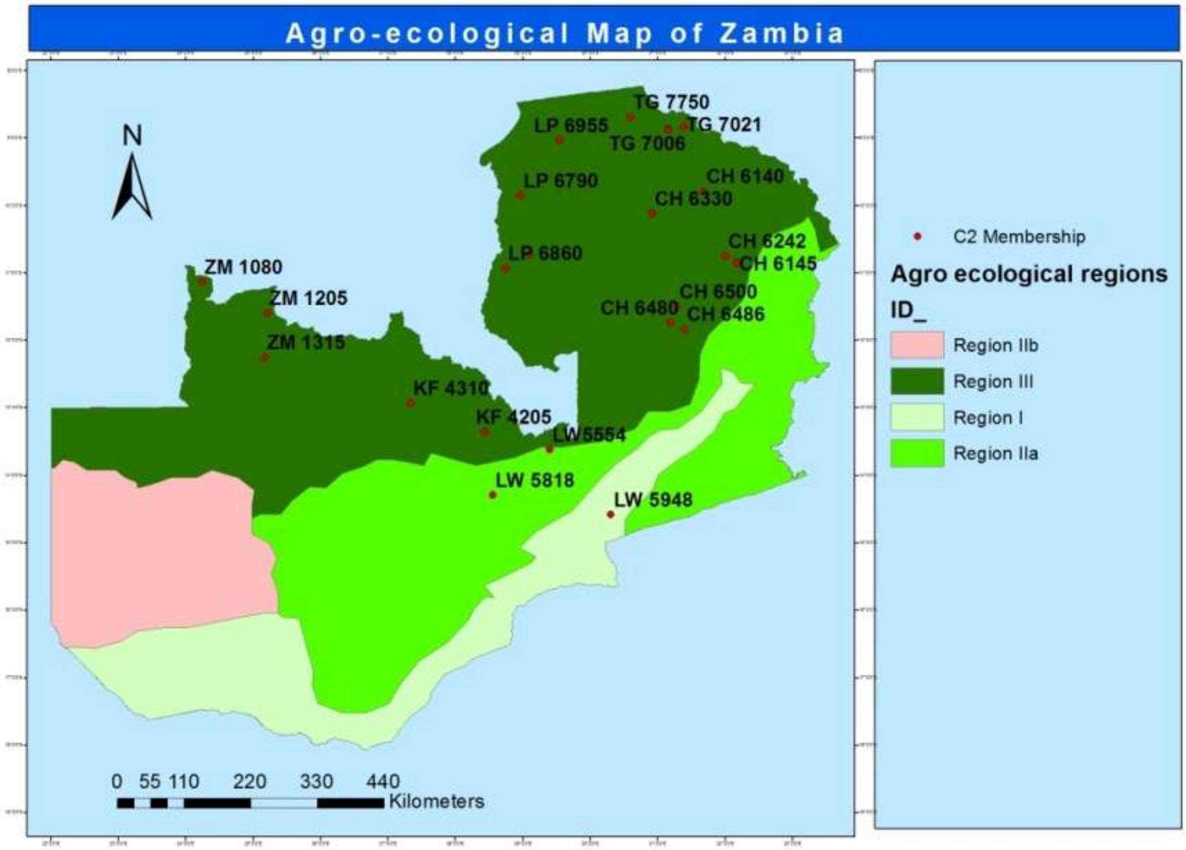

Figure 5: Map of Zambia showing position of membership of cluster 2 across agro-ecological regions.

Table 3: Summary of River stations in cluster C_2.

No	Name of River and location	Station number
1	Lucheche River below Lake Chila	7021
2	Mbesuma River Pontoon	6145
3	Mukubwe River at Kambasa	6955
4	Lunzua River at lunzua weir	7006
5	Lunzua River at Kambole Bridge	7005
6	Chambishi River at Chandaweyaya	6140
7	Luangwa River at Mumbuluma	6860
8	Lwitikila River at Mpika Road	6486
9	Lwitikila River at Lwitikila Falls	6480
10	East Lumwana River at Mwinilunga Bridge	1315
11	Lufubu River at chipili	6765

No	Name of River and location	Station number
12	Lufubu River at Keso Falls	7750
13	Luswishi River at Kilundu	4310
14	Kabompo River at Solwezi Road	1205
15	Rufunsa River at Janeiro	5948
16	Mulungushi River at Great North Road	5818
17	Luombe River at Chishimba Falls	6330
18	Kafulafuta River at Ibenga Mission	4205
19	Katete River at Katete Village	5554
20	Chipoma River at Chipoma falls	6242
21	Zambezi River at Kaleni hill	1080
22	Kanchibiya River at Mpika kasama Road	6500
23	Ng'ona River at Ntumbachushi	6790

5.2.3 Cluster 3 – C_3 Agro-ecological region II

This cluster had a membership comprising of rivers draining agro-ecological zone I (Figure 6). They have ephemeral characteristics and cease to flow in hot-dry seasons of every year within the window period of this research study and are shown in Table 4.

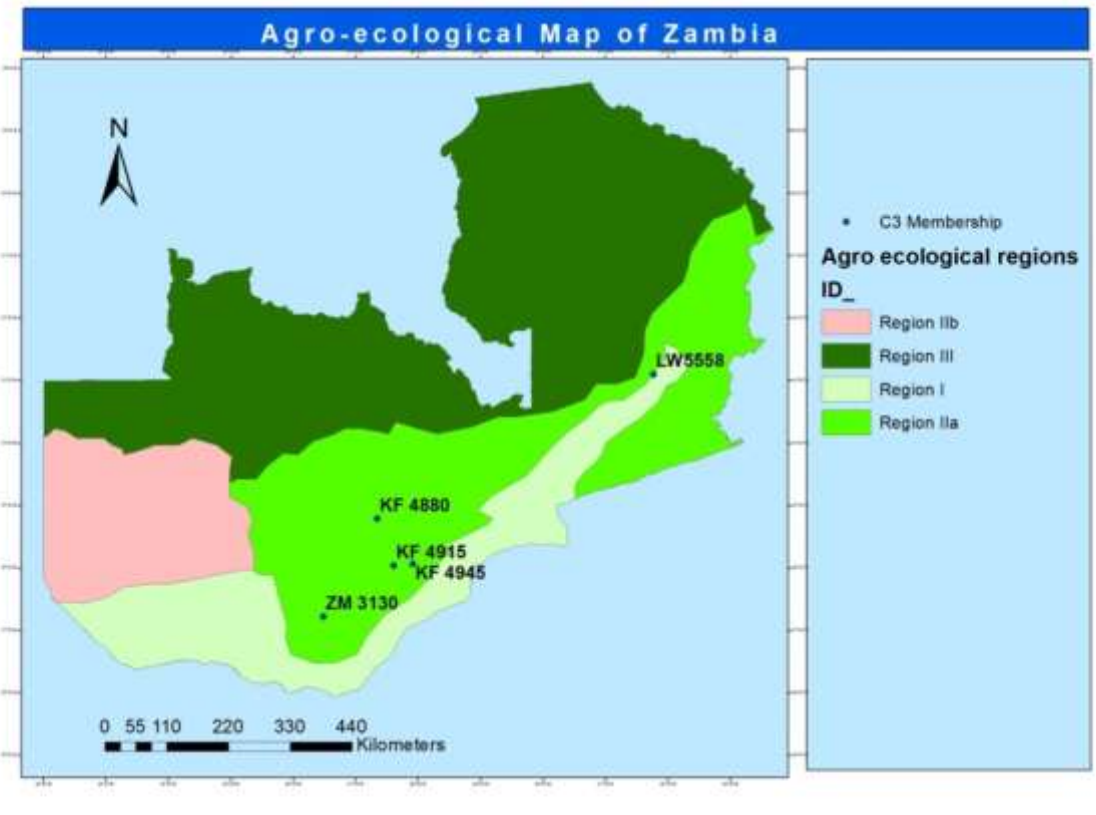

Figure 6: Map of Zambia showing position of membership of cluster 3 across agro-ecological regions.

Table 4: Summary of River stations in cluster C3.

No	Name of River and location	Station number
1	Kaleya River at Avillion Weir	4945
2	Nangoma River at Myooye	4880
3	Lutembwe River at Lutembwe Weir	5558
4	Chimbumbu River at Chimbumbu Farm	4915
5	Kalomo River at Kalomo Dam site	3130

5.2.3 Trend analysis

Time series trends were used to illustrate the general trends of precipitation, discharge and temperature over the temporal window period of the study. For instance, the time series trends of precipitation (Figure 7), discharge (Figure 8) and temperature (Figure 9) on the Kafue River at the Hook Bridge station.

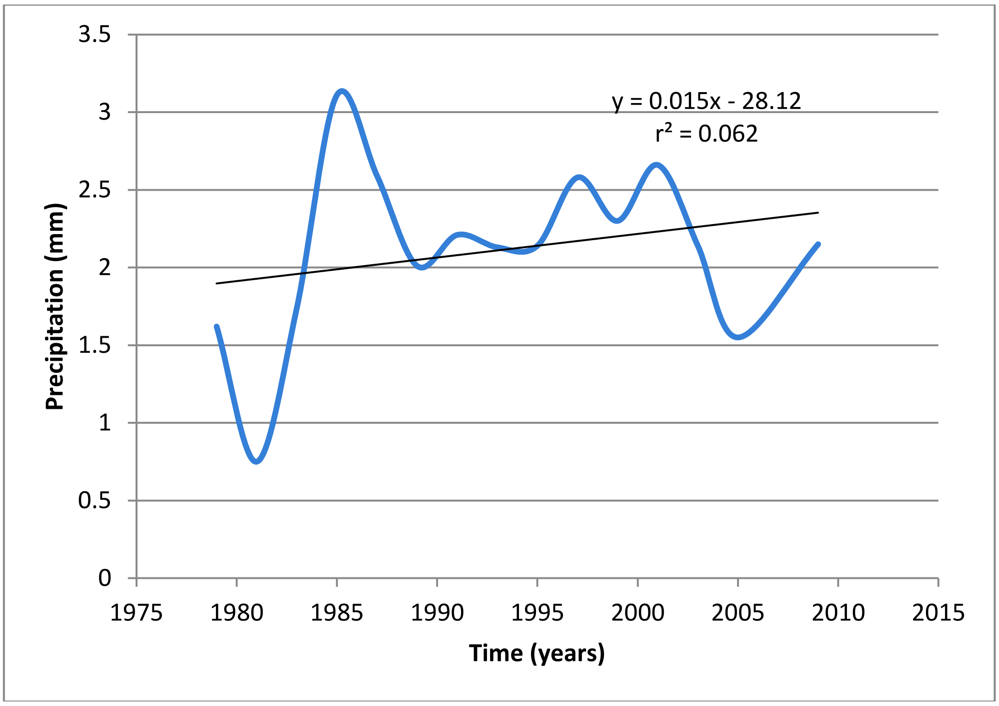

Figure 7: Time series precipitation trend on Kafue River at the Hook Bridge station

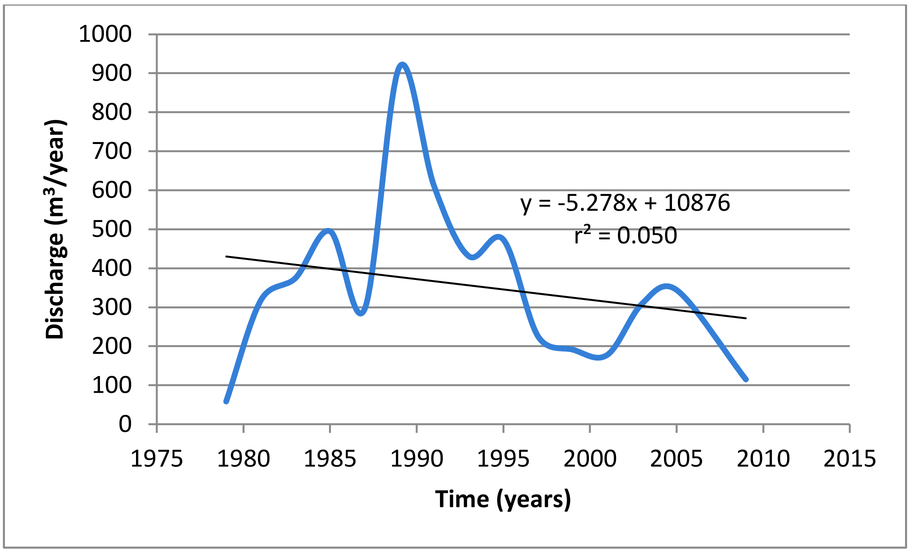

Figure 8: Time series discharge trend on Kafue River at the Hook Bridge station

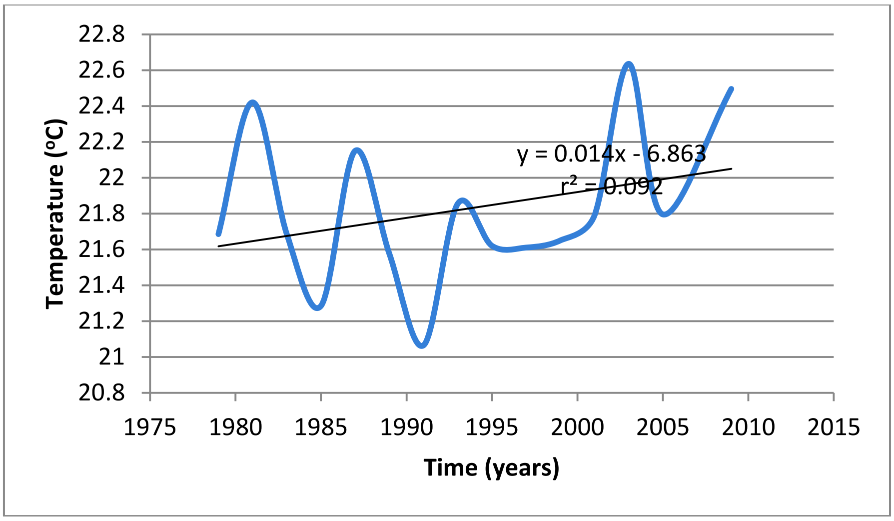

Figure 9: Time series temperature trend on the Kafue River at the Hook Bridge station

Going by the classification of stream flows, at least four samples were picked that had relatively better data trend (less filled gaps) from each cluster to represent the entire membership. P values were used to determine the linearity of temperature-precipitation and temperature-discharge relationships. If **P>0.5** it means that there is no linear relationship while if **P<0.5** there is a linear relationship. The r^2 values show percentage dependence of precipitation and discharge on temperature, for instance, the regression analyses on the trends illustrated in Figures 8 and 9 show that precipitation on Kaleya River at Avillion weir station is 21.6 percent dependent on temperature (Figure 8) while discharge on Kafue River at the Hook Bridge is 18.9 percent dependent on temperature (Figure 9).

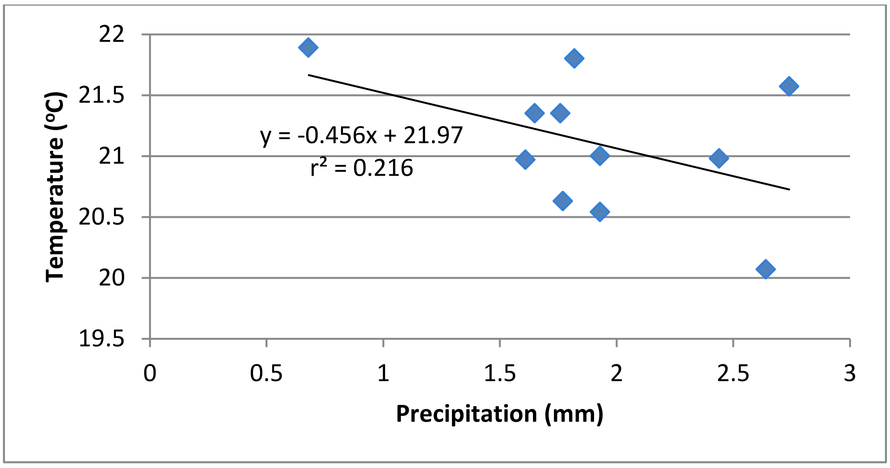

Figure 10: Linear relationship of average temperature and precipitation at Kaleya River at the avillion weir station

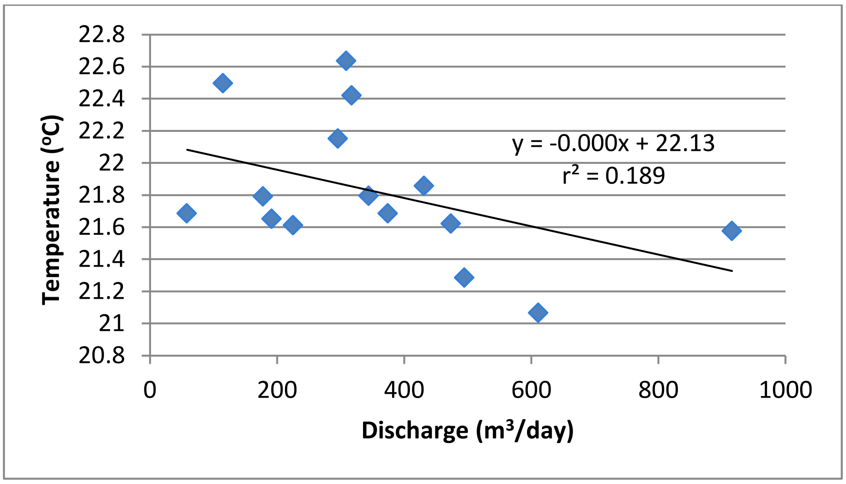

Figure 11: Linear relationship of average temperature and discharge at Kafue River at the Hook Bridge station

5.3 Results

The following results were obtained after doing the analysis.

5.3.1 Time series trends

Time series for temperature and precipitation showed positive trends across all cluster memberships. For discharge, flows in clusters C_1 and C_2 memberships showed negative trends while cluster C_3 membership showed a positive trend (Appendices 3 to 6).

5.3.2 Temperature-precipitation relationship

From the trend analysis conducted, all clusters – $C_{3,}$ C_2 and C_1 membership gave **P** values of less than 0.5, for temperature – precipitation relationship, therefore, the hypothesis that there is a linear relationship between temperature and precipitation for the rainfall and temperature is true. The relationship is negative.

5.3.2 Temperature-discharge relationship

For the temperature-discharge relationship, Stations members in clusters C_2 and C_1 gave ***P*** values of less than 0.5. There is a negative relationship between temperature and discharge for these stations, as discharge increases, temperature decreases.

However, **P** values for temperature - stream discharge relationship for membership of cluster C_3 were greater than 0.5. The hypothesis that there is a linear relation between temperature and stream flow for this group did not hold.

The regression analyses conducted on the cluster membership gave a range of **P** values (Table 5). Appendices 7, 8 and 9 give details of the summary outputs of the analyses.

Table 5: Summary results of P values for temperature-precipitation and temperature-discharge responses across the Three cluster memberships.

CLUSTER	**CLUSTER DESCRIPTION**	**RANGE OF P – VALUES**			
		Temperature-precipitation relationship	**No. Of members**	**Temperature-discharge relationship**	**No. Of members**
C_1	Representation of weather and hydrological data on rivers draining large surface areas	0.26 - 0.50	10	0.32 - 0.50	10
C_2	Representation of perennial rivers on agro-ecological zone III	0.13 - 0.50	23	0.60 – 0.87	18
C_3	Representation of weather and hydrological data on ephemeral streams within agro-ecological zone II	0.10 - 0.50	5	0.31 - 0.50	5

CHAPTER SIX: DISCUSSION OF RESULTS

6.1 Introduction

This chapter discusses the results presented in Chapter Five as follows; Time series trends of precipitation, discharge and temperature of each cluster, temperature-precipitation relationships and temperature discharge relationships.

6.2 Time series trends

The results obtained on time series analysis showed that average temperatures across all gauge stations for the temporal window period chosen for the study had an upward trend. This means that average temperatures have been permanently going upwards with time. While this has been the case over time, precipitation has shown a rise though in a diminishing trend. A critical review of the daily precipitation intensities shows that the number of rainy days annually had been decreasing with higher rainfall intensities being recorded in some days.

With river flows, rivers grouped in cluster 1 - C_1 showed downward flow trends in the temporal window period of the study. These rivers are generally of the highest catchment order thus defining the structural characteristics of catchments. Rivers such as the Kafue, the Chambeshi and the Luapula among others drain large catchment areas and their water surface areas are vulnerable to high evaporation. As temperatures go up, the rate of evaporation goes up. This explains the draw down over this temporal window period of 30 years.

Rivers in cluster 2 - C_2 showed an upward trend. These streams are perennial and only show signs of changes in dry cool seasons where temperatures are higher. About 87 percent of these streams are in agro-ecological zone III with average annual precipitation of 1500mm. Despite an upward trend in temperatures, the areas they drain receives more than enough rainfall to keep them flowing throughout the hydrological years.

Streams in cluster 3 - C_3 displayed a downward trend. This is typical of ephemeral streams whose flows largely depend on groundwater. They completely cease to flow in cool dry seasons and only resume flowing when water tables become high.

6.3 Temperature-precipitation relationship

The results for temperature-precipitation for all cluster memberships showed that there is a negative linear relationship. This entails that in seasons with higher temperatures there is less to no precipitation. Jain (2007) observed that as the temperatures rise to a certain peak, the ITCZ shifts to the zone of higher temperature and triggers the onset of precipitation. As rainfall intensifies the temperatures reduce. For this study, temperature somehow predicted precipitation on these stations.

6.4 Temperature-discharge relationship

Temperature – discharge relationship for membership of Clusters C_2 and C_1 gave ***P*** values of less than 0.5 with a negative relationship, therefore, the hypothesis that there is a linear relationship between the two variables has been proved. This has been partly supported by previous studies. Usually in Zambia, the hot and dry season were the country experiences high temperatures sees most of the rivers with minimum flows that are mostly due to base flow (Jain, 2007). During this period there are high levels of evaporation from water surface bodies due to low humidity levels and high temperatures. This induces high draw-down in rivers, streams and lakes thus the higher the seasonal temperatures, the lower the stream flows (Christensen *et al*. 2007 & Jain, 2007). For the output summary of the linear regression see Appendix 8b.

However, the hypothesis did not hold for cluster C_1 membership, therefore, there is no linear relationship between temperature and stream discharge. These streams are ephemeral and as such their flows will entirely depend on the sub-surface water (Kennard *et al* 2010), which is a function of precipitation rather than temperature. For the output summaries see Appendix 7b**.** Stream flows in ephemeral streams are not directly influenced by rainfall but rather by other factors such as base flows. During dry spells, the water tables experience a draw down beyond the surface levels making these streams dry. In wet seasons, the water tables start rising until they rise beyond the surface levels. This makes the streams flow once again.

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATIONS

This chapter highlights the conclusion drawn from the findings of the study. It also highlights the recommendations made.

7.1 Conclusion

Based on the results obtained from the study, despite the data having exhibited extraneous levels of single gaps that had to be filled by linear interpolation, the following were the findings.

Firstly, temperatures and precipitation across the country are rising with time. This is supported by studies that have reported that very large time series temporal windows indicate temperature rise.

Secondly, temperature is a relative predictor of precipitation and discharge (P values: 0.1 – 0.5) in streams across the country. This has been seen in almost all the clusters of hydrological and meteorological gauge stations used that showed similar trends. Temperature-precipitation relationship exhibits a negative linear trend in that during dry seasons, the temperatures are high across the country. In this period, there are no rains but as temperature gets higher and higher, this induces rainfall due to increased humidity in the air. As the rainfall intensifies, usually mid rainy season, temperatures start going down hence the negative relationship.

Thirdly, temperature predicts stream flow negatively in large rivers with greater catchment areas (>40,000km^2) across all agro-ecological zones and perennial rivers in Agro-ecological zone III. This has been attested by the trend and regression analyses conducted on such streams by the study. During hot and dry seasons when temperatures are high, large rivers have greater surface areas that are exposed to direct heat and sunlight. This induces high evaporation rates that take back large quantities of water to the atmosphere. This induces a huge draw down in these rivers reducing their flows.

Fourthly, temperature does not predict stream flow of ephemeral streams. The flow of these streams is dependent on base flows. The study consequently rejected the linearity between temperature and stream flow on some on the stations for the case of cluster C_2 gauge members. This means that precipitation

7.2 Recommendations

Based on the study findings, the following recommendations were formulated.

i. To carry out a comprehensive analysis of this nature, more parameters should be brought on board as temperature may not be the only weather predictor of precipitation and stream flow.

ii. Institutions with the responsibility of collecting weather data should not only put emphasis on precipitation data but also on these other parameters like intensity, humidity and evaporation.

iii. Institutions such as the ZMD, WARMA and DWA with the mandate to collect this information should make sure that consistent data is available for research purposes.

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APPENDIX

Appendix 1a: The metrics developed from the five indicators of hydrologic alterations using the flow data used in the study: Magnitude

STATION	CvMDF	BFI	CvBFI	LFQ10th	LFQ1st	HFQ90th	HFQ99th	FM1ARI	FM2ARI
7750	0.450	0.500	0.110	0.002	0.001	0.031	0.065	0.021	0.050
7021	0.220	0.080	0.050	0.014	0.009	0.034	0.046	0.030	0.041
7006	0.330	0.690	0.080	0.002	0.001	0.010	0.015	0.010	0.014
7005	0.210	0.710	0.060	0.002	0.001	0.008	0.011	0.007	0.011
6500	0.330	0.500	0.130	0.000	0.000	0.015	0.022	0.023	0.023
6486	0.330	0.590	0.060	0.004	0.003	0.044	0.051	0.047	0.051
6480	0.290	0.653	0.090	0.003	0.002	0.018	0.032	0.011	0.025
6330	0.370	0.670	0.100	0.003	0.001	0.021	0.034	0.017	0.028
6289	0.350	0.510	0.100	0.001	0.000	0.012	0.016	0.005	0.013
6242	0.250	0.530	0.060	0.004	0.002	0.038	0.062	0.066	0.070
6145	0.250	0.540	0.070	0.006	0.003	0.077	0.100	0.053	0.093
6140	0.230	0.580	0.060	0.002	0.001	0.014	0.020	0.014	0.019
6955	0.390	0.610	0.130	0.002	0.002	0.014	0.041	0.031	0.048
6910	0.670	0.870	0.110	0.016	0.005	0.273	0.317	0.097	0.146
6865	0.390	0.610	0.170	0.001	0.000	0.017	0.028	0.019	0.025
6860	0.210	0.720	0.060	0.003	0.002	0.011	0.017	0.010	0.016
6790	0.120	0.790	0.050	0.005	0.004	0.011	0.019	0.019	0.022
6765	0.350	0.500	0.100	0.000	0.000	0.014	0.030	0.023	0.028
6670	0.440	0.590	0.200	0.001	0.000	0.011	0.020	0.004	0.011
5554	0.061	0.934	0.027	0.003	0.003	0.004	0.006	0.001	0.001
5557	0.276	0.733	0.187	0.014	0.012	0.029	0.127	0.113	0.153
5818	0.510	0.496	0.191	0.001	0.000	0.010	0.031	0.022	0.032
5940	0.488	0.321	0.190	0.000	0.000	0.015	0.041	0.024	0.041
5948	0.471	0.697	0.118	0.000	0.000	0.001	0.001	0.001	0.002
5558	0.535	0.537	0.313	0.000	0.000	0.077	0.143	0.096	0.138
4350	0.345	0.507	0.088	0.001	0.001	0.014	0.018	0.008	0.015
4977	0.288	0.895	0.112	0.005	0.001	0.013	0.014	0.008	0.009
4669	0.489	0.504	0.103	0.001	0.000	0.009	0.022	0.008	0.014
4890	0.215	0.763	0.766	0.001	0.000	0.002	0.003	0.002	0.002
4205	0.621	0.496	0.224	0.000	0.000	0.007	0.019	0.006	0.014
4945	0.273	0.521	0.209	0.000	0.000	0.002	0.004	0.006	0.008
4310	0.403	0.527	0.210	0.001	0.001	0.020	0.028	0.020	0.026
4880	1.221	0.137	0.684	0.000	0.000	0.006	0.133	0.112	0.215
4915	0.067	0.300	0.426	0.000	0.000	0.004	0.017	0.018	0.024
3130	0.085	0.220	0.385	0.000	0.000	0.008	0.052	0.059	0.093
2360	0.166	0.964	0.015	0.000	0.000	0.000	0.000	0.000	0.000
1610	0.269	0.619	0.105	0.002	0.001	0.010	0.018	0.007	0.013
1315	0.384	0.522	0.103	0.001	0.000	0.023	0.033	0.024	0.029
1205	0.400	0.455	0.123	0.001	0.000	0.020	0.060	0.035	0.060
1080	0.211	0.703	0.046	0.005	0.003	0.024	0.032	0.006	0.025

Appendix 1b: The metrics developed from the five indicators of hydrologic alterations using the flow data used in the study: Frequency

STATION	LFspl10th	CvLF10th	LFspl1st	CvLF1st	HFspl90th	CvHFspl90th	HFspl99th	CvHF99st
7750	19.000	1.050	7.000	2.740	27.000	0.930	10.000	2.030
7021	17.000	0.850	8.000	1.580	27.000	0.870	7.000	2.800
7006	20.000	1.200	10.000	2.180	36.000	2.180	18.000	2.180
7005	34.000	0.810	6.000	1.800	43.000	1.800	17.000	1.800
6500	19.000	0.990	3.000	3.000	55.000	0.510	24.000	1.080
6486	27.000	0.780	5.000	2.100	30.000	0.840	14.000	1.140
6480	29.000	0.870	10.000	1.760	30.000	1.070	10.000	2.110
6330	8.000	1.530	7.000	2.420	28.000	0.890	13.000	2.100
6289	16.000	0.660	3.000	3.870	18.000	3.870	9.000	1.770
6242	16.000	0.780	3.000	2.080	93.000	0.400	30.000	1.030
6145	20.000	0.710	3.000	2.150	20.000	0.610	8.000	1.510
6140	18.000	0.580	8.000	1.580	30.000	0.660	11.000	1.100
6955	19.000	1.310	11.000	1.570	65.000	1.570	15.000	1.570
6910	5.000	1.810	1.000	3.610	10.000	1.380	6.000	2.450
6865	16.000	1.240	5.000	1.620	23.000	0.720	8.000	2.490
6860	22.000	0.640	10.000	1.370	39.000	0.730	11.000	1.760
6790	32.000	0.930	7.000	1.770	138.000	0.420	29.000	1.120
6765	13.000	0.910	4.000	3.000	37.000	0.560	10.000	1.790
6670	7.000	1.080	2.000	2.650	9.000	0.880	4.000	2.240
5554	26.000	1.077	3.000	2.894	79.000	0.584	29.000	1.141
5557	83.000	0.870	21.000	1.304	48.000	0.650	11.000	0.909
5818	11.000	1.095	2.000	2.000	44.000	0.563	14.000	1.895
5940	10.000	1.204	5.000	2.182	38.000	0.664	13.000	1.321
5948	22.000	1.120	7.000	1.464	43.000	0.581	17.000	1.041
5558	30.000	0.954	30.000	0.954	81.000	0.548	18.000	1.252
4350	10.000	0.816	3.000	2.000	11.000	0.782	2.000	2.550
4977	7.000	1.895	2.000	3.742	18.000	2.223	2.000	2.550
4669	12.000	0.816	4.000	1.658	20.000	0.707	2.000	3.742
4890	10.000	0.548	1.000	3.464	5.000	1.265	3.000	3.464
4205	13.000	1.252	8.000	1.953	31.000	0.822	11.000	2.051
4945	45.000	0.489	18.000	0.598	82.000	0.291	27.000	0.500
4310	18.000	0.952	3.000	2.809	32.000	0.661	11.000	1.429
4880	10.000	1.781	7.000	2.039	60.000	0.599	14.000	1.770
4915	20.000	1.229	17.000	1.114	68.000	0.591	22.000	1.203
3130	13.000	0.422	13.000	0.422	62.000	0.744	20.000	1.118
2360	8.000	1.788	8.000	3.873	18.000	1.291	8.000	1.871
1610	15.000	1.000	4.000	2.458	21.000	0.795	3.000	2.082
1315	13.000	1.002	4.000	1.768	25.000	0.426	7.000	1.385
1205	16.000	0.923	5.000	2.366	40.000	0.592	8.000	1.510
1080	47.000	0.786	6.000	2.281	91.000	0.480	27.000	0.804

Appendix 1c: The metrics developed from the five indicators of hydrologic alterations using the flow data used in the study: Duration

STATION	No.0Qs	CvNo.0Qs	HFsplDur.90th	CvHFsplDur.90th	HFsplDur.99th	CvHFsplDur.99th
7750	0.000	0.000	22.826	0.749	5.500	0.510
7021	0.000	0.000	24.333	1.232	8.143	1.039
7006	0.000	0.000	18.484	1.504	3.375	0.900
7005	0.000	0.000	14.657	1.122	3.000	0.602
6500	44.000	2.940	10.058	0.508	2.364	0.644
6486	0.000	0.000	19.429	0.863	4.583	0.619
6480	0.000	0.000	22.560	0.823	5.100	0.492
6330	0.000	0.000	21.257	0.693	4.538	0.283
6289	0.000	0.000	32.278	0.451	6.444	1.267
6242	0.000	0.000	6.449	0.483	1.966	0.413
6145	0.000	0.000	29.100	0.659	7.375	0.854
6140	0.000	0.000	17.714	0.756	4.364	0.709
6955	0.000	0.000	6.537	0.851	2.857	0.603
6910	0.000	0.000	63.875	1.255	8.667	1.218
6865	0.000	0.000	23.522	0.485	8.167	0.286
6860	0.000	0.000	14.711	0.615	5.200	0.407
6790	31.000	3.000	4.282	0.486	1.957	0.568
6765	0.000	0.000	10.971	1.103	4.000	0.788
6670	0.000	0.000	68.500	0.475	14.000	0.711
5554	0.000	0.000	5.709	1.561	1.621	0.255
5557	0.000	0.000	9.729	1.065	4.545	0.988
5818	0.000	0.000	11.614	1.630	3.286	0.483
5940	61.000	2.354	14.342	0.706	4.385	0.691
5948	0.000	0.000	11.349	1.194	2.588	0.411
5558	1108.000	1.288	6.580	1.856	3.000	0.860
4350	0.000	0.000	49.818	0.567	27.500	0.855
4977	0.000	0.000	28.278	0.557	27.000	0.296
4669	0.000	0.000	26.950	0.975	26.500	0.000
4890	0.000	0.000	95.000	0.273	15.667	0.000
4205	0.000	0.000	15.871	1.387	4.364	0.516
4945	164.000	1.014	3.829	1.510	1.222	0.158
4310	0.000	0.000	17.750	0.793	5.091	0.477
4880	250.000	2.153	7.667	0.910	3.500	0.549
4915	1045.000	1.499	7.779	0.915	2.318	0.402
3130	1123.000	0.770	7.855	0.701	2.400	0.423
2360	0.000	0.000	32.333	0.994	7.000	0.495
1610	0.000	0.000	28.857	0.491	21.000	0.739
1315	0.000	0.000	16.680	0.844	6.429	0.890
1205	0.000	0.000	13.700	0.945	6.500	0.967
1080	0.000	0.000	5.044	0.772	1.963	0.680

Appendix 1d: The metrics developed from the five indicators of hydrologic alterations using the flow data used in the study: Timing

STATION	STATION NAME	Jul.DMax	CvJul.DMax	Jul.DMin	CvJul.DMin
7750	Lufubu River at Keso	81.560	0.250	288.000	0.060
7021	Lucheche River below lake Chila	116.750	0.490	268.310	0.120
7006	Lunzua River at weir	92.560	0.170	311.630	0.080
7005	Lunzua River at Kambole Rd Bridge	90.690	0.280	302.250	0.070
6500	Kanchibiya river at Mpika/Kasama Rd Br.	66.940	0.230	299.500	0.070
6486	Klwitikila River at Mpika Road Bridge	69.070	0.350	298.200	0.060
6480	Lwitikila River at Lwitikila Falls	70.190	0.330	296.000	0.080
6330	Luombe River at Chishimba Falls	66.690	0.520	292.500	0.060
6289	Chambeshi River at old Pontoon	95.750	0.220	297.000	0.070
6242	Chipoma River at Chipoma Falls	48.310	0.660	295.440	0.090
6145	Chambeshi River at Mbesuma pontoon	78.730	0.350	298.200	0.060
6140	Chambeshi River at Chandaweyaya	79.930	0.310	300.210	0.070
6955	Mukubwe River at Kambasa	95.250	0.220	284.830	0.050
6910	Chisela River at Bulaya Pontoon	197.210	0.390	293.930	0.080
6865	Kalungwishi River at Chimpempe Bridge	82.070	0.290	290.710	0.050
6860	Luangwa River at Mumbuluma Falls	84.310	0.240	288.130	0.080
6790	Ng'ona River near Ntumbachushi Falls	64.380	0.590	283.130	0.050
6765	Lufubu River at Chipili	67.000	0.360	293.200	0.060
6670	Luapula River at Chembe ferry	116.000	0.540	306.310	0.090
5554		58.067	1.138	283.200	0.181
5557	Msipazi at Chadidza Road Bridge	263.154	0.331	78.538	1.439
5818	Mulungushi river at G.North Road Bridge	49.400	0.450	299.200	0.075
5940	Luangwa River at Great East road Bridge	77.000	0.640	303.500	0.054
5948	Rufunsa river at Janeiro Village	39.071	0.903	302.643	0.246
5558	Kova/Kova Drift D/S	70.062	0.608	280.500	0.159
4350	Kafue River at Chilenga	83.467	0.209	301.133	0.056
4977	Kafue River at kasaka	167.067	0.567	78.667	1.489
4669	Kafue River at the Hook Bridge	77.067	0.268	295.800	0.068
4890	Kafue River at Nyimba	128.308	0.339	319.846	0.171
4205	Kafulafuta River at Ibenga Mission	58.642	0.427	297.929	0.108
4945	Kaleya River at Avillion Weir	21.800	2.033	281.400	0.205
4310	Luswishi River at Kilundu	72.750	0.287	301.812	0.065
4880	Nangoma River at Myooye	51.400	0.571	281.000	0.183
4915	Magoye River at Chimbumbu Farm	42.312	0.823	299.562	0.091
3130	Kalomo River at Kalomo Dam Site	38.067	0.809	271.533	0.075
2360	Kataba River at Siandi Road Bridge	42.000	0.805	292.875	0.072
1610	Kabompo River at Manyinga Road Bridge	88.250	0.134	288.000	0.059
1315	E. Lumwana River at Solwezi-Mwinilunga	93.727	0.639	306.273	0.049
1205	Kabompo River at Solwezi Mwinilunga Br.	69.067	0.378	282.333	0.050
1080	Zambezi at Kaleni Hill Road Bridge	68.188	0.440	274.500	0.097

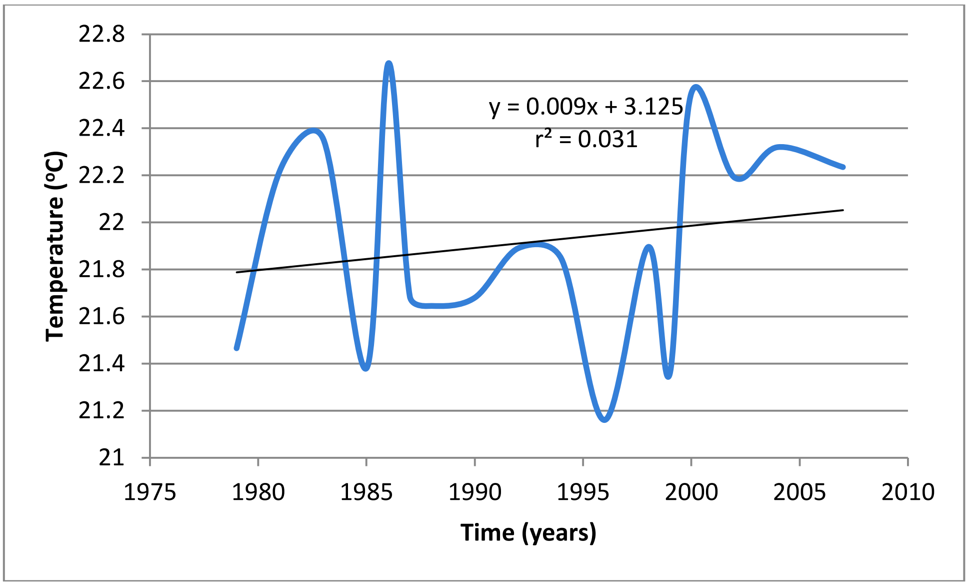
Appendix 1e: The metrics developed from the five indicators of hydrologic alterations using the flow data used in the study: Rate of change in flow events.

STATION	STATION NAME	RiseRate	CvRiseRate	Fallrate	CvFallrate
7750	Lufubu River at Keso	0.0010	0.6300	0.0010	0.6800
7021	Lucheche River below lake Chila	0.0010	0.5600	0.0010	0.5200
7006	Lunzua River at weir	0.0000	0.3100	0.0000	0.3400
7005	Lunzua River at Kambole Rd Bridge	0.0000	0.2700	0.0000	0.2900
6500	Kanchibiya river at Mpika/Kasama Rd Br.	0.0010	0.4700	0.0000	0.2900
6486	Klwitikila River at Mpika Road Bridge	0.0010	0.3500	0.0010	0.3000
6480	Lwitikila River at Lwitikila Falls	0.0010	0.5200	0.0010	0.5300
6330	Luombe River at Chishimba Falls	0.0010	0.6400	0.0000	0.5800
6289	Chambeshi River at old Pontoon	0.0000	1.5000	0.0000	1.2500
6242	Chipoma River at Chipoma Falls	0.0030	0.4600	0.0030	0.5200
6145	Chambeshi River at Mbesuma pontoon	0.0010	0.9600	0.0000	0.6300
6140	Chambeshi River at Chandaweyaya	0.0000	0.2600	0.0000	0.2600
6955	Mukubwe River at Kambasa	0.0020	0.5500	0.0010	0.5800
6910	Chisela River at Bulaya Pontoon	0.0010	1.3700	0.0010	1.1100
6865	Kalungwishi River at Chimpempe Bridge	0.0000	0.4500	0.0000	0.3100
6860	Luangwa River at Mumbuluma Falls	0.0000	0.4900	0.0000	0.3900
6790	Ng'ona River near Ntumbachushi Falls	0.0010	0.3400	0.0010	0.5900
6765	Lufubu River at Chipili	0.0010	0.5800	0.0010	0.7500
6670	Luapula River at Chembe ferry	0.0000	0.6300	0.0000	0.6000
5554		0.0000	0.6440	0.0000	0.6770
5557	Msipazi at Chadidza Road Bridge	0.0020	0.5900	0.0010	0.6090
5818	Mulungushi river at G.North Road Bridge	0.0010	0.7840	0.0010	0.8760
5940	Luangwa River at Great East road Bridge	0.0010	0.7770	0.0010	0.8790
5948	Rufunsa river at Janeiro Village	0.0000	0.4250	0.0000	0.4980
5558	Kova/Kova Drift D/S	0.0120	0.3320	0.0090	0.3980
4350	Kafue River at Chilenga	0.0000	0.4310	0.0000	0.5210
4977	Kafue River at kasaka	0.0000	0.3100	0.0000	0.3280
4669	Kafue River at the Hook Bridge	0.0000	0.6850	0.0000	0.8850
4890	Kafue River at Nyimba	0.0000	0.6910	0.0000	0.4620
4205	Kafulafuta River at Ibenga Mission	0.0000	0.6680	0.0000	0.9400
4945	Kaleya River at Avillion Weir	0.0010	0.2600	0.0000	0.2280
4310	Luswishi River at Kilundu	0.0000	0.4740	0.0000	0.2690
4880	Nangoma River at Myooye	0.0050	1.0440	0.0040	1.1350
4915	Magoye River at Chimbumbu Farm	0.0010	0.6210	0.0010	0.6390
3130	Kalomo River at Kalomo Dam Site	0.0040	0.7550	0.0030	0.7910
2360	Kataba River at Siandi Road Bridge	0.0000	0.4860	0.0000	0.2620
1610	Kabompo River at Manyinga Road Bridge	0.0000	0.3190	0.0000	0.1340
1315	E. Lumwana River at Solwezi-Mwinilunga	0.0010	0.3560	0.0020	2.4330
1205	Kabompo River at Solwezi Mwinilunga Br.	0.0010	0.5340	0.0010	0.0600
1080	Zambezi at Kaleni Hill Road Bridge	0.0010	0.3170	0.0010	0.3890

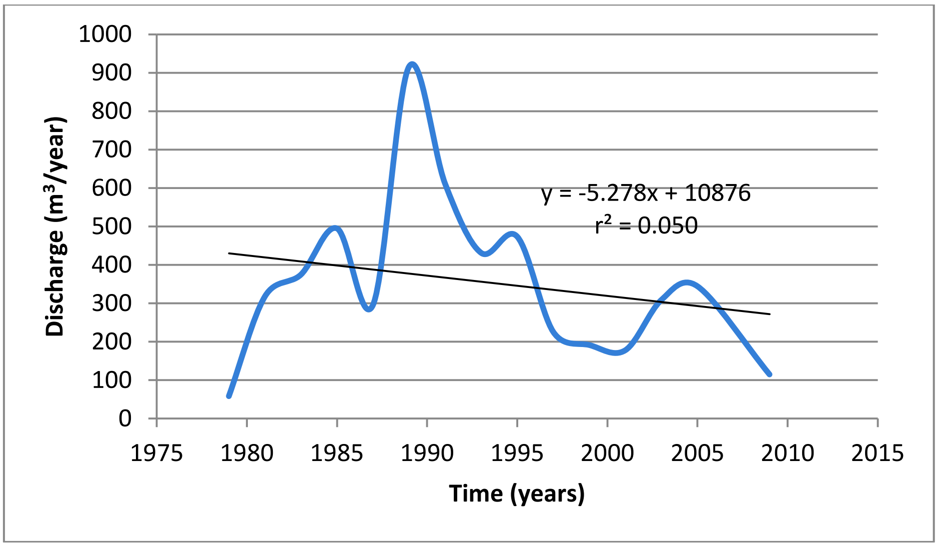
Appendix 2: The coordinates and codes for the weather stations and the corresponding hydrometric station codes with their coordinates

UTM Location		Weather station Number	Corresponding hydrometric		UTM Location	
X	Y		Number	Name	X	Y
30.9375	-11.0841	111309	CH 6480	Lwitikila River at Lwitikila falls	30.9355	-11.0915
31.5625	-9.8352	98316	CH 6140	Chambeshi River at Chandaweyaya	31.6829	-9.7887
32.1875	-10.7719	108322	CH 6145	Chambeshi river at Mbesuma pontoon	32.1667	-10.8515
29.0625	-10.7719	108291	LP 6765	Lufubu River at Chipili	29.0945	-10.7298
28.75	-9.8352	98288	LP 6790	Ng'ona River at Ntumbachushi	28.9641	-9.8536
28.75	-10.7719	108288	LP 6860	Luangwa River at Mbumbulu	28.7361	-10.9305
29.6875	-9.2108	92297	LP 6955	Mukubwe River at Kambasa	29.5407	-9.0333
28.75	-12.0208	120288	LP 6670	Luapula River at Chembe ferry	28.7363	-11.9817
29.375	-9.5229	45294	LP 6865	Kalungwishi River at Chimpempe	29.4491	-9.5515
30.9375	-8.8985	89309	TG 7750	Lufubu River at Keso	30.5889	-8.6898
31.25	-8.8985	89313	TG 7021	Lucheche River below Lake Chila	31.3801	-8.8357
30.9375	-14.2064	142309	LW 5818	Mulungushi River at GN road	28.549	-14.2964
30.3125	-14.5186	145303	LW 5948	Rufunsa River at Janeiro	30.3028	-14.5851
28.125	-15.7626	158281	KF 4977	Kafue River at Kasaka	28.207	-158303
25.9375	-14.8309	148259	KF 4669	Kafue River at Hook Bridge	25.9142	-14.9465
27.5	-13.8942	139275	KF 4350	Kafue River at Chilenga	27.4253	-13.8972
23.125	-15.4553	155231	ZM 2360	Kataba River at Siandi Bridge	23.2833	-15.5676
26.5625	-16.7042	167266	ZM 3130	Kalomo River at Kalomo Dam site	26.4833	-16.7833
27.8125	-15.7676	158278	KF 4945	Kaleya River at Avillion Weir	27.9163	-15.9363
27.5	-15.1431	151275	KF 4880	Nangoma River at Myooye	27.3433	-15.9363
24.375	-11.3964	114244	ZM 1080	Zambezi River at Kaleni Hill	24.2429	-11.1316
25.3125	-11.3964	114253	ZM 1205	Kabompo River at Solwezi Road	25.2061	-11.5957
25	-12.333	123250	ZM 1315	E. Lumwana River at Mwinilunga Bridge	25.1707	-12.2528

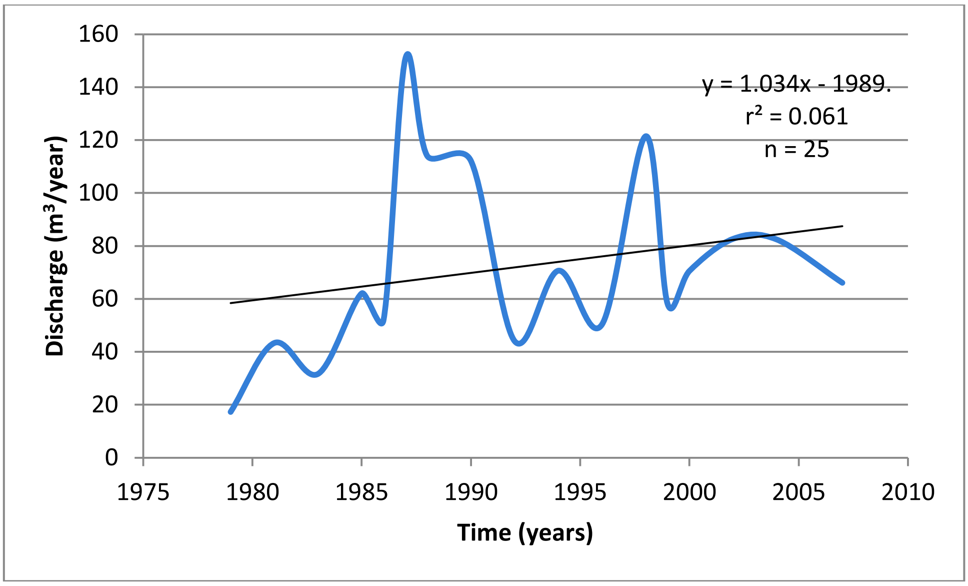
Appendix 3: Time series trend of temperature, a picture of all clusters - Lufubu River at Keso station



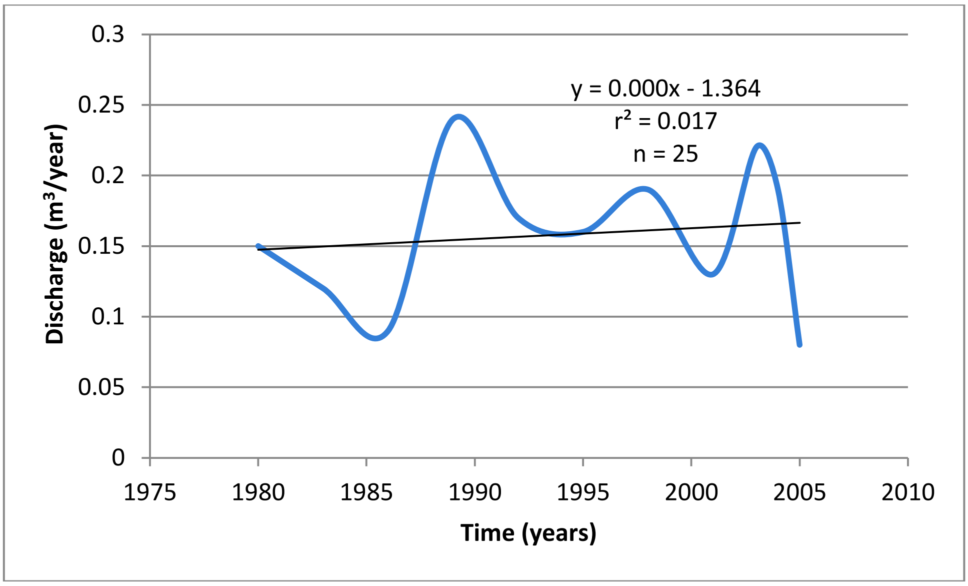
Appendix 4: Discharge time series trend on Kafue River at the hook bridge station – case of cluster C_1 membership



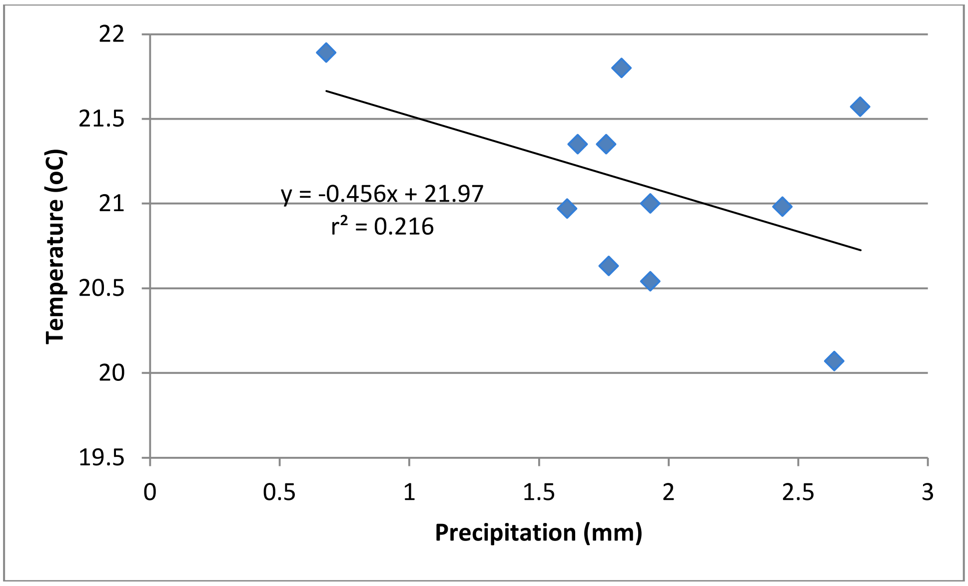
Apendix 5: Discharge time series trend on ufubu River at Keso station – a case of cluster C_2 membership



Appendix 6: Discharge time series trend on Kaleya river at Avillion Weir – a case of cluster C_1 membership



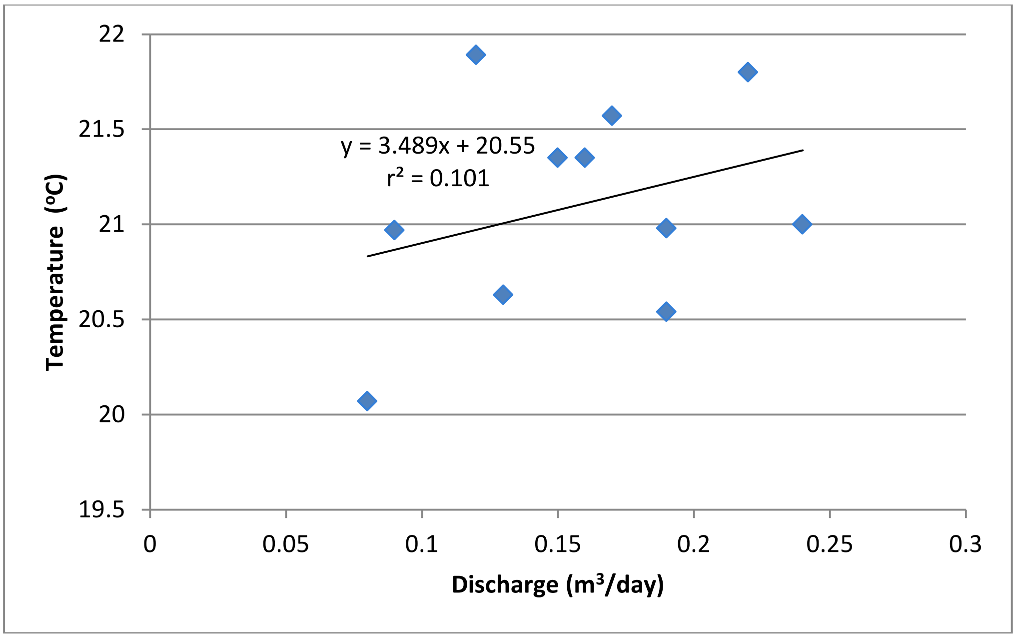
Appendix 7a: Graph and summary regression results showing the linearity of temperature-precipitation trend, Kaleya River at Avillion Weir (situation for cluster – 3)



Summary output regression table for Kaleya River for average temperature-precipitation at Avillion Weir station

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.47					
R Square	0.22					
Adjusted R Square	0.13					
Standard Error	0.52					
ANOVA						
	df	**SS**	**MS**	**F**	**Significance F**	
Regression	1	0.67	0.67	2.49	0.15	
Residual	9	2.43	0.27			
Total	10	3.1				
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
Intercept	21.97	0.57	38.35	0	20.68	23.27
X Variable 1	-0.46	0.29	-1.58	**0.15**	-1.11	0.2

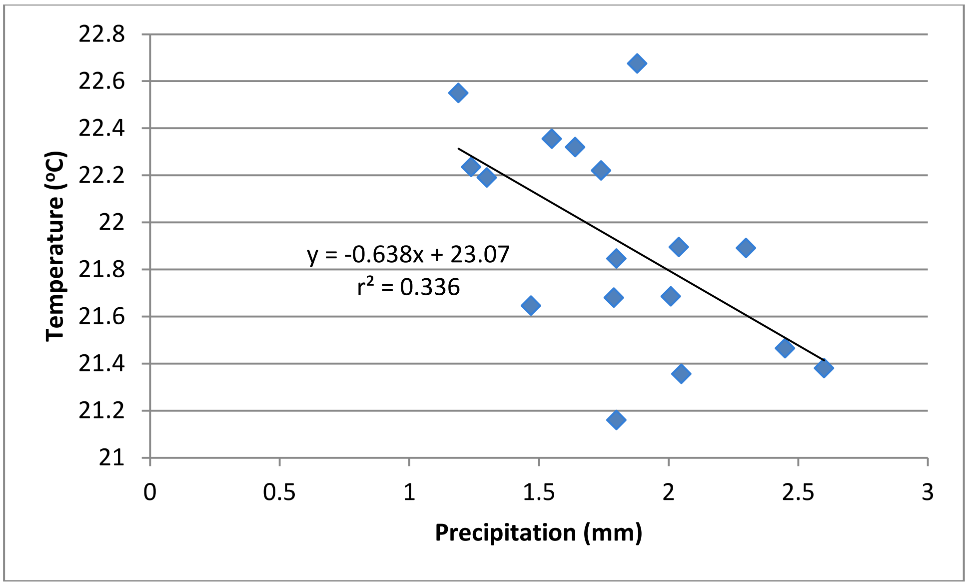
Appendix 7b: Graph and summary regression results showing the linearity of temperature-Discharge trend, Kaleya River at Avillion Weir (situation for cluster – 3)



Summary output table for Kaleya River station for average temperature-discharge at Avillion Weir station

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.32					
R Square	0.1					
Adjusted R Square	0					
Standard Error	0.56					
ANOVA						
	df	SS	MS	F	Significance F	
Regression	1	0.31	0.31	1.01	0.34	
Residual	9	2.78	0.31			
Total	10	3.1				
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
Intercept	20.55	0.57	35.86	0	19.26	21.85
X Variable 1	3.49	3.46	1.01	**0.34**	-4.35	11.33

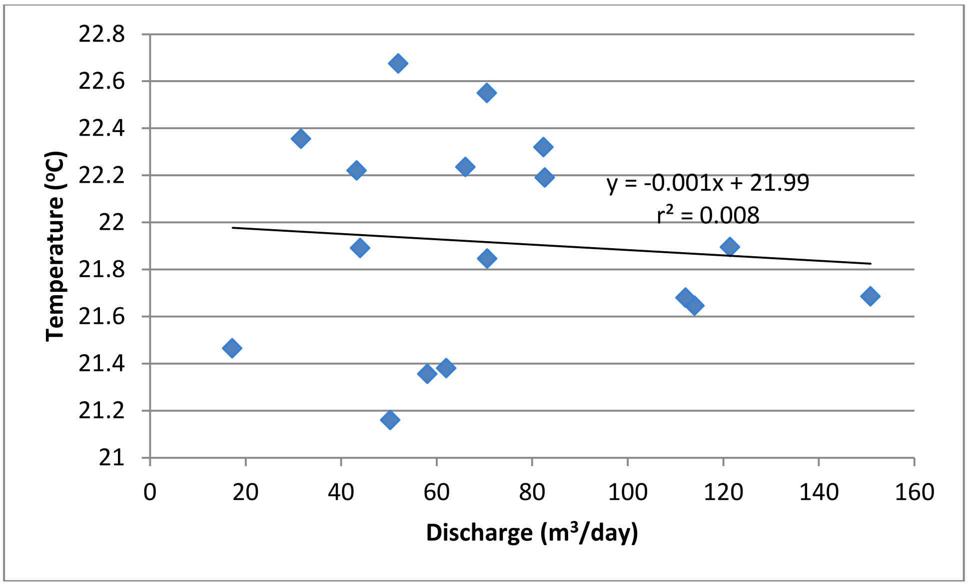
Appendix 8a: Graph and summary regression results showing the linearity of temperature-precipitation trend, for Lufubu River station at Keso (situation for cluster – 2)



Summary output regression table for the Kafubu River at Keso Station (temperature-precipitation)

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.58					
R Square	0.34					
Adjusted R Square	0.29					
Standard Error	0.37					
ANOVA						
	df	SS	MS	F	Significance F	
Regression	1	1.07	1.07	7.62	0.01	
Residual	15	2.1	0.14			
Total	16	3.17				
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
Intercept	23.07	0.43	53.7	**0**	22.16	23.99
X Variable 1	-0.64	0.23	-2.76	**0.01**	-1.13	-0.15

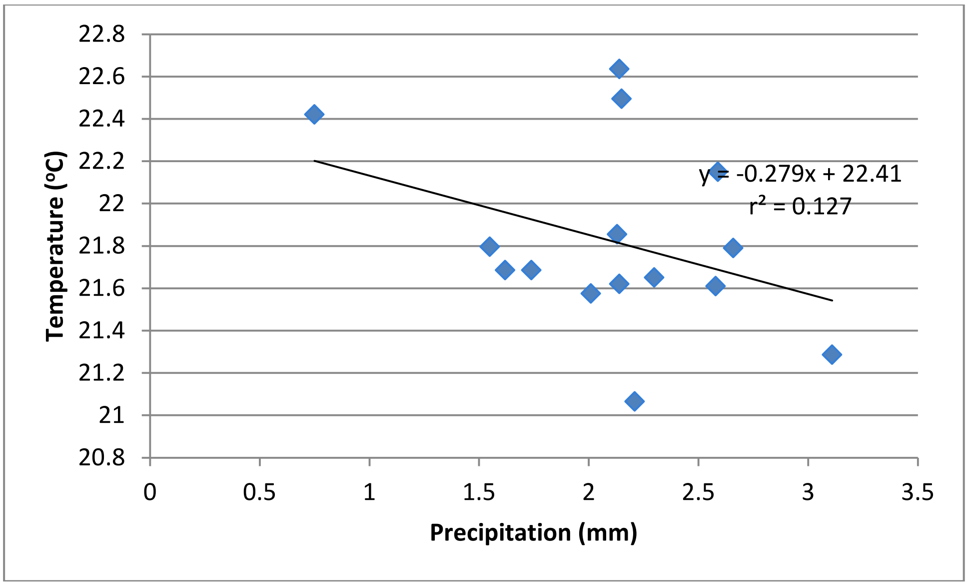
Appendix 8b: Graph and summary regression results showing the linearity of temperature-discharge trend for Kafubu River at Keso station (situation for cluster – 2)



Summary output regression table for the Kafubu River at Keso Station (temperature-discharge)

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.09					
R Square	0.01					
Adjusted R Square	-0.06					
Standard Error	0.46					
ANOVA						
	df	**SS**	**MS**	**F**	**Significance F**	
Regression	1	0.03	0.03	0.12	0.73	
Residual	15	3.14	0.21			
Total	16	3.17				
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
Intercept	22	0.26	84.34	0	21.44	22.55
X Variable 1	0	0	-0.35	**0.73**	-0.01	0.01

Appendix 9a: Graph and summary regression results the linearity of temperature-precipitation trend for Kafue River station at the Hook Bridge (situation for cluster – 1)

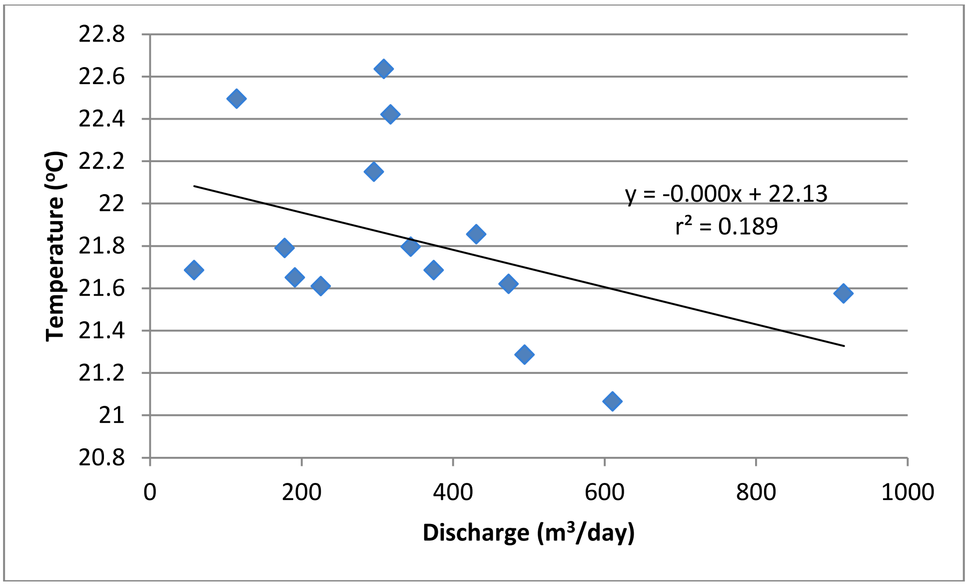


Summary output regression table for the Kafue Hook Bridge Station (temperature-precipitation)

SUMMARY OUTPUT

Regression Statistics								
Multiple R	0.36							
R Square	0.13							
Adjusted R Square	0.06							
Standard Error	0.42							
ANOVA								
	df	**SS**	**MS**	**F**	**Significance F**			
Regression	1	0.34	0.34	1.90	0.19			
Residual	13	2.32	0.18					
Total	14	2.66						
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**	**Lower 95.0%**	**Upper 95.0%**
Intercept	22.41	0.44	50.80	0.00	21.46	23.36	21.46	23.36
X Variable 1	-0.28	0.20	-1.38	**0.19**	-0.72	0.16	-0.72	0.16

Appendix 9b: Graph and summary table showing the linearity of temperature-discharge trend for Kafue River station at the Hook Bridge (situation for cluster – 1)



Summary output regression table for the Kafue Hook Bridge Station (temperature-discharge)

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.43					
R Square	0.19					
Adjusted R Square	0.13					
Standard Error	0.41					
Observations	15					
ANOVA						
	df	**SS**	**MS**	**F**	**Significance F**	
Regression	1	0.5	0.5	3.03	0.11	
Residual	13	2.16	0.17			
Total	14	2.66				
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
Intercept	22.13	0.21	106.19	0	21.68	22.58
X Variable 1	0	0	-1.74	0.11	0	0