ABSTRACT

Climate change according to IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This study focused on assessing rainfall and runoff data of a micro catchment in the Odzi sub catchment to see if any trends existed and how far the results would explain climate change. The main river in the subcatchment is the Odzi River. Total catchment area is 2 486 km^2.

For runoff, this study dealt with 5 stations. Of the five stations, only station E32 showed a significant change (p=0.04) in runoff over time. The rest of the stations had no significant downward trends at 95% confidence level. A further analysis into the possible causes of this difference was done by looking at land use patterns in the catchment area supplying flows through station E32. This particular station is on the irrigation board of the Odzani river. Thus, this decline is most likely explained by an increase in abstructions by irrigators.

For rainfall, this study dealt with 4 stations. Rusape and Odzi Police rail stations showed no significant change in rainfall over the 1959-2006 period. Mukandi showed a negative trend or drop in rainfall over the same period of 1959-2006. However, Nyanga station showed a rising trend in rainfall over the same period. Such a variation within the same catchment is expected under the given conditions of global and local temperature rises or it could merely be because of spatial variation. Therefore, this could be the reason for decline in rainfall over station Mukandi and an upward trend over Nyanga. However, a further study is necessary to establish the main causes of these two contrasting outcomes.

The Sub Catchment has an estimated population of 33409. It was calculated that 24206 persons of an estimated total population of 33409 could be sustained with life line water in the sub catchment. Therefore, these results show that the water situation in the sub-catchment is stressed. About 9000 out of about 34000 persons cannot be sustained (life line) by the available surface water. Further on, with the increase in population and the factoring in of water requirements by food grown, this figure could be seen going up.

DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgement has been made in the text.

Signature………………….Name………………………………Date

ACKNOWLEDGEMENTS

All blessings, and honour, and glory, and power be unto the Ancient of Days from this time hence forth and forever, amen and amen. He maketh all things beautiful in their time. He gave me this master's programme and took care of me through out my studies. Many prayers have been offered by the Hatcliffe congregation for me to sail through on this endeavor.

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DEDICATION

This work is dedicated to my two boys Joshua and Caleb Nyasha Nyoni and their mother (Dorcas) who were a source of inspiration and comfort-They form my home. I also dedicate this piece of work to my Parents, Parents in-law and my uncle DT Rwafa. They support progress and encouraged me to take up the programme.

LIST OF ACRONYMS

IPCC	Inter-Governmental Panel on Climate Change
WMO	World Meteorological Organisation
ZINWA	Zimbabwe National Water Authority
GHG	Green house gases

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CHAPTER 1
INTRODUCTION

1.1Background

One of the most significant impacts of global climate change will be on the hydrological system and hence the river flows and available water resources. (Alemaw and Chaoka, 2002).

Berham (1999) and Berham et al. (2001) found a recent decrease in mean annual runoff in Southern African catchments that occurred since 1975, particularly marked in Zambia, Angola, Mozambique and South African High Veldt. They attributed this decline mainly to declining rainfall as well as population increase and changing land use and water use patterns.

According to the Intergovernmental Panel on Climate Change (IPCC, 1995, 2001), global mean temperatures have risen 0.3-0.6 ºC since the late 19^{th} century and global sea levels have risen between 10 and 25 cm. Furthermore, recent studies on Climate change in Southern Africa have revealed that there is warming of almost 1ºC with high rainfall variability (±30%) accompanied by recent droughts of 1992 and 1995, which have highlighted the sensitivity of the region's water resources to variations of climate (Hulme et al,1996).

Long-term observations also suggest that temperatures have increased 0.5°C over the past 100 years, that the seasonality of rainfall is changing, and that annual flows of some rivers such as the Zambezi are declining. Droughts appear to be increasing in frequency and severity (Bergkamp et al, 2003). It is therefore evident that truly temperatures are going up according to the cited sources which result in extreme weather conditions like floods and droughts. This is supported below.

Bergkamp et al, (2003) went on to say that the region is starting to experience intense flooding, a phenomenon that is inconsistent with the long-term climate of the region. Between 1999 and 2002, the region was hit by a series of intense rainfall episodes including *tropical cyclone Connie* that produced the worst flood in 50 years. Two weeks later, *tropical cyclone Elaine* further inundated the region, causing extensive flooding in the Limpopo River Basin. Such an event is supposed to occur only once every thousand years. The overall conclusion is that Southern Africa is facing more and more climate variability.

Literature has it that since 1990, there have been over 30 floods worldwide, in each of which material losses exceeded one billion US$ and /or the number of fatalities was greater than one thousand. The highest material flood losses, of the order of 30 billion US$, were recorded in China in the summer of 1998 (26.5 billion US$ in 1996), while the storm surge in Bangladesh during two days of April 1991 caused the highest number of fatalities (140000) (Kundzewicz et al, 2004)

The impact of climate change on water resources through increased evaporation (due to global warming as shown above) combined with regional changes in precipitation characteristics (such as total amount, variability, frequency of extremes) has been found to have the potential to affect mean runoff, the frequency and intensity of floods and droughts, soil moisture and water supply for irrigation and hydro-electrical power (Pankaj etal, 2005)

Thus, this study shall concentrate on analysing rainfall and runoff data with regards to climate change. These two factors are linked to climate change as has been highlighted above.

Furthermore, Dublin principle number one states that water is finite, vulnerable and an essential resource which should be managed in an integrated manner (ICWE, 1992). Also according to Steyl et al, (n.d), water is one of the key natural resources available to human kind whose scarcity can be seen as the most limiting factor to economic growth and social development. It is therefore compelling for this current study to seek to find possible interventions or adaptation techniques to the curb the threat posed on human beings and their economic and social development if climate change is found to be evident in the area of study.

Kundzewcz et al, (2004) also asserted that detection of changes in long time series of hydrological data is an important scientific issue: It is necessary if we are to establish the true effect of climate change on our hydrological systems, and it is fundamental for planning of future water resources and flood protection. Flood protection systems have been designed and operated based on the assumptions of stationarity of hydrological processes of river stage or discharge. Can hydrological processes be conceived as stationary? Is the past a key to the future?

Studies of trend detection (Kundzewcz et al, 2004) are also of importance because of our need to understand the changes of the “natural” world. The process of river flow has been directly influenced by changes caused by man (e.g. land –use changes: urbanization, deforestation, changes in agricultural practices, and engineering works: drainage systems, dam construction, river regulation, e.t.c).

Bergkamp et al (2003) also contended that existing commitments to reduce greenhouse gas emissions (main causer of global warming) are insufficient to halt present climate change, making adaptation a necessity. On their own, neither planned nor spontaneous adaptation would be able to mobilise the society-wide movement for adaptation that will be needed. A combination of approaches, ranging from engineering types to societal processes, will be required. This means a combined top-down / bottom-up approach should be adopted that brings together the public and private sectors, and civil society-commonly dubbed as an integrated approach to the problem.

In Zimbabwe, modeling studies show that annual mean temperature has increased by 0.4°C while rainfall has declined by 5% since 1900. Rainfall is likely to fall by between 5 and 18% of its 1961-90 average by the year 2080 (Hulme and Sheard, 1999:4). This represents a major threat to food security since livelihoods are predominantly based on rain-fed and labour intensive farming.

1.3 Problem statement

Rainfall (and hence available water resources) within the micro-catchment is becoming more variable thus becoming more unable to meet the catchment's water requirements (demands) and this is generally suspected to be because climate change in the region.

1.4 Justification

Studies on rainfall behaviour in Zimbabwe, Botswana and northern South Africa concluded that between 1971 and 95 there was a reduction in rainfall totals and intensities accompanied by increased length and intensity of mid-season dry spells (Foxall, 2004).

1.5Objectives

1.5.1Main objective

The study aims to investigate whether or not climate is changing as well as its impact on available water resources of the Odzi sub-catchment using rainfall and runoff data.

1.5.2Specific Objectives

1. To carry out literature review on climate change.
2. To collect time series data for runoff and rainfall from stations within the micro-catchment and perform quality control of the data provided.
3. To perform a trend analysis so as to determine the existence or absence of climate change signatures from data.
4. To assess water availability using provided rainfall and runoff data.

CHAPTER 2

Literature review

2.1 Introduction

Climate change according to IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. Land use change and pollution act on physical and biological systems, making it difficult to attribute changes to particular causes (of climate change) in some specific cases (IPCC, 1995, 2001).

2.2 Climate change versus Climate Variability

It is very important for this study to differentiate between climate variability and climate change (c.f. Kundzewicz & Robson, 2004), where the former is the natural variation in the climate from one period to another, while the latter refers to a long-term alteration in the climate. Climate variability appears to have a very marked effect on many hydrological series (Kundzewicz et al, 2004). The author goes on to say that it has two important consequences:

- Climate variability can cause apparent trend. Climate variability can easily give rise to apparent trend when records are short-these are trends that would be expected to disappear once more data had been collected.
- Climate variability obscures other changes. Because climate variability is typically large, it can effectively obscure any underlying changes either due to climate change or to anthropogenic causes, such as urbanization.

2.3 Causes of Climate Change

Any factors that affect the balance between the outgoing and incoming solar radiation energy will change the climate. These factors are divided into two categories, i.e. natural factors and anthropogenic/human factors.

Natural Factors:

- ***Changes in the Solar Output*** – Solar radiation, whose source is the sun which is the ultimate source of all energy in the climate system, is an integral part of shaping the earth's climate. Changes in the energy from the sun, which is not constant cause climate change. There is evidence of an 11-year solar cycle in the temperature record of the earth.

- ***Changes in the Earth's orbit*** – Variations in the orbit change where and when the solar energy is received on the earth thereby affecting the amount of energy that is reflected and absorbed. Orbital variations which are in some sense an extension of solar variability, because slight variations in the earth's orbit lead to changes in the distribution and abundance of sunlight reaching the earth's surface.

Anthropogenic factors:
Change in climate is also a result of enhanced GHG emissions due to human activities, such as the combustion of fossil fuels like coal and oil, which release carbon dioxide, methane and nitrous oxides to the atmosphere (van Aalst, 2006). Though a small number of scientists contest the conclusions of climate change research, the vast majority agree that the Earth's climate is changing and that much of the change can be attributed to human activities (Bergkamp et al,2003).

The biggest factor of present concern is the increase in carbon dioxide levels due to emissions from fossil fuel combustion, followed by aerosol (particulate matter in the atmosphere) which exerts a cooling effect. These are referred to as green house gases and they cause greenhouse effect. Other green house gases causing similar damages are nitrous oxide, water vapor, methane and ozone. Under natural conditions, these keep the earth warm enough to be habitable. By increasing their concentrations and by adding new green house gases like Chloro fluorocarbons(CFCs), man kind is capable of raising the global average annual mean ambient temperature(IPCC, 1990).

Greenhouse effect – Energy from the sun is absorbed by the greenhouses gases such as water vapour, carbon dioxide (increased by 30%), methane (increased by 150%) and nitrous oxide (increased by 17%). Once the energy is captured, it cannot escape thus raising temperatures. It is highly likely that the1990s was the warmest decade in instrumental record of between 1961 to 2000 (Chidzambwa, 2006).

Sources of Greenhouse Gases (GHG)

Green house gases have got several sources which shall be briefly stated below.

1. Energy

Combustion of carbon based fuels producing carbon and methane. Electricity supply in Zimbabwe is mainly from coal-based thermal fuels. The figure below show the distribution of coal use in Zimbabwe.

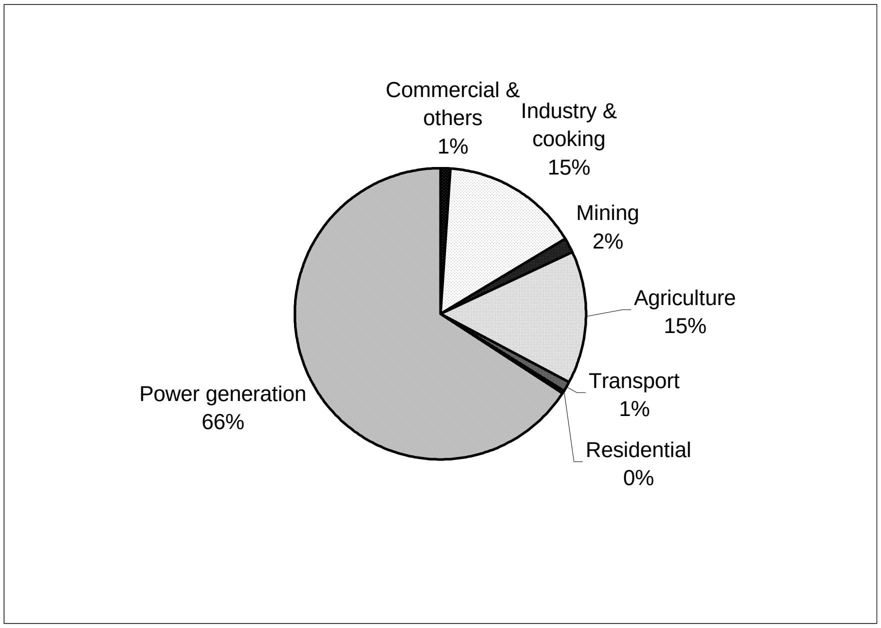

Figure 2.1: Distribution of coal use in Zimbabwe

Over 96% of the supply of energy is from carbon-based fuels (Zimbabwe Initial National Communication- 1998)**.**

The total global warming potential (contribution to the total greenhouse effect) for each gas is shown in the table below. (Source IPCC SAR: 1995)

GHG	**Global Warming Potential**
CO_2	1
CH_4	24.5
N_2O	320
NO_x	40
CO	3

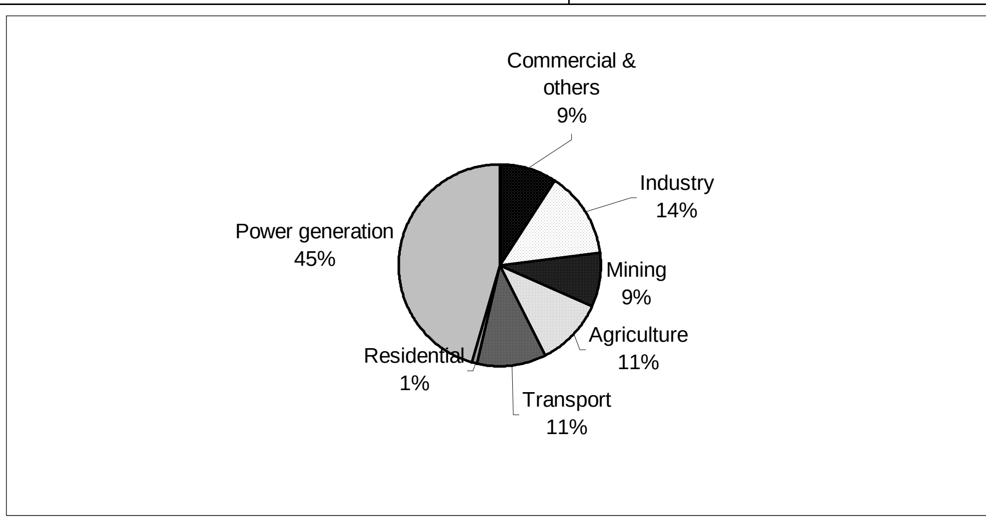

Figure 2.2: Sectoral distribution of GHG emissions from commercial fuels.

2. Industrial processes and automobiles

This change in climate is a result of enhanced GHG emissions[1] due to human activities, such as the combustion of fossil fuels like coal and oil, which release carbon dioxide, methane and nitrous oxides to the atmosphere (van Aalst, 2006) where they will add to the already existing volumes of these dangerous greenhouse gases. Some of the industries causing this threat are listed below:

- Mining Industry
- Metallurgical industries
- Beer, wine and spirit manufacturing industries
- Sugar manufacturing industries
- Cement production industries
- Fertiliser manufacturing industries e.g Sable chemicals

3. Agriculture

The burning of crop wastes, fermentation, manure management and Savanna burning all cause an increase in Carbon monoxide(incomplete combustion),Carbon dioxide(complete combustion) in the atmosphere as well as the NOx gases.

4. Land-use change

Wood fuel, accounts for 90% of energy requirements of the rural community (Chidzambwa, 2006). Thus the use of this fuel always results in the release of Carbon monoxide and Carbon dioxide to the atmosphere. Natural fires, land clearing for agriculture and the making of bricks, all result in the release the greenhouses especially Carbon dioxide to the atmosphere.

2.4 Why Climate Change a cause for concern

2.4.1 Changes in intense precipitation

According to IPCC, (2001), a statistically significant increase in global land precipitation over the 20th century has been noted. Instrumental records of land surface precipitation continue to show an increase of 0.5 to 1% per decade over much of mid-and high latitudes of the Northern Hemisphere(IPCC,2001), particularly pronounced in autumn and winter (IPCC,2001a), i.e. seasons when catchments' capacity to store precipitation water are limited.

The precipitation increase refers to both mean values and extremes, but in many areas the extremes in precipitation are likely to have changed more than the mean. This is particularly important, as changes in extremes may have greater impact than changes in average conditions. It is very likely (estimate of confidence: 90-99% chance) that in regions where the total precipitation has increased, there have been even more pronounced increases in heavy and extreme precipitation events. Moreover, increases in

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[1]GHGs are a key condition for life on earth; otherwise the earth would be 34 °C lower than today.s. Since the industrial revolution in 1750, the quantity of greenhouse gases has been enhanced to detrimental levels which aggravate global climate change (Eriksen and Naes, 2003:3)

heavy and extreme precipitation have also been documented even in the regions where the total precipitation has remained constant or slightly decreased (number of days with precipitation decreasing stronger than the total precipitation volume) (WMO, 2004).
It results directly from physics (Clausius-Clapeyron law) that the atmosphere's capacity to absorb moisture (and its absolute potential water content, pool of precipitable water, and thus potential for intensive precipitation) increases with temperature. This is a sufficient condition, caeteris paribus, for an increase in flooding. Increases in heavy precipitation events can arise from other causes, such as changes in thunderstorm activity and large scale storm activity. Higher and more intense precipitation has been already observed e.g. in the USA and in the UK (IPCC, 2001)

There are also numerous studies restricted to a single drainage basin or a country corroborating these findings. There is evidence that the frequency of extreme rainfall has increased in the UK(IPCC,2001a) and a greater proportion of precipitation is currently falling in larger events than in earlier decades (Osborn et al,2000).

Observations according to Kundzewicz et al, (2004) confirm that atmospheric moisture is increasing in many places. For example, a growth of 5% per decade was observed in the USA (Trenberth, 1998). Increased atmospheric moisture contents favors more intensive precipitation events thus increasing the risk of flooding.

As stated in IPCC (2001a), Australian annual mean rainfall has increased by a marginally significant amount over the last century. However, increases in heavy rainfalls have been observed over many parts of Australia in the 20th century (IPCC, 2001). After 1877, increases (some statistically significant) have been noted in mean rainfall for New Zealand's west coast. This is partially explained by the increase in El Nino conditions over recent decades. There is some evidence of long-term variations in the Australasian region in storm frequency and tropical cyclones (IPCC, 2001a).

However, in the Southern Hemisphere, devastating floods and severe droughts have been reported more frequently in recent times, the West African and Sahel drought since the early-1970s (Ward, 1998; Nicholson and Palao, 1993), the November-December 1997 and February 2000 floods in East Africa and southeast southern Africa respectively. Significant changes in the characteristics of the short-duration (e.g. daily) rainfalls were identified some of which corresponded to the declining number of rain days (Szilagyi, 2001; Smakhtina, 1998; Albergel, 1988), to declining frequencies of occurrence of the light daily rainfall events and sometimes to an increase in the frequency of heavy events (Valimba, 2004; Stone *et al.*, 2000; Mason *et al*, 1999; Smakhtina, 1998; Mason and Joubert, 1997). All these changes are due to climate change.

Another source of historical climate record for Africa shows warming of approximately 0.7ºC over most of the continent during the 20th century; a decrease in rainfall over large portions of the Sahel (the semi- arid region south of the Sahara); and an increase in rainfall in east central Africa. Over the next century, these trends in warming and changes in precipitation patterns are expected to continue and are accompanied by a rise in sea level and increased frequency of extreme weather events (IPCC, 2001)

While exact nature of the changes in temperature, precipitation, and extreme events is not known, there is some agreement about the following general trends as simulated by global climate models:

- Sea levels are projected to rise by 15 to 95 centimeters (6 to 37 inches) by 2100.
- Climate Change scenarios for Africa indicate future warming across the continent ranging from 0.2 degrees Celsius per decade (high scenario) (Desanker, 2002). This warming will be greatest over the interior of semi arid margins of Sahara and Central Southern Africa (Moyo, 2005).

According to the IPCC8, Zimbabwe is a warmer country at the end of the twentieth century than it was at the beginning. Since 1900, the temperature has increased by 0.4°C while a 5% decline in rainfall is notable across Zimbabwe through the same period in spite of some wet seasons in the 1920s, 1950s and 1970s. The early 1990s were probably the driest period due mainly to the prolonged El-Nino conditions that prevailed during these years in the Pacific Ocean (Hulme and Sheard, 1999). Figure 3.3 overleaf shows the changes in mean annual temperature and rainfall between 1901 and 1998 in Zimbabwe.

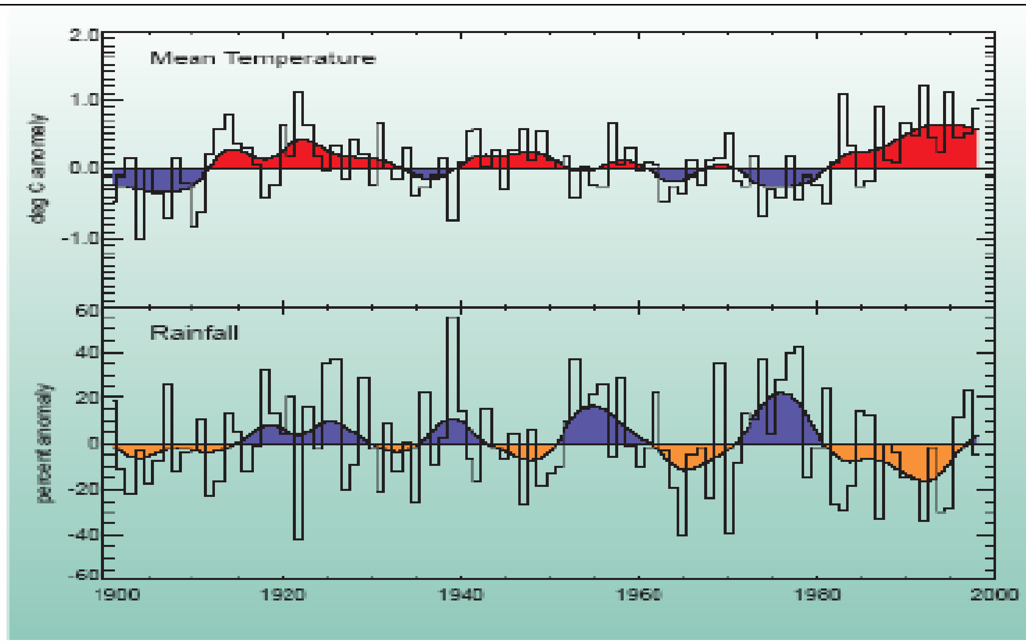

Figure 2.3: Changes in annual mean temperature, 1901-1998(top), and annual rainfall, 1901-1998 (bottom), **across** Zimbabwe. Changes are with respect to the average 1961-90 climate values of 21.3ºC and 622mm, respectively (Hulme and Sheard, 1999:1)

Brief overview of Rainfall in Zimbabwe

Rainfall season in Zimbabwe lasts for not more than five months, November to March. The average rainfall for the whole country is about 675mm and the distribution is far from even as shown in Figure 2.3 of the accumulated rainfall for the 2003/2004 season. Rainfall is as low as 300mmm in the Limpopo valley and as high as 3000mmm in the Eastern highlands.

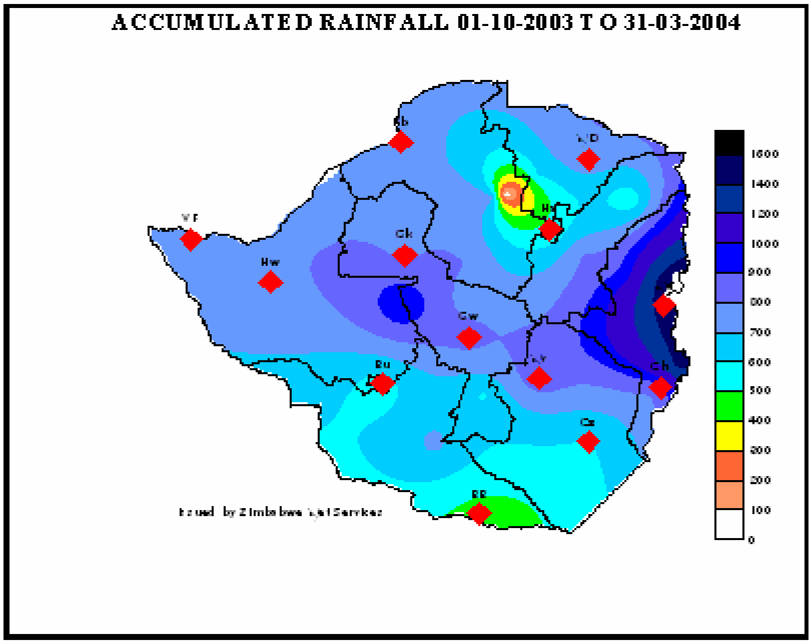

Figure 2.4: Rainfall patterns in Zimbabwe (01-10-2003 to 31-03-2004)
Source: Meteorological department (2004)

The map shows that in the eastern highlands, rainfall decreases as you move inland.

2.4.2 Changes in high river flow

Studies have shown a trend that runoff tends to increase with increase in precipitation and decrease with decrease in precipitation, depending on availability of data (IPCC, 2001). However, this does not directly translate to general changes in flood flows, even if there are a number of studies reporting that flows have become more frequent.

According to studies by Krasovskaia, (1995), Risbey and Entekhabi, (1996) variations in flow from year to year have been found to be much more strongly related to precipitation changes than to temperature changes. This study aims at establishing the presence or absence of trends in river flow data gathered over a long time so as to ascertain whether or not climate change occurred.

Globally, no uniform increasing trend in flood flow has been detected (cf. Mitosek, 1992). However, as stated by Robson and Chiew (2000), it is possible that changes are occurring but there is not enough data available for it to be detectable. In case of a weak trend, a series must be very long in order for the trend to be detected and this is very important for such a study. Climate –related changes in flood frequency are complex, depending on the flood generating mechanism. Flood magnitudes typically increase with warming if high flows result from heavy rainfall and decrease where they are generated by spring snow melts (IPCC, 2001).

However according to the WMO, (2004), it would be a gross oversimplification to say that, based on the studies reported in literature, in general, floods have exhibited growing trends world wide. Only some series show a significant trend and out of those only some (yet, typically more than half) feature a positive trend, while others exhibit negative trends.

Caspary (2000) analyzed time series of discharge in four rivers in Germany. After having smoothed the year- to-year oscillation of annual peak discharge, he found a marked recent increase in the amplitude of floods. He also compared floods of different recurrence intervals for two consecutive sub periods. The 100-year -flood determined from the older data in the first sub-period corresponds to much lower return periods (between 5 and 30-year-flood) for the more recent data. Large flows are therefore becoming more frequent. However, no space-covering study placing these results in a truly regional perspective has been available yet.

Nobilis and Lorenz (1997) analyzed the flood trend in Austria. They considered different periods of observation (40 year interval: 1952-1991 and parts thereof).Only in a portion of cases, a significant trend was detected. The quantitative results depended on the sub-period and the characteristics studied (whether annual maxima, or number of floods per year, or partial duration series). The portion of cases for which a significant trend was detected ranged from 4.3% to 31.5%.Among those cases where a significant trend was detected; there were more examples of positive trend (64.3%) than of negative trend (35.7%). Analysis of the full 40 year period results in detecting a positive trend in 66.3% of the cases with significant trend.

Zhang et al, (2001) analyzed trends in Canadian stream flow computed for the past 30-50 years for the 249 stations from the Canadian Reference Hydrometric Basin Network. They found that annual mean stream flow has generally decreased, with significant decreases detected in the southern part of the country. Significant negative trends are observed across much of Southern Canada for annual maximum flow. The number of decreases noted is higher than the number of increases.

Kunstmann et al, (2003) investigated the impact of climate change on the temporal and spatial distribution of precipitation, temperature, evapo- transpiration and surface runoff in the Volta Basin (400000Km^2) of West Africa. Trend analysis showed clearly positive trends with high level of significance for temperature time series. Precipitation time series showed both positive and negative trends, although most significant trends were negative. In the case of river discharge, a small number of (mostly positive) significant trends for the wet season were observed.

Alemaw and Chaoka (2002) also investigated possible trend in the annual river flow of 502 rivers in the region of Southern Africa and observed that the trends have been linear and declining in general. The records used in the study ranged from 1950 to late 1990 and several areas were found with evidence of declining runoff (Chingombe et al, 2005).

A study also by Valimba, (2003) concluded that significant changes in the river flows regimes the Southern African were identified in the 1970s through early 1980s. These changes led to decrease in river flows in western Zambia, Namibia and northeast South Africa considerably affecting the flows during the high flow months in which 34 -80 % of annual flow volumes are observed.

Flows in the Zambezi, upstream of the Victoria Falls have decreased to about half of flow before the change, while periods of no flow are observed in recent decades (Magadza, 1995) in some perennial rivers and are extending in seasonal rivers. In the other parts of Southern Africa, alternating increases and decreases in river flow indices were observed which corresponded mainly to interannual patterns of rainfall variation.

It was not possible, however, to provide strong links between the identified changes in stream flows and those in rainfall due to a) short available flow records, b) lack of the detailed information of land use, water use and other socio- economic activities within the catchments and c) unavailability of the stations detail such as the rating curves and their quality, gauge history (e.g. on the relocations of the gauging sites).

Chigombe et al (2005) described the development and application of a procedure that identifies trends in the hydrological variables. The non- parametric Mann-Kendall (MK) statistic test to detect trends was applied to assess the significance of the trends in the time series. Different parts of the hydrologic cycle were studied through 15 hydrologic variables, which were analysed for a network of Upper Mazowe catchment.

The distribution of the significant trends indicated that for the two periods monthly flow significantly decreased with the exception of the month of September for the less than 30 years series. The field significance of trends over the two time series was evaluated by the bootstrap test at the significance level of 0.05 and none of the two flow regimes expressed field significant changes.

Andersson et al, (2005) ran three transient climate change experiments which showed a significant warming in all seasons that is most pronounced in September –November. Precipitation was predicted to decrease during June –November on the continental scale while simulated changes in December –May were found to be small.

The experiment ran scenarios of Pungwe basin rainfall for the 1991-2020, and 2021-2050 periods compared to the 1961-1990 period and these indicated that approximately 10% reduction of annual runoff, with no significant variability between sub-basins was expected. The results also showed that a slight decrease of rainfall for 2021-2050, compared to the 1991-2020 was also expected.≈

2.4.3 Potential effects of Climate Change on Hydrological cycle

The effects of climate change are expected to be greatest in the developing world, especially in countries reliant on the production as a major source of income (IPCC, 2001). The impacts can be adverse or beneficial.
Climate change can affect adversely the following:

- Precipitation, according to Carter and Hulme (1999), either increases or decreases depending on latitude. The results are based on the current climatic models. Precipitation decrease affects the availability of water for domestic use (primary water), food production, industrial usage, hydropower generation as well as increasing vector borne (e.g. malaria) and water borne diseases (e.g. cholera).
- Agriculture due to shifts in growing seasons and water availability(e.g. Mearns et al.,1997)
- Increased occurrence of coastal flooding due to sea level rises (e.g.Warrick et al.,1993)
- Inland flooding due to changes in precipitation regimes(e.g. Booij,2002)
- Climate change can also affect the safety and quality of the human and natural environment through an increase in floods, droughts and erosion, and a decrease in water quality and ecosystem diversity. These impacts may subsequently have marked socio-economic consequences as was explained earlier on.
- Evaporation-The rate of evaporation from the land surface is driven essentially by meteorological controls, mediated by the characteristics of vegetation and soils, and constrained by the amount of water available. Climate change has the potential to affect all of these factors in a combined way that is not yet clearly understood (IPCC, 2001).
- Soil Moisture- This varies not only with the degree of climate change but also with soil characteristics (IPCC, 2001).
- Groundwater Recharge and Resource-Aquifers are replenished by effective rainfall, rivers and lakes. The changes occurring in any one of these will certainly impact on recharge and consequently on available ground water resources (IPCC, 2001).

2.5 Selection of stations

Selection of which stations to use in a study is also important (cf. Kundzewicz and Robson, 2004 cited in WMO, (2004)). For example, the issue of detecting a climate change signature in river flow data is very complex because the process of river flow is the integrated result of several factors, such as precipitation inputs, catchment storage and evaporation losses but also the river training measures taken over time and the morphological processes changing the river conveyance (Pinter et al., 2003, 2001).

Furthermore, climate change signals may be overshadowed by strong natural background variability. These factors mean that particular care is needed in selecting data and sites for use in studying climate change. In order to study climate change signature in river flow records, data should ideally be taken from pristine / baseline Rivers and should be of high quality and extend over a long period. Where pristine sites are not available, it maybe possible to eliminate other influences by eliminating all stations down stream of dams or weirs. Other options (though more cumbersome) of solving this problem could be reconstructing natural flows, or using conceptual flow naturalization. Hence, catchments featuring strong changes in land-use and land cover change (e.g. deforestation, urbanization), river regulation (e.g. dikes or dams) are not appropriate (WMO, 2004).

2.6 Water resources, climate change and food security

Climate change threatens to make the poor of the world hungrier and thirstier. According to Eriksen and Naes (2003:16), climate change induced reductions in rainfall amount and raised temperature will lead to reduced runoff and increased water stress. This will disrupt water dependent activities including those on which livelihoods and food security are based.

In the semi-arid conditions in which much of SSA lies, this will exacerbate the challenge to produce or access adequate food since irrigation activities will be affected. Chigwada (2004:27) argues that agricultural production will decrease as a consequence. Using the case of Malawi, where only 45% of the rural population has access to safe drinking water, he argues that the rapidly growing population will increase the demand for irrigation and water resources will be inadequate and scarce leading to a significant loss in livestock and crop productivity especially in the low rainfall areas.

In Zimbabwe, simulation studies show that the doubling of atmospheric carbon dioxide will reduce the regime of perennial rivers in the Eastern Highlands to seasonal as with the case for dry regions (MMET, 1998:63). The table overleaf (MMET, 1998:64) shows the projected changes in river discharge versus demand with and without climate change for some of the major catchments in Zimbabwe.

Catchment Area	**1995 existing demand**	**2075 without climate change**	**2075 with climate change**
Sebakwe	21	106	202
Odzi	19	102	204
Gwayi	24	121	240

Table 2.1: projected changes in river discharge versus demand with and without climate change

Water Availability

The term catchment in this study refers to the total water collecting area for any storage work. Yield from a reservoir (catchment), is the volume of water which is abstracted over a specified period of time and has a unit, for example, of millions of cubic metres per year (Allen et al., 1994). Also, according to Sontosh (1994), reservoir yield is the amount of water that can be drawn from a reservoir in a certain interval of time and it depends on inflow into the reservoir and will vary from time to time. The time interval may vary from a day for small distribution reservoirs to a month or a year for large reservoirs (Moyo, 2005).

Moyo (2005), asserted that there are several methods used in reservoir yield estimation, which are, in a way, based on empirical formulae, and depend on reservoir catchment characteristics. One of these methods which shall be used in this study is the T.B. Mitchell's method.

Moyo (2005), also went on to say that yield estimates are based on long flow records from the site of interest. On the issue of records, Alexander (1995), said that it is usually sufficient to select a gauging station in the area which has a long, reliable record.

2.6.1 Parameters affecting reservoir yield

According to Kabell (1974), the following are the parameters which affect the yield from a given reservoir:

a. Inflow parameters

i. Mean Annual Runoff (M.A.R)

This is the long term average runoff and represents the total input to the system. The higher the M.A.R, the greater the yield. It is preferably estimated using a minimum of 30 years of data.

ii. Coefficient of variation (Cv) of runoff

This is the measure of the variation in runoff from year to year. It is obtained by dividing the standard deviation by the mean annual runoff. For a catchment where the variations are higher, there must be a greater volume of water held in the reservoir from good years to balance the low runoff in poor years. This results in the lowering of the yield, due to the water being subject to evaporation losses over a greater period of time, hence the higher the Cv, the lower the yield.

iii. Monthly recession factor, r

This factor is a measure of the shape of the annual inflow hydrograph. A low value of monthly recession will indicate a river system in which the bulk of the flow is concentrated within a short period, while a high value of r will apply to a river system having more constant regimes throughout the year. The latter condition will favour a higher yield.

b. Reservoir characteristics

i. Storage capacity

The larger the storage capacity of a reservoir, the higher the yield will be. However, this rule follows the law of diminishing returns, and increases in capacity are rewarded with ever- smaller increases in yield until a point is reached where no extra yield can be generated, regardless of the reservoir capacity. In this case, the additional inflow impounded during the less frequent high annual inflows is all lost through increased evaporation from the enlarged surface area.

ii. Surface -area curve

The relationship between the surface area and the capacity of the reservoir will have a significant effect on evaporation losses and hence on yield.The surface area is obtained from the plan metered basin area. Clearly, a shallow reservoir of a given capacity will have a lower yield than a deep reservoir of the same capacity.

iii. Evaporation

Evaporation from the surface of a reservoir constitutes the principal deduction from the total water available for use. It is measured from the Pan Evaporation dish located on the dam site. The magnitude of this deduction will depend primarily on the mean net evaporation for the appropriate climatic zone, but also depend on the reservoir characteristics, the Cv of inflow, and the pattern and the risk factor of draw off.

iv. Yield risk factor: The acceptable risk of failure of an assured yield will have an effect on the potential water utilization from the catchment. If the risk factor is low, a greater proportion of water must be held in storage over the years, with consequent increased evaporation losses. Conversely, if a higher risk factor can be tolerated, the reservoir can be drawn down to a lower level each year resulting in less evaporation and a greater yield.

v. Pattern of draw- off: At a constant risk level, the magnitude of the yield is affected to some degree by the pattern of draw-off. A different yield will apply if draw-off is constant throughout the year, or if it varies on a seasonal basis. This study however is going to assume a constant rate of draw- off through out the year.

This type of study of estimating catchment potential yield was classified by MRRWD as Class C. This is the maximum potential catchment yield that can be obtained at the given risk factor over an indefinite span of years. In this case storage is required not merely to balance low and high flows within the seasons of one year, but to balance years of high total run off with years of low total run off. The amount of storage capacity required is thus comparatively high and the yield- storage relationship is not very favourable.

The water may be held in storage over several years resulting in greater cumulative evaporation loss. This class therefore represents the ultimate yield that can be derived from a catchment, and for the full development of the country's water resources it is necessary to provide the required storage capacity and to exploit this class of water yields (Mitchell, 1989).

CHAPTER 3

Area of Study

3.1 Introduction

This study shall show all the catchments locations at national level first (Figure 3.1) then followed by the isolated Save catchment with its sub catchments (Figure 3.2). Finally, the Odzi catchment (Figure 3.3) as well as the micro catchment (Figure 1.4). Area description in terms of climate, hydrology, land use, population, physiography and possible impacts of climate change in study area shall be presented.

Map showing all Catchments in Zimbabwe

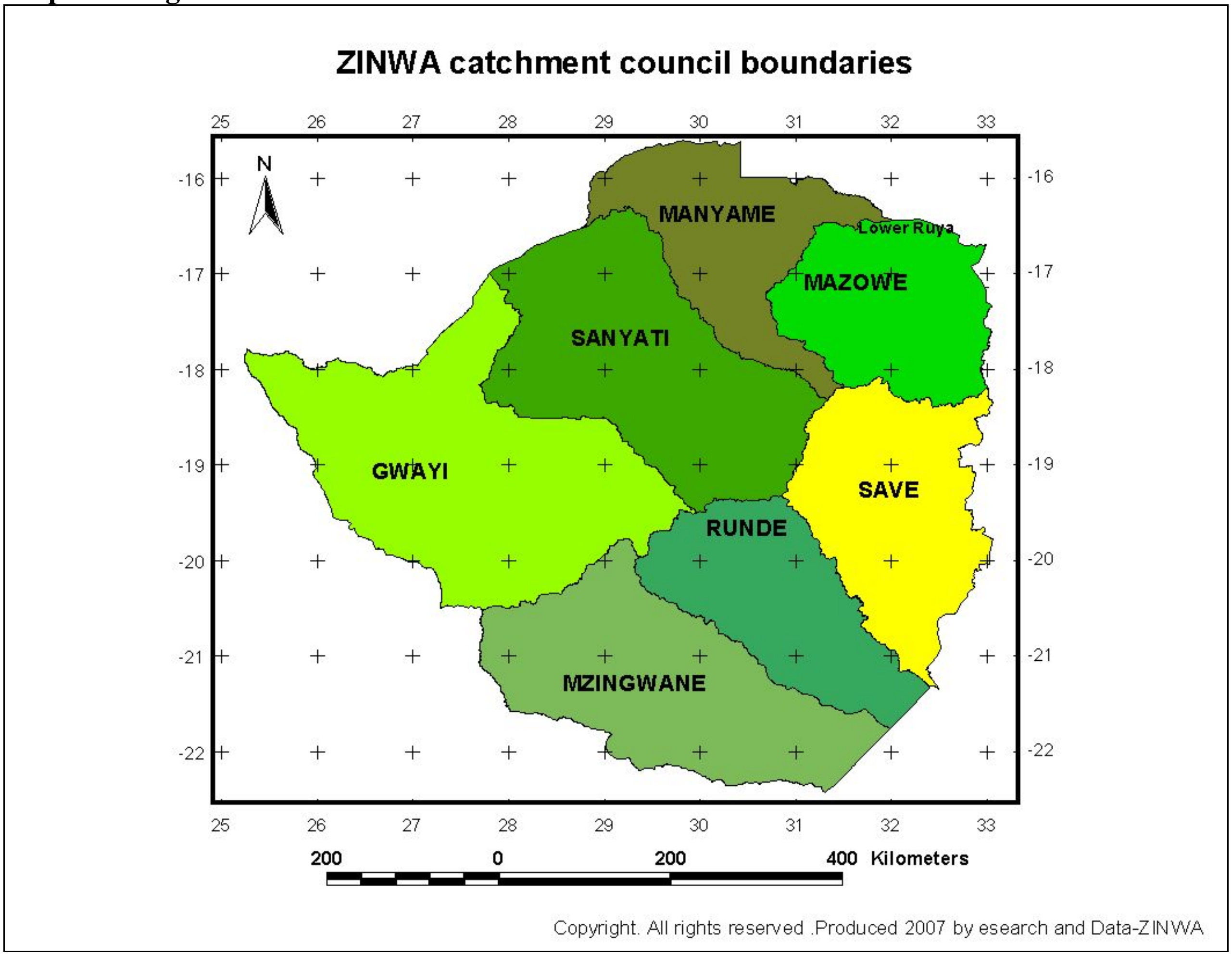

Figure 3.1 Map showing all catchments in Zimbabwe
Source:ZINWA

Map showing the Save catchment and its sub catchments

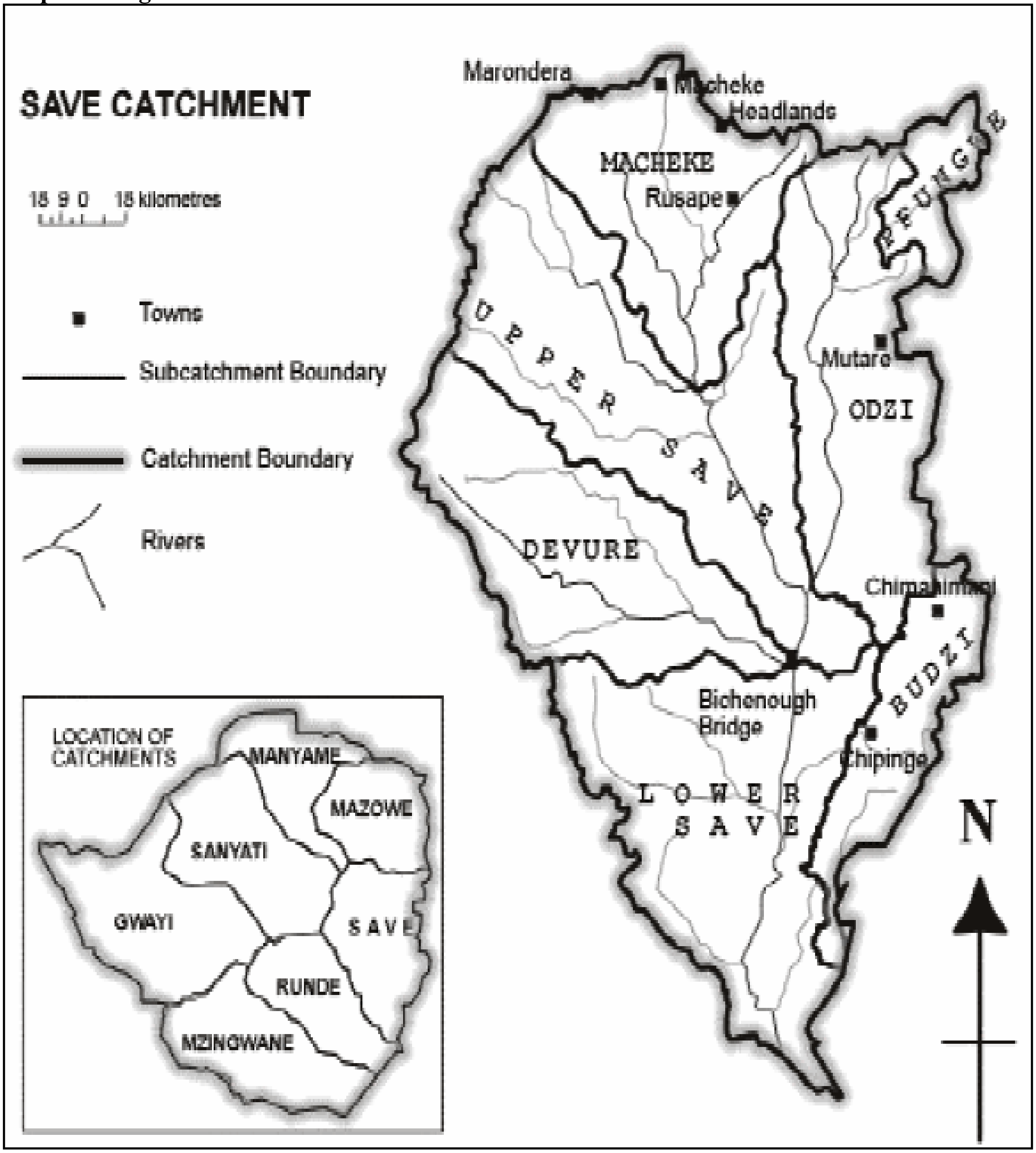

Figure 3.2: Save catchment area and its sub- catchment areas
Source:ZINWA

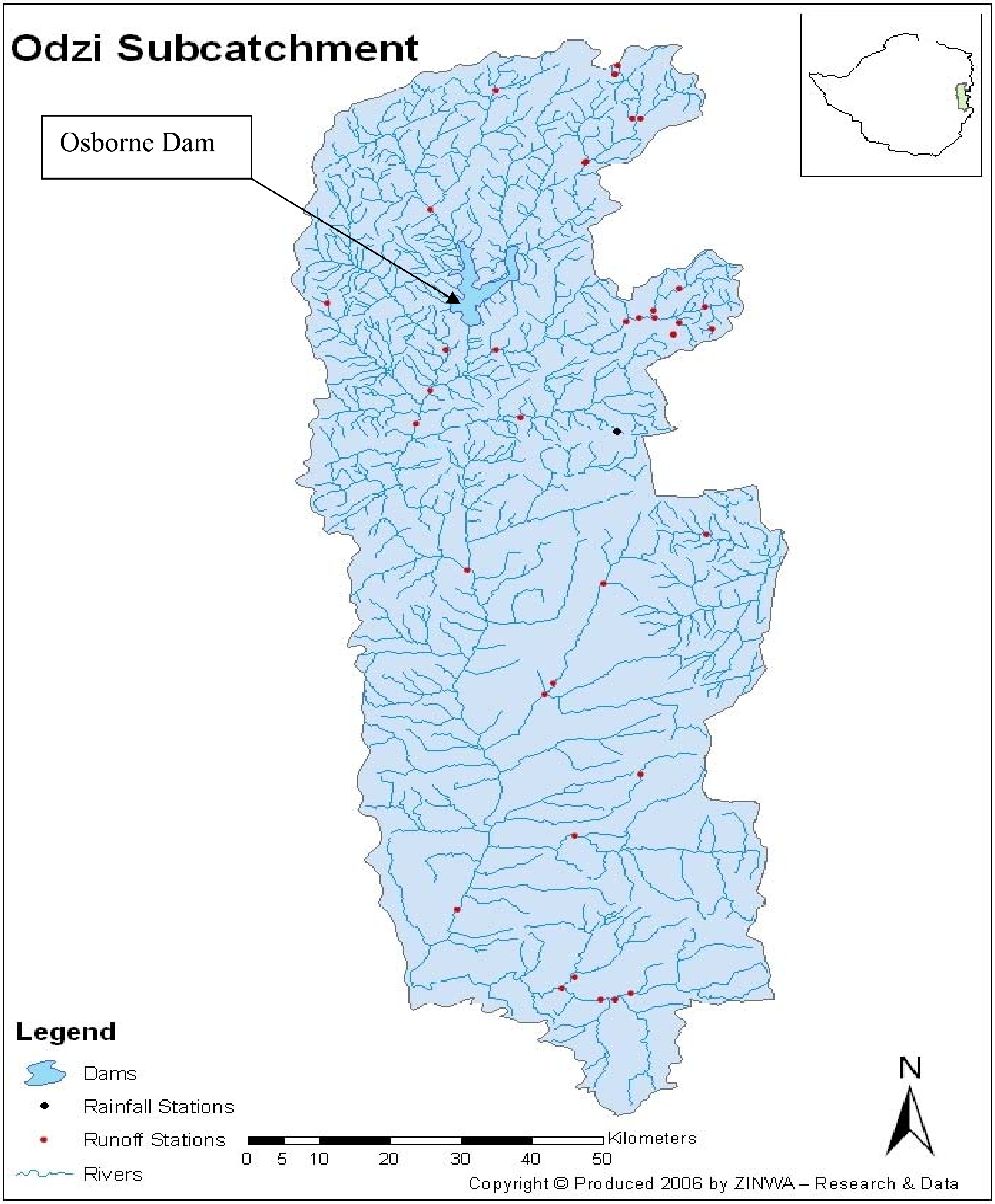

Figure 3.3: Odzi subcatchment

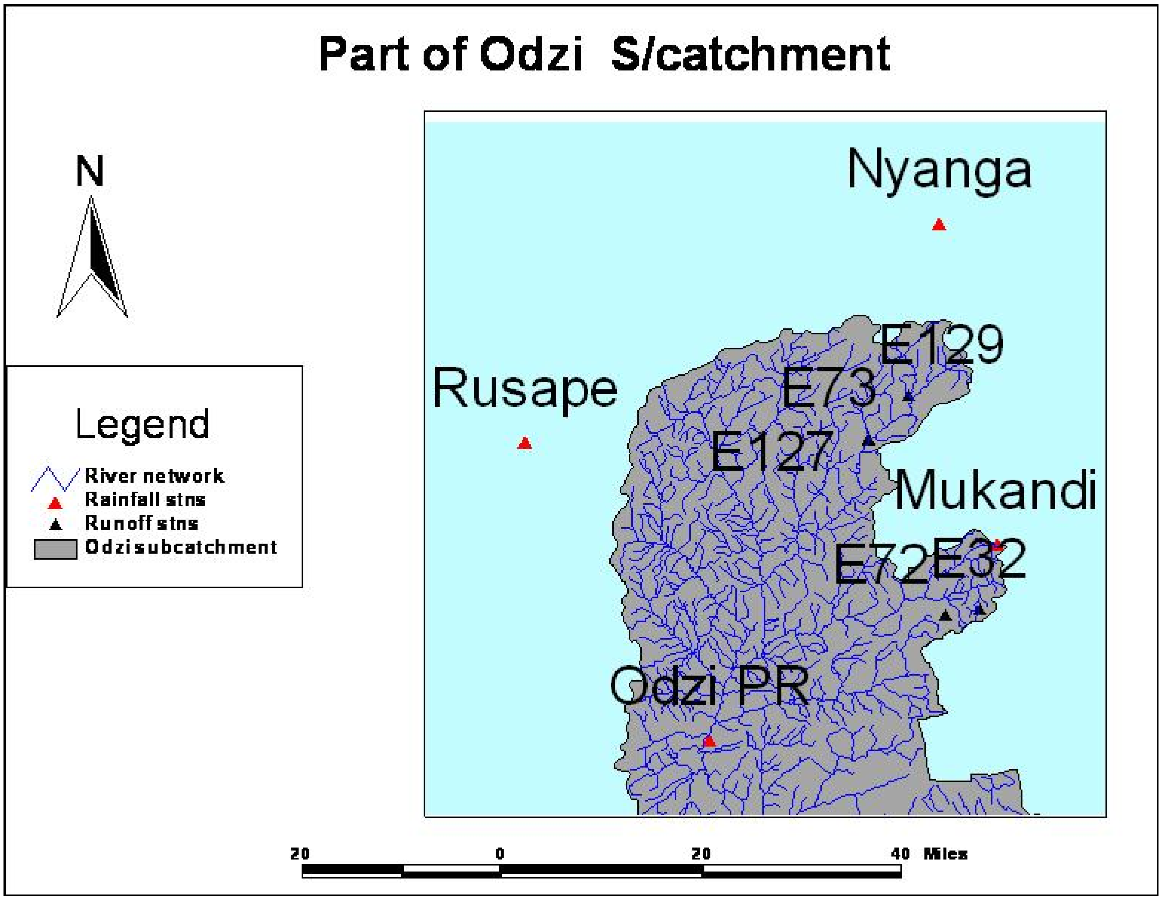

Figure3.4: Portion of Odzi subcatchment being the study area showing runoff and rainfall station locations.

The Odzi sub catchment studied is found in the eastern mountainous areas of Zimbabwe (Figure 3.1). Odzi river is the main river in this sub-catchment. It is a perennial river that rises in the Eastern Highlands and flows to the south before feeding the Save River. Total catchment area is 2 486 km^2; altitude difference is large, 950 to 2 160 m a.s.l (Lidén et al, 2001). However this study shall focus on the upper sections of the sub catchment, as shown in figure 3.4 hereafter termed micro catchment.

3.2 Demography and land use

Population density of whole catchment is above 60 persons per km^2 in large parts of the catchment; land use is a mixture of communal lands, commercial farms and forests (Lidén et al, 2001). On the commercial areas, large farms are found, which run extensive farming. The main crop in this part of Zimbabwe is tobacco during the rainy season and wheat during the dry season; and this is made possible by irrigation. Most of the farms also have cattle (Magnus et al, 1999).

In the communal areas, the farming is performed on a much more intensive basis. Small fields are mainly used for maize cultivation; in the drier areas; however, rapocko (a maize- relative) and sorghum (a relative to sugarcane) are cultivated (Magnus et al, 1999). Cattle and goats are the most common livestock.

In the mountainous parts of the catchment, the land is mainly covered with forests and in some areas companies carry on forestry. Big plantations of pines and gum trees, which are clear cut when it is time for harvesting, are common. Also in the drier areas of the communal lands, there are irrigation systems such as canals extracting water from the rivers.

The shortage of land and sometimes the unwillingness to carry water has forced people to cultivate on the riverbanks in many places in the catchment area. This is a serious problem since the soil is bare when the first rains come and it is very easily eroded, which causes land degradation and river siltation. Another problem is the removal of vegetation cover due to cattle and goat activities close to the riverbanks. However most people seem to be aware of the problem but in times of increasing population and scarce resources it is not easy to find a solution (Magnus et al, 1999).

3.3 Physiographic

The geology of the area is dominated by granitic bedrock and in-situ weathered sandy soils (Lidén et al, 2001). The landscape is hilly, specially in the upper parts where the mountains reach heights up to 2000 m but also the western spur of Chimanimani mountains where some tributaries rise (Magnus et al, 1999).

Granite forms the foundation of the area. The bedrock is very old; around 3.8 billion years. In fact, it is among the oldest geological formations that can be found on earth since the area is situated in the middle of the continent and therefore not recently exposed to tectonic movements. This also means that the bedrock is strongly weathered and bare rock is rarely seen except for the mountain peaks (Magnus et al, 1999). A greenstone belt of volcanic origin (Phaup, 1937) strikes the drainage basin NE and crosses Odzi River around Odzi location.

The soils within the river basin are mostly of igneous origin and rather thick. The parent material is the underlying bedrock since most soils have been formed *in situ* (Thompson & Purves, 1978). Most of the soils are predominantly sandy (Anderson et al 1993).A typical soil classification for the area in the soil taxonomy system according to Anderson et al (1993) is typical Ustipsamment.

In some areas, red late rite clay is found. Which type of soil that is most erosive is under discussion among scientists. However, the coarse-grained sands and sandy loams that dominate the catchment area are considered to be highly erosive (Stocking & Elwell, 1973). One important factor could be that compared to a clayey soil the vegetation is sparser on a sandy soil and thereby the soil is more easily eroded.

3.4 Hydrology

The climate is seasonal with a rainy season from November to March.
The upper catchment area receives up to 1500 mm rainfall per year while the area west of the river is much drier and receives about 450 mm/ year (see Figure 3.5 below) and average runoff is 150 to 400 $mmyr^{-1}$ with a coefficient of variation of 174%.The upper mountainous parts receive the highest amounts (Magnus et al, 1999).

Rainfall map of the Odzi Sub catchment

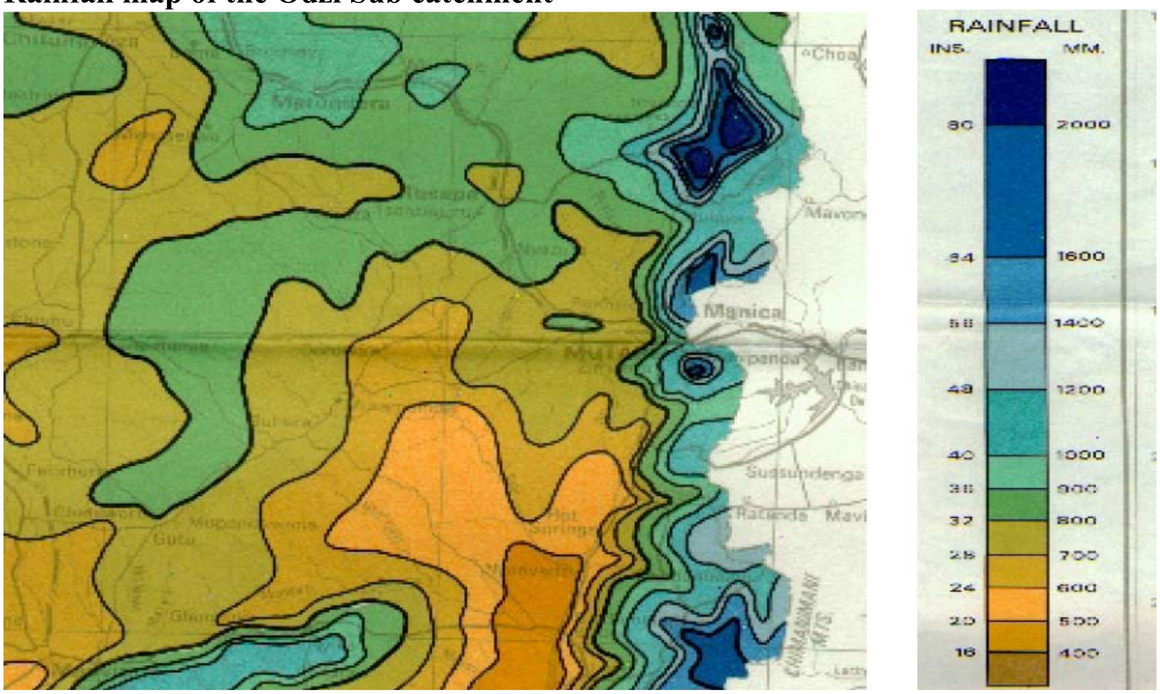

Figure 3.5: Mean annual rainfall over the study area (Mean annual rainfall, 1984) Source: Met department

The irregular seasonal availability of water has led to the establishment of irrigation systems (Liden et al, 2001). However, in 1999, the rainy season was an extraordinary one and the catchment received between 120- 140% of the normal rainfall (Met office, 1999).The average potential evapo-transpiration is around 4 mm/day in the catchment area.

3.5 Water supply and demand

River abstractions, canals and small weirs are commonly found in the catchment. The three main reservoirs on the Odzi River are Osborne, Small Bridge and the Odzani. The Odzani and Small bridge provide the city of Mutare with freshwater, while the Osborne Dam (shown in Figure1.3) was constructed in 1990 for downstream irrigation purposes.

The dam, which is located just downstream of the Nyatanda and Odzi confluence, has a total capacity of 400 Mm^3 and acts as a sediment trap for a large part of the catchment.

The Osborne dam with a total capacity of 400Mm^3 supplies farmers downstream of the dam (Magnus et al, 1999). The river width is approximately 100 m and the river slope is 0.14 (Lidén et al, 2001).

3.6 Possible impacts of climate change in study area

According to Eriksen and Naes (2003:16), climate change induced reductions in rainfall amount and raised temperature will lead to reduced runoff and increased water stress. This will disrupt water dependent activities including those on which livelihoods and food security are based. In the semi-arid conditions in which much of the communal land of the sub-catchment lies, this will exacerbate the challenge to produce or access adequate food since irrigation activities will be affected. Chigwada (2004:27) argues that agricultural production will decrease as a consequence.

CHAPTER 4

RESEARCH METHODS

4.1 Introduction

The objective of this chapter is to outline the procedure used in data collection and analysis. This helps focus the project so as to avoid collecting too few or too much data beyond the scope of the project. In short, only that data and analysis that best answers the research questions of the project will be used. However, before any data is collected, there is need to select the appropriate stations to use.

4.2 Criteria for selecting stations

- Before choosing stations, the catchment to work with should be chosen first. It should not feature strong changes in land use and land cover (e.g. deforestation, urbanization). Rivers with regulation facilities (e.g. dikes or dams) are not appropriate.
- Availability of long series (the longer the better); at least 40 years of data (few exceptions in areas with scarce data).
- Topicality (records ending as recently as possible-ideally).
- Minimum gaps in data.
- Geographic distribution (avoiding many neighboring stations).
- Priority- smaller catchments (more likely to be without strong anthropogenic influence), especially in the developed countries. (WMO, 2004).

4.3 Data collection and Data Quality control

Data for monthly rainfall and runoff for the upper part of the chosen catchment (***microclimate***) was collected from Meteorological as well as the ZINWA offices. This included the area above the Osborne dam (see figures 3.3 and 3.4). Data were physically checked to see if there are no missing values. To check for outliers, graphs of monthly data were plotted over the given period varying from station to station. The outliers were eliminated by replacing them with long term averages calculated over that whole period provided for each station. (e.g. extreme conditions like El nino floods).

4.3.1 Rainfall data

Monthly Rainfall data for the aforementioned area were collected from the Meteorological department for four stations namely, Mukandi (Latitude 18°41'', Longitude 32°49'') Nyanga (Latitude18°13'', Longitude 32°44''), Odzi Police rail (Latitude 18°58'', Longitude 32°24'') and Rusape (Latitude 18°32'', Longitude 32°08'') (see figure 3.4). Data were from July 1959 to June 2006 for all the stations. It was of high quality, with missing data in few months.

4.3.1.1 Data completion through regression

Data for all but Rusape station were missing in few months. Thus regression analysis had to be done for Mukandi, Nyanga and Odzi Police rail with Rusape being chosen as the base station. October data for the period (1959-2005) was used in the regression analysis for all the stations with Rusape being the base station.

4.3.2 Runoff data

Data for five stations (E32, E72, E73, E127 and E129) were collected from ZINWA which pertain to the upper part of the Odzi Subcatchment (see figure 3.4). Station data E32 (Latitude18°47'', Longitude 32°37'') are from1957 to 2005. Station E72 (Latitude18°47'', Longitude 32°45'') data are from 1961 to 2005. Station data E73 (Latitude18°32'', Longitude 32°38'') are from 1961 to 2005. Station data E127 (Latitude18°32'', Longitude 32°38'') are from 1969 to 2005. Station data E129 (Latitude18°28'', Longitude 32°41'') are from 1970 to 2005.

4.3.2.1 Data correction and completion

Collected data were found in-complete with several missing data in the stations E32, E72, E73, and E129. Only E127 had complete data. To complete data for the other stations, regression analysis was performed.

First, station E72 being the proposed base was regressed with station E127, being the only station with completed data. After completing missing data for the station E72, this station was then used to complete data for the other remaining stations.

4.3.2.2 Correlation of Rainfall and Runoff

Annual maxima rainfall data for Rusape, Mukandi, Odzi Police Rail and Nyanga were correlated with annual maxima runoff data for station E127 (using the non parametric Spearman's rho) under the following hypothesis to test if there is a relationship and if it is significant:

Ho: $r=0$

H1:$r\neq0$

Station E127 was chosen for its proximity to the four rainfall stations. Having detected significant correlations for the four above cases, the two variables (runoff and rainfall) were regressed to come up with a regression equation that would then relate rainfall to runoff for each case.

4.4 Data analysis

The statistical methodology used in this report follows that of Kundzewicz (2004), as adopted from Kundzewicz and Robson (2004).

4.4.1 Background to statistical analysis

In order to carry out a statistical test, it is necessary to define the null and alternative hypotheses, which describe what the test is investigating.

4.4.1.1 Hypothesis

For this study, to test for significant changes in the rainfall and runoff time series, the null hypotheses (H_0) are that there are no changes. The alternative hypotheses (H_1) are that there are changes (increasing or decreasing over time).

4.4.1.2 The significant level

This will be used to measure whether the test statistic is very different from the range of values that would typically occur under the null hypothesis. Thus a 95% significance level would be interpreted as strong evidence against the null hypothesis-with a 1 in 20 chance of that conclusion being wrong. That is, there is a 5 %(i.e. 100%-95%) probability that we incorrectly rejected the hypothesis and detected a trend when none is present (5% probability of the type I error). Another type of error (type II error) occurs when the null hypothesis is incorrectly accepted when in fact the alternative hypothesis is true (i.e. we fail to detect a trend when one is present). A test that has low type II error probability is said to be powerful and more powerful tests are to be preferred.

4.4.1.3 Assumptions

In carrying out a statistical test it is always necessary to consider assumptions (cf. Kundzewicz and Robson, 2004). The following assumptions are proposed and tested to see if they are relevant:

1. ***Normality of data***
   That is assuming that data used are normally distributed. This is violated when the data doesn't follow a normal distribution. The Null hypothesis (H_0) is that the data are normally distributed and the alternative is vice-versa.
2. ***Constancy of the distribution***
   This assumes that all data points have an identical distribution. This is violated if there are seasonal variations or any other cycles in the data or if there is an alteration over time in the data that is not allowed for in the test.
3. ***Independence***
   This assumption is violated if there is autocorrelation (correlation from one time value to the next: also referred to as serial correlation or temporary correlation).

Whether it is appropriate to use a classical test procedure, will depend on the assumptions that can be made on the data. This can be summarized as follows: Case 1: Data are normally distributed and independent. However, this is an unlikely scenario for hydrological data.
Case 2: Data are non-normal, but are independent and non-seasonal. In this case, any of the basic distribution-free tests are suitable.
Case 3: Data are non-normal, and are not independent or are seasonal. In this case, the data do not meet the assumptions for any of the basic tests and it is necessary to use a resampling method to evaluate significance levels (WMO, 2004).

4.4.3 Rainfall and Runoff analysis

4.4.3.1 Test for normality

The Kolmogorov-Smirnov test was used to test if rainfall and runoff data were normally distributed. This was the first step in the trend analysis as it was needed to help decide on whether to use parametric or non parametric tests. Parametric tests require the data to be normally distributed.
The following hypothesis was used:

Ho: Data are normally distributed
H1: Data are not normally distributed

The next step in analysis was to test for trends in the rainfall and runoff data. This was done in conjunction with tests for independence and equal distribution. The significance of changes was computed using standard formulae (Radzeijewski and Kundzewicz, 2004).

4.4.3.2 Test for independence and equal distribution

Kendall's Turning point test was used to test for independence and equal distribution of the time series data. Monthly data was used. If a series is not independent, it means there is auto correlation (serial correlation). Von Storch and Navarra (1995) observed that the presence of serial correlation could complicate the identification of trends since a positive serial correlation (negative test statistic) can increase the expected number of false positive outcomes for the Mann-Kendall test.

Suggestions have been made to remove the serial correlation from the data set prior to applying a trend test. Approaches common have been to resample the data set. This is done by generating many random time series with distribution identical to that of the original time series (Kundzewicz et al, 2004).

4.4.3.3 The Mann-Kendall's test for trends

In this study, the focus was on a particular distribution-free method, the Mann-Kendall test, which is frequently applied to detect trends. This testing approach was selected because it allows the investigation to have minimum assumptions (constancy of distribution and independence) about the data. It is possible to avoid assumptions about the form of the distribution that the data derive from. For example, there is no need to assume data are normally distributed (WMO, 2004).

The Mann-Kendall test belongs to a group of rank-based test. Rank-based tests use the ranks of the data values (not the actual data values). A data point has the rank „r. if it is the rth largest value in the data set. There are a number of widely used and useful rank-based tests. Most rank-based tests assume that data are independent and identically distributed. Rank-based tests have the advantage that they are robust and usually simple to use. The Mann-Kendall test is a rank-based test similar to Spearman's rho (same power and still based on ranks) but using a different measure of correlation which has non-parametric analogue. The Mann-Kendall test statistic is given below:

$$[S={}^{(n-i)}\sum_{(l-1)} {}^{n}\sum_{(j-i-1)} \mathrm{Sgn}\,(X_j-X_i)] \quad \ldots\ldots 1)$$

Where X_i and X_j are the sequential data values, n is the data set record length, and
$\mathrm{Sgn}\ \theta = +1$ if $\theta>0$
$\mathrm{Sgn}\ \theta = 0$ if $\theta=0$
$\mathrm{Sgn}\ \theta = -1$ if $\theta<0$

The Mann-Kendall test has two parameters that are of significance to trend detection. The significance level that indicates the trend's strength and the slope magnitude estimate that indicates the direction as well as the magnitude of the trend constitutes the parameters.

A permutation approach is used to generate the distribution of the test statistic. The Mann-Kendall statistic S is calculated for each of the large number of different random orderings (permutations) of the data set. Comparison of the test statistic for the original data set to the distribution of the test statistic obtained from the permutation data sets and a significant level is done. The rationale behind this approach is that under the null hypothesis of no trend in the data, each ordering of the data set is likely to be equal. Therefore, the null distribution of the test statistic can be estimated from the permutation approach. This approach can be applied with any statistical test for trend (Chingombe et al, 2005)

The non-parametric robust estimate of the magnitude of the slope, β, is given by:

[β=Mean [$(X_j-X_i)/(j-i)$] for all $i<j$]……………………………………………………2)

4.4.4 Calculating Water Availability

Subcatchment Yield estimation was calculated based on T.B Mitchell's method of Reservoir Yield estimation. The subcatchment was subdivided into two sub-subcatchments as shown on map below.

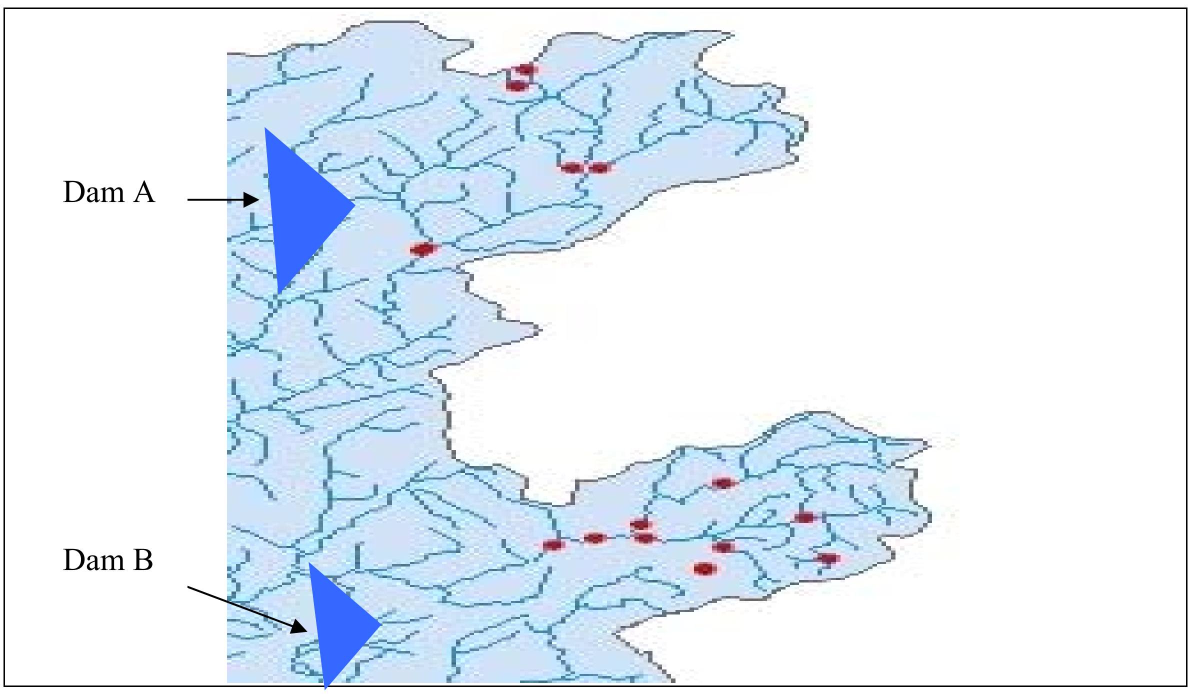

Figure 4.1: Sub- subcatchment of Odzi showing imaginery dams.

Dams A and B were assumed to be collecting runoff water from sub zones E05 and E04 respectively. This method uses five sets of yield curves. Each curve has its own unique CV and these CVs range from 60 to 120. These curves were computed for constant annual draw-offs assuming that all inflow into the dams appear during the first three months of the hydrological year (October, November and December) and there is no usable in flow for the remaining nine months.

The yield ratio Q/MAR was read off from the curves after calculating EF, V/MAR and MAR/EF. EF (Evaporation factor) = $(eA)^3 / (0.7V)^2$. **(See APPENDIX D for calculations)**

4.4.5 Interpretation of results

The higher the significance level the more significant the trend. If test results suggest that there is a significant change in a data series, then it is important to try and understand the cause. Although one may be interested in detecting climate variability using runoff data, there may be many other explanations to the changes detected (Kundzewicz and Robson, 2004). Common causes of change in flows include:

- Changes directly caused by man (urbanization, reservoirs, drainage systems, water abstraction, land use change, river training, river erosion etc);
- Climate variability
- Climate change
- Natural catchment changes (natural changes in channel morphology)
- Problems linked to data.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

This section presents the results of the analysis that was done on rainfall and runoff. Results of the trend analysis as well as relationships between these two factors were also closely examined to see how far they could explain climate change, if any was detected. Grey areas were also going to be highlighted for further scrutiny. To assess trends, the non parametric Mann Kendall's test (a test of monotonic change of Y variable with time) shall be used.

5.2 Results

5.2.1 Regression analysis for rainfall and runoff data

a. Rainfall data

With Rusape as base station and the intercept being forced to zero for the best fit, the following results were obtained:

Regression Table

Station	R^2 value	Resultant equation
Mukandi	0.7	Yrus=0.45Xmukandi
Odzi Police Rail	0.68	Yrus=0.79Xodzi
Nyanga	0.79	Yrus=0.73Xnyanga
Multiple regression	0.83	Yrus=0.15Xmukandi+0.30Xodzi+0.33Xnyanga

Table 5.1: Regression table showing regression results

The obtained relationship equations were then used to fill in miss data in the bid to improve the quality of data. The results show that the R^2 values for single station regression analysis are smaller than those for multiple regression analysis, though the difference is not significant.

b. Runoff data

With station E72(Y) as base station and the intercept being forced to zero for the best fit, the following results were obtained:

Multiple Regression Table

Station	R^2 value	Resultant equation
E32(X_1)	0.55	$Y=0.21X_1$
E73(X_2)	0.91	$Y=0.08X_2$
E127(X_3)	0.90	$Y=0.34\ X_3$
E129(X_4)	0.90	$Y=0.22\ X_4$
MultipleRegression	0.92	$Y=-0.02X_1+0.05X_2+0.02\ X_3+0.09\ X_4$

Table 5.2: Regression table showing regression results

The obtained relationship equations were then used to fill in miss data in the bid to improve the quality of our runoff data. The results show that the R^2 values for single station regression analysis are smaller than those for multiple regression analysis, though the difference is not significant for all but station E32.

5.2.2Test for Correlation and regression

a. Nyanga and E127

There is a significant correlation(r=0.68) between runoff (E127) and rainfall (Nyanga) with a test statistic t=5.382 and p=0.00. Ho is rejected when p<0.05, therefore the hypothesis was rejected at 95 % confidence level. A positive correlation existed. Having detected a significant correlation, the two variables (Rainfall-station Nyanga and Runoff-station E127) were then regressed and the following relationship was obtained:

$$Y=0.0018X^{1.74}$$

Where: Y: Predicted Runoff data
X: Rainfall data

The coefficient of determination (R^2) is 61%, meaning that 61% of variation of runoff can be explained by rainfall.

(Graphs of regressions in APPENDIX C)

b. Odzi Police Rail and E127

There is a significant correlation(r=0.555) between runoff (E127) and rainfall (Odzi Police Rail) with a test statistic t=3.890 and p=0.04%. Ho is rejected when p<0.05, therefore the hypothesis was rejected at 95 % confidence level. Therefore, there is a positive correlation. Having detected a significant correlation, the two variables (Rainfall-station Odzi Police Rail and Runoff-station E127) were then regressed and the following relationship was obtained:

$$Y=0.008X^{1.173}$$

Where: Y: Predicted Runoff data
X: rainfall data

The coefficient of determination (R^2) is 47%, meaning that 47% of variation of runoff can be explained by rainfall.

(Graphs of regressions in APPENDIX C)

c. Rusape and E127

There is a significant correlation(r=0.660) between runoff (E127) and rainfall (Rusape) with a test statistic t=5.128 and p=0.00%. Ho is rejected when p<0.05, therefore the hypothesis was rejected at 95 % confidence level. Therefore, there is a positive correlation. Having detected a significant correlation, the two variables (Rainfall-station Rusape and Runoff-station E127) were then regressed and the following relationship was obtained:

$$Y=0.0277X^{1.354}$$

Where: Y: Predicted Runoff data
X: Rainfall data

(Graphs of regressions in APPENDIX C)

The coefficient of determination (R^2) is 48%, meaning that 48% of variation of runoff can be explained by rainfall.

d. Mukandi and E127

There is a significant correlation(r=0.588) between runoff (E127) and rainfall (Mukandi) with a test statistic t=4.233 and p=0.02%. Ho is rejected when $p<0.05$, therefore the hypothesis was rejected at 95 % confidence level. Therefore, there is a positive correlation. Having detected a significant correlation, the two variables (Rainfall-station Mukandi and Runoff-station E127) were then regressed and the following relationship was obtained:

$$\mathbf{Y=0.047X^{1.505}}$$

Where: Y: Runoff data

X: Predicted rainfall data

The coefficient of determination (R^2) is 59%, meaning that 59% of variation of runoff can be explained by rainfall.

(Graphs of regressions in APPENDIX C)

To validate the above results, ANOVA was done and the following results were obtained:

ANOVA table

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3251368	4	812842	70.56287	1.75E-35	2.423286
Within Groups	2015895	175	11519.4			
Total	5267263	179				

Table 5.3: ANOVA table of results

The analysis provides a test of the hypothesis that each sample is drawn from the same underlying probability distribution against the alternative hypothesis that underlying probability distributions are not the same for all samples. The p- value for f=70.56 is $1.75*10^{-35}$ which is significantly less than p=0.05. Therefore Ho is rejected. Therefore the data reflected sufficient evidence to support the models postulated.

5.2.3 Trend analysis

Before trend analysis was carried out, test for normal distribution was done and the results were that for all runoff and rainfall stations, p=0.00 which is $p\leq0.05$. Therefore, the assumption of normal distribution was rejected in light of the above evidence. Therefore, non parametric tests were preferred and thus used in the trend analysis. This was done to justify the reason for choosing the non parametric Mann Kendall's trend test. **(See APPENDIX C).**All trend analyses were done in conjunction with tests for independence and equal distribution.

5.2.3.1 Rainfall data

5.2.3.1.1 before resampling data.

a. Test for independence and equal distribution

Kendall's Turning point test (KTP) for independence and equal distribution was used under the following hypothesis:
Ho: series independent and equally distributed
H1: series not independent
Ho is rejected when p≤5%.
Results are shown below:

Table of Results

Station	KTP test statistic	P (%)	MK test Statistic	P (%)	Decision (R-resempling) (N-No resempling)
Rusape	-7.46	0.01	-0.72	47.05	R;series dependent
Mukandi	-7.57	0.01	-2.56	1.05	R;series dependent
Odzi	-14.77	0.01	-0.36	71.55	R;series dependent
Nyanga	-7.57	0.01	2.46	1.39	R;series dependent

Table 5.4: Statistical analysis results before resampling

The above results showed that all the stations had p<0.05 in the Kendall's test, therefore the Null hypothesis was rejected in favor of the alternative that the data were dependent and thus had auto correlation. Hence the need to resample the data using block permutation or block bootstrapping before Trend analysis as shown below.

5.2.3.1.2 after resampling data

Station	**Test**	**Kendall's Test**		**Mann Kendall's Trend Test**	
		KTP test statistic	P (%)	MK test Statistic(S)	P (%)
Rusape	Block permutation	-7.47	30.5	-0.72	31.69
	Block bootstrapping	-7.47	40.28	-0.72	32.42
Mukandi	Block permutation	-7.57	11.4	-2.56	0.27
	Block bootstrapping	-7.57	37.47	-2.56	0.27
Odzi	Block permutation	-14.77	25.4	-0.36	60.83
	Block bootstrapping	-14.77	43.71	-0.36	59.68
Nyanga	Block permutation	-7.57	60.51	2.46	0.58
	Block bootstrapping	-7.57	52.87	2.46	0.38

Table 5.5: Statistical analysis results after resampling

The above results showed that all the rainfall stations had p>0.05 in the Kendall's test, therefore the Null hypothesis of independence was retained. The data therefore had no auto correlation that would affect the Trend analysis. Therefore the above Trend analysis results were adopted as they were free from auto correlation as shown from the test results.

b.Detailed Analysis of results

Only results from bootstrapping were used in the Trend analysis as in essence both test had similar results. Monthly rainfall data (mm/month) were also plotted against months for the specified time period provided for each station to augment findings.

Station Rusape

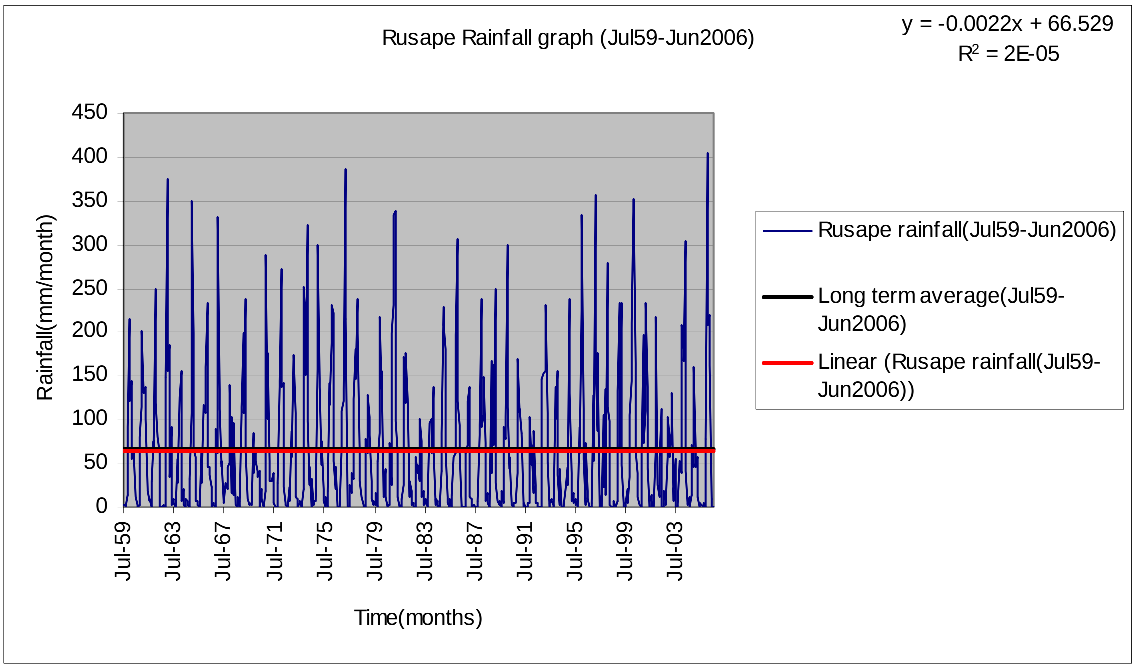

Figure 5.1: Station Rusape time series and trend line

The trend line shows a negative gradient of -0.002. This shows that over time, rainfall is decreasing though at a very small rate. The graph also shows that the trend line is almost parallel to the mean line as it is obscured. Mann Kendall's test, however showed a test statistic of S=-0.72 with p=0.32 (p>0.05) at 95% confidence level. This means that the Ho hypothesis of no change is retained. There is therefore no significant Trend at 95% confidence level. There is therefore no significant change in rainfall on this station over time. Rate of change of slope with respect to time is -0.0013.

Station Mukandi

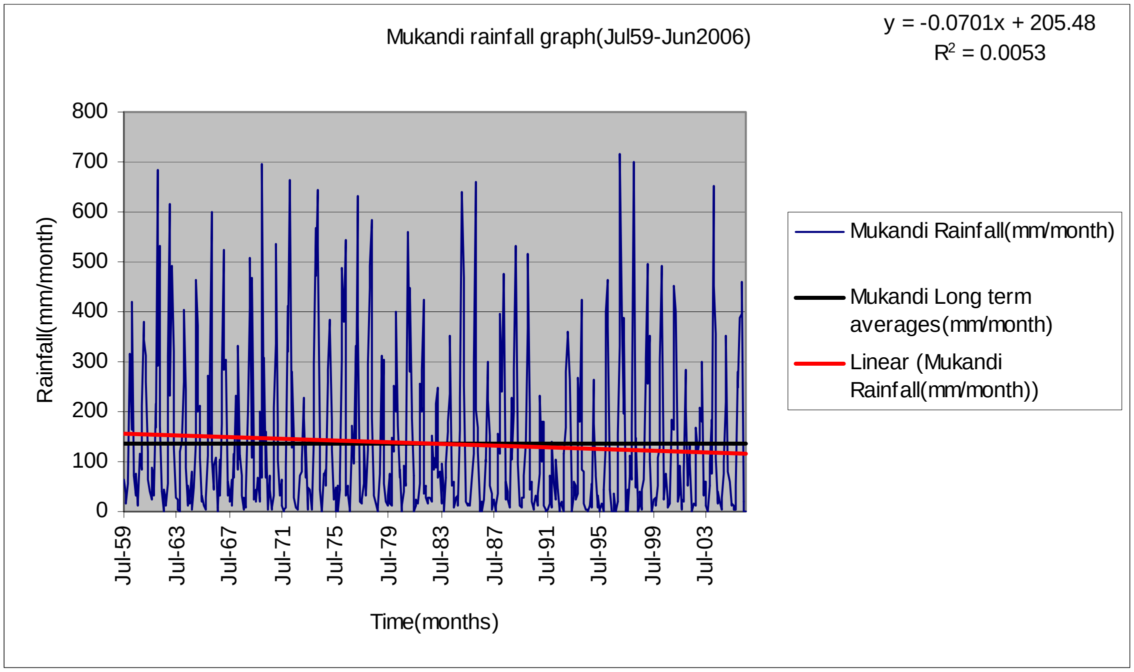

Figure 5.2: Station Mukandi time series and trend line

The trend line shows a negative gradient of -0.07. This shows that over time, rainfall is decreasing. The graph also shows that the trend line is dropping and crosses the mean line around 1980. Mann Kendall's test, however showed a test statistic of S=-2.56 with p=0.0027 ($p \leq 0.05$) at 95% confidence level. This means that the Ho hypothesis of no change is rejected in light of the evidence that at 95% confidence level, $p \leq 0.05$. Therefore, the Trend is significant at 95% confidence level. There is a drop in rainfall on this station over time. Rate of change of slope with respect to time is -0.00068.

Station Odzi Police Rail

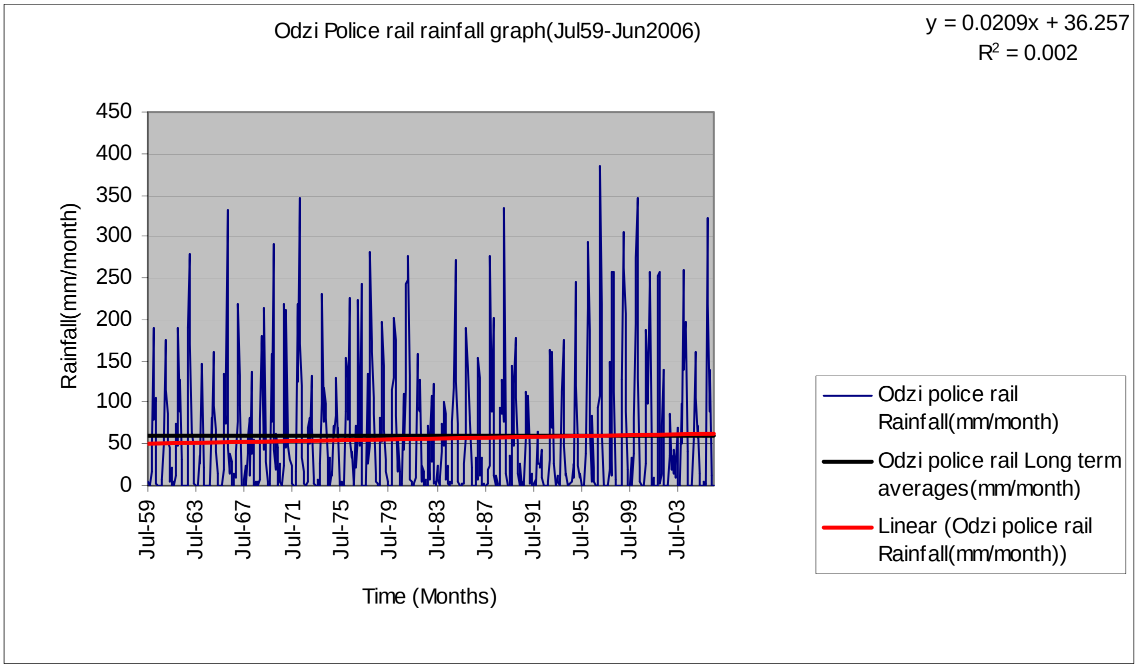

Figure 5.3: Station Odzi Police Rail time series and trend line

The trend line shows a positive gradient of +0.02. This shows that over time, rainfall is increasing. The graph also shows that the trend line is rising and crosses the mean line around 1989. Mann Kendall's test, however showed a test statistic of S=-0.36 with p=0.60 (p>0.05) at 95% confidence level. This means that the Ho hypothesis of no change is retained. Though a slightly drop exists (S=-0.36), it is not significant in the light of the evidence that p=0.60 at 95% confidence level. There is therefore no significant change in rainfall on this station over time. Rate of change of slope with respect to time is -2.19E-005.

Station Nyanga

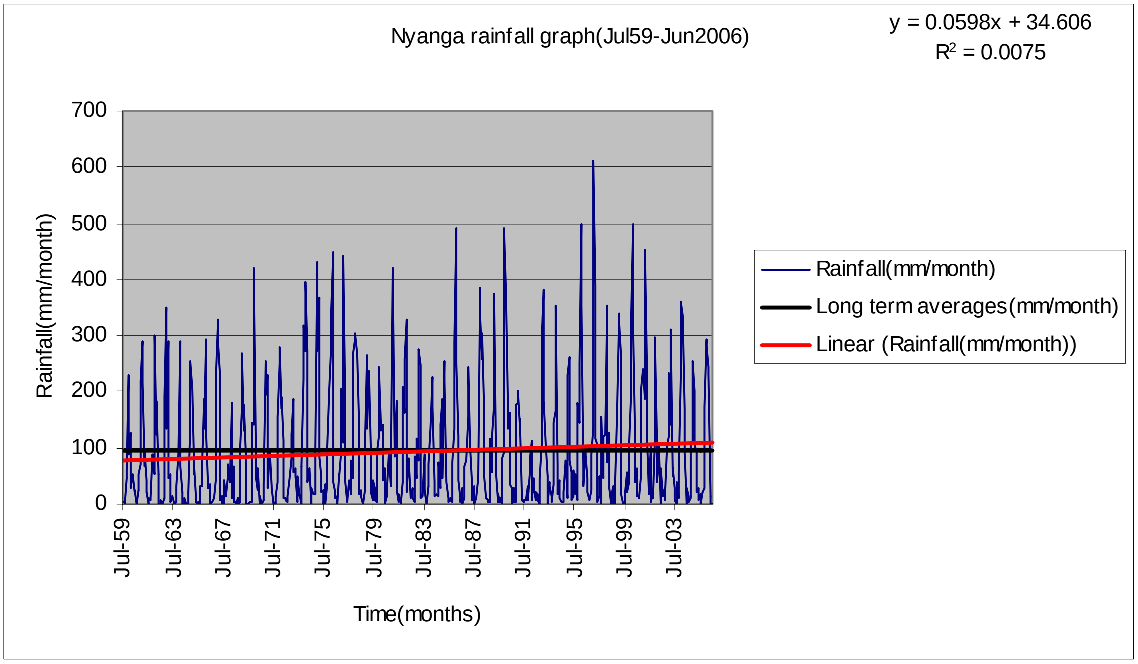

Figure 5.4: Station Nyanga time series and trend line

The trend line shows a positive gradient of +0.06. This shows that over time, rainfall is increasing. The graph also shows that the trend line is rising and crosses the mean line around 1984. Mann Kendall's test, however showed a test statistic of S=+2.46 with p=0.0016 ($p \leq 0.05$) at 95% confidence level. This means that the Ho hypothesis of no change is rejected in light of the evidence that at 95% confidence level, $p \leq 0.05$. The Trend is significant at 95% confidence level. There is therefore, a rise in rainfall as S=+2.46 which means that the correlation of rainfall with respect to time is positive. Rate of change of slope with respect to time is +0.00069.

c. Discussion of Results

Rusape and Odzi Police rail stations showed no significant change in rainfall over the 1959-2006 period. Mukandi showed a negative trend or drop in rainfall over the same period of 1959-2006. However, Nyanga station showed a rising trend in rainfall over the same period. Such a variation within the same catchment is expected under the given conditions of rises in temperature. Literature has shown that temperature increase can result in two extreme weather conditions, a drought or a flood. Therefore, this could be the reason for decline in rainfall over station Mukandi and an upward trend over Nyanga. However, further a further study is necessary to really establish the main causes of these two contrasting outcomes.

5.2.3.2 Runoff data

5.2.3.2.1 before resampling data.

a. Test for independence and equal distribution

Kendall's Turning point test (KTP) for independence and equal distribution was used under the following hypothesis:

Ho: series independent and equally distributed

H1: series not independent

Ho is rejected when p≤5%.

Results are shown below:

Table of Results

Station	KTP test statistic	P (%)	MK test Statistic	P (%)	Decision (R-resampling) (N-No resempling)
E32	-19.07	0.01	-4.68	0.01	R;series dependent
E72	-17.03	0.01	-1.59	11.27	R;series dependent
E73	-17.75	0.01	-3.63	0.03	R;series dependent
E127	-17.8	0.01	-4.34	0.01	R;series dependent
E129	-15.5	0.01	-2.85	0.44	R;series dependent

Table 5.6: Statistical analysis results before resampling

The above results showed that all the stations had $p<0.05$ in the Kendall's test, therefore the Null hypothesis was rejected in favor of the alternative that the data were dependent and thus had auto correlation. The negative sign of the test statistics means that there is positive correlations which increase the expected number of false positive outcomes for the Mann-Kendall test.

Hence the need to resample the data using block permutation or block bootstrapping before Trend analysis as shown below.

5.2.3.2.2 after resampling data

Station	Test	Kendall's Test		Mann Kendall's Trend Test	
		KTP test statistic	P (%)	MK test Statistic(S)	P (%)
E32	Block permutation	-19.07	9.16	-4.68	3.8
	Block bootstrapping	-19.07	35.5	-4.68	4.4
E72	Block permutation	-17.03	52.3	-1.59	44.1
	Block bootstrapping	-17.03	51.2	-1.59	43.14
E73	Block permutation	-17.74	0.32	-3.63	10.36
	Block	-17.75	20.8	-3.63	7.2

	bootstrapping				
E127	Block permutation	-17.00	31.4	-4.34	6.3
	Block bootstrapping	-17.00	44.7	-4.34	6.8
E129	Block permutation	-15.5	11.2	-2.85	23.6
	Block bootstrapping	-15.5	34.1	-2.85	24.4

Table 5.7: Statistical analysis results after resampling

The above results showed that all the stations (except for the block permutation analysis of station E73 with p=0.32) had p>0.05, therefore the Null hypothesis was retained. The data were therefore independent and no auto correlation was going to affect the Trend analysis. Therefore the above Trend analysis results were adopted as they were free from auto correlation as shown from the test results.

b. Detailed Analysis of results

Only results from bootstrapping were used in the analysis as the difference between the two is insignificant in all but one case as stated above. Monthly runoff data (mm/month) were also plotted against months for the specified time period provided for each station to augment findings.

Station E32

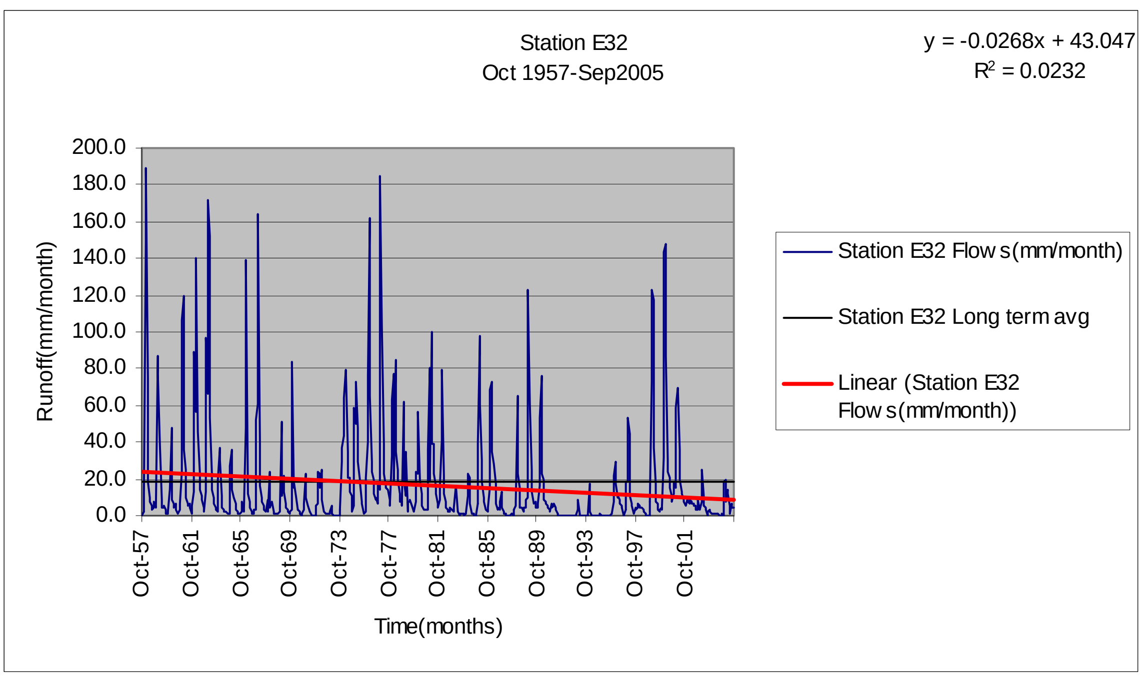

Figure 5.5: Station E32M time series and trend line

The trend line shows a negative gradient of -0.03. This shows that over time, flows are decreasing. The graph also shows that the trend line is dropping and crosses the mean line around 1970. Mann Kendall's test, however showed a test statistic of S=-4.68 with p=0.04 (p≤0.05) at 95% confidence level. This means that the Ho hypothesis of no change is rejected in favor of a significant change/drop in runoff at 95% confidence level. Runoff is therefore decreasing. Rate of change of slope with respect to time is -0.001.

Station E72

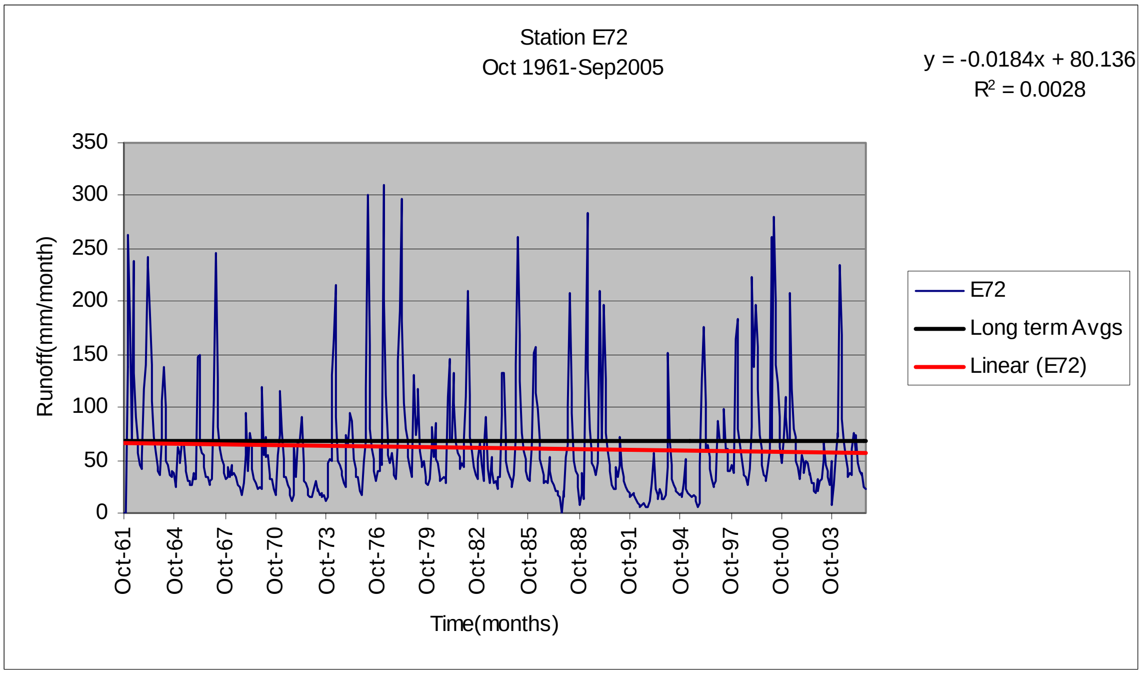

Figure 5.6: Station E72 time series and trend line

The trend line shows a negative gradient of -0.02. This shows that over time, flows are decreasing. The graph also shows that the trend line is dropping and crosses the mean line around 1968. Mann Kendall's test, however showed a test statistic of S=-1.59 with p=0.43 (p>0.05) at 95% confidence level. This means that the Ho hypothesis of no change is retained. Though a slightly drop exists (S=-1.59), it is not significant in the light of the evidence that p=0.43 at 95% confidence level. Rate of change of slope with respect to time is -0.00043.

Station E73

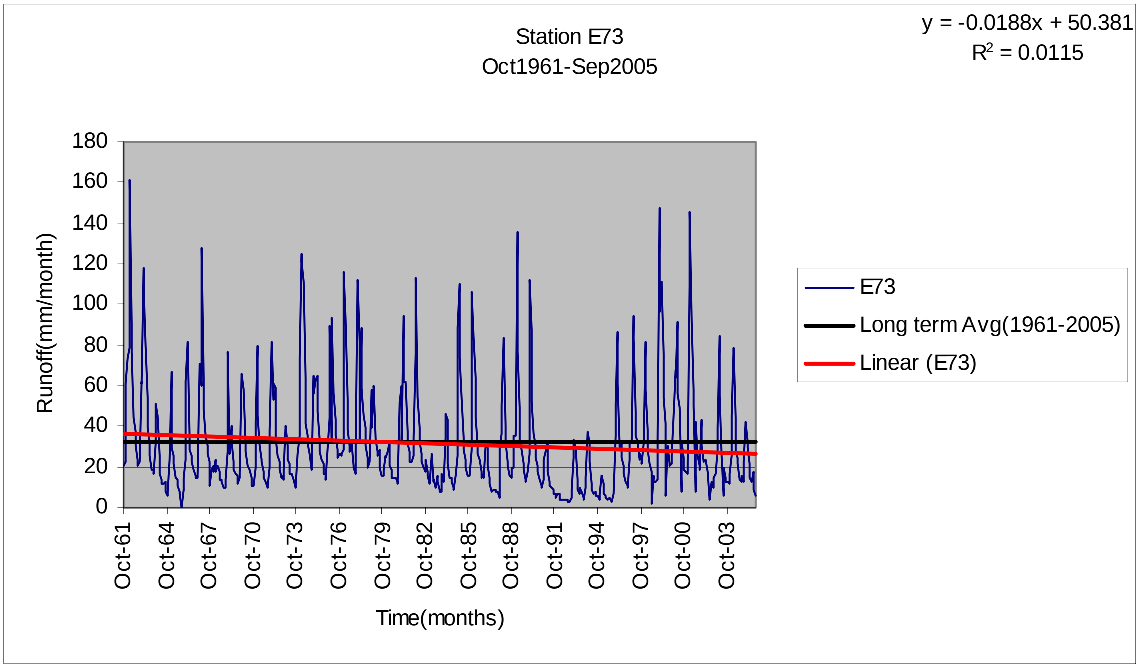

Figure 5.7: Station E73 time series and trend line

The trend line shows a negative gradient of -0.02. This shows that over time, flows are decreasing. The graph also shows that the trend line is dropping and crosses the mean line around 1980. Mann Kendall's test, however showed a test statistic of S=-3.63 with p=0.07 (p>0.05) at 95% confidence level. This means that the Ho hypothesis of no change is retained. Though a slightly drop exists (S=-3.63), it is not significant in the light of the evidence that p=0.07 at 95% confidence level. Rate of change of slope with respect to time is -0.001.

Station E127

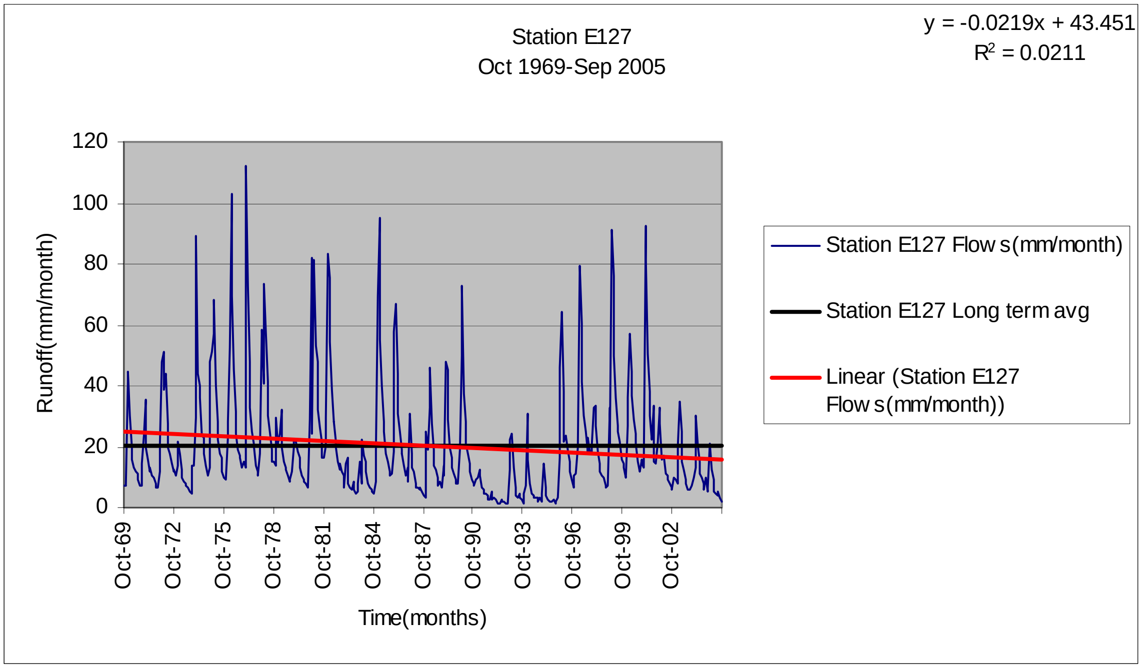

Figure 5.8: Station E127 time series and trend line

The trend line shows a negative gradient of -0.02. This shows that over time, flows are decreasing. The graph also shows that the trend line is dropping and crosses the mean line around 1984. Mann Kendall's test, however showed a test statistic of S=-4.34 with p=0.07 (p>0.05) at 95% confidence level. This means that the Ho hypothesis of no change is retained. Though a slightly drop exists (S=-4.34), it is not significant in the light of the evidence that p=0.07 at 95% confidence level. Rate of change of slope with respect to time is -0.0016.

Station E129

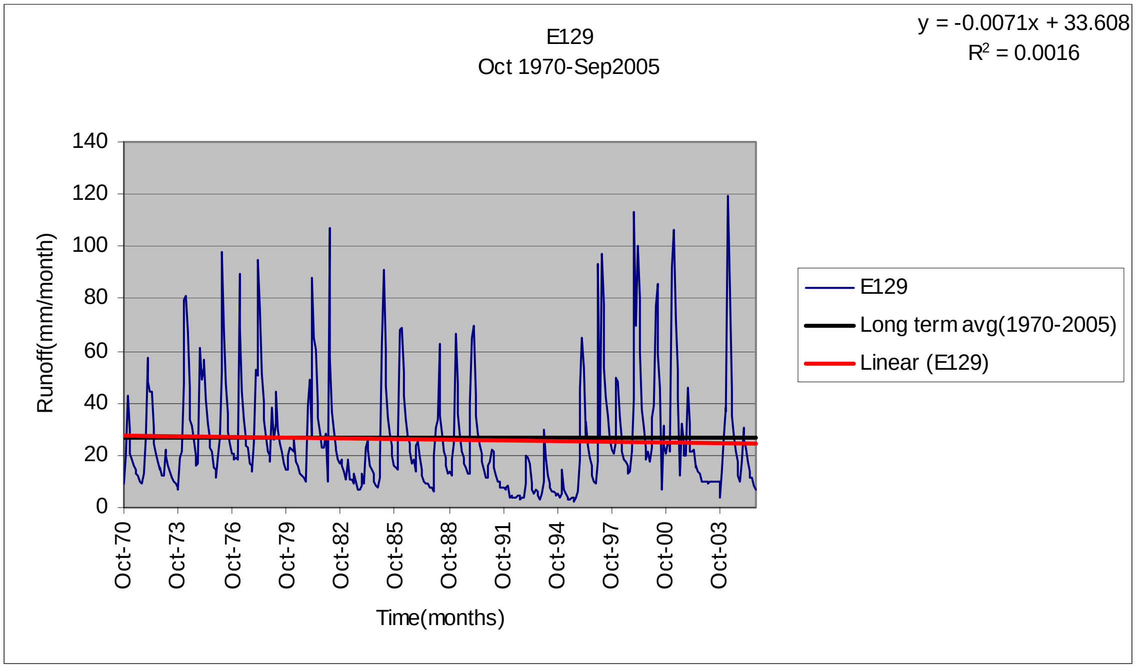

Figure 5.9: Station E129 time series and trend line

The trend line shows a very small negative gradient of -0.007. This shows that over time, flows are decreasing but at a very slow rate. The graph also shows that the trend line is dropping and crosses the mean line around 1980. Mann Kendall's test, however showed a test statistic of S=-2.85 with p=0.14 (p>0.05) at 95% confidence level. This means that the Ho hypothesis of no change is retained. Though a slightly drop exists (S=-2.85), it is not significant in the light of the evidence that p=0.07 at 95% confidence level. Rate of change of slope with respect to time is -0.00096.

Discussion of Results

Of the five stations, only station E32 showed a significant change in runoff over time. The rest of the stations had no significant downward trends at 95% confidence level. The further away the test statistics(S) values are from 0 the more significant a trend. A further analysis into the possible causes of this difference was done by looking at land use patterns in the catchment area supplying flows through station E32 (See Figures 5.10 and 5.11). This particular station is on the irrigation board of the Odzani river. Thus, this decline is most likely explained by an increase in abstractions by irrigators.

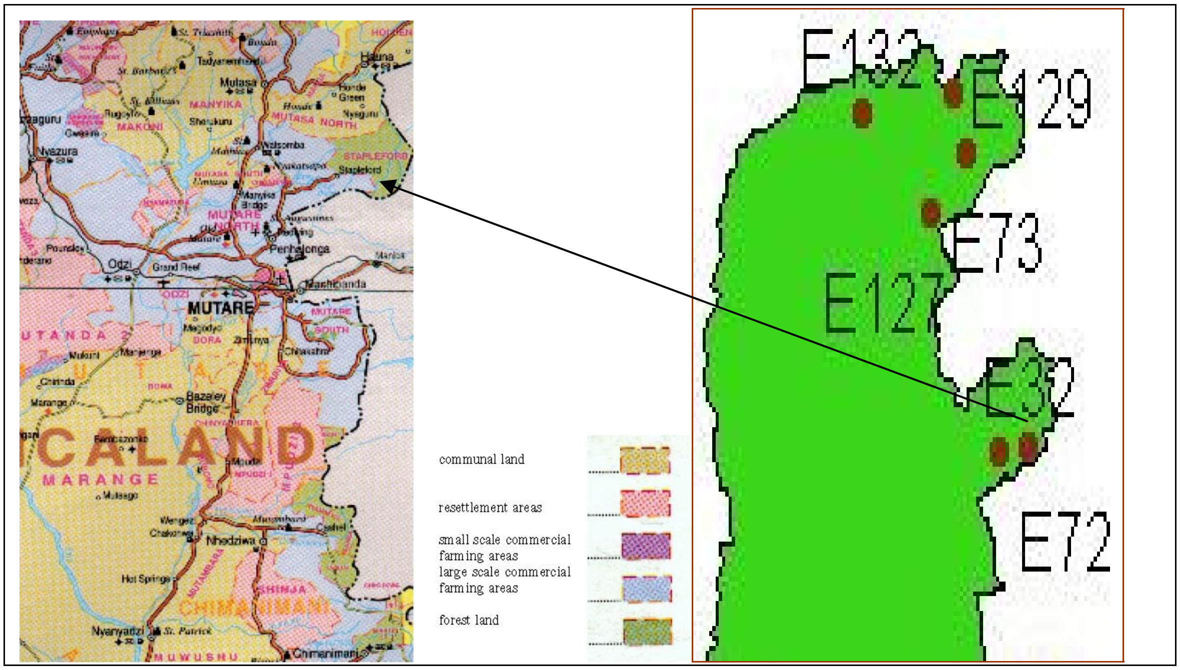

Figure 5.10: Odzi Landuse map

Figure 5.11: Extract of Odzi subcatchment runoff stations

The land use map of the sub-catchment shows that station E32 is in a catchment area where there is mainly active forestry. Just above this forestry land use, is communal land use. Deforestation, as a likely situation in communal areas as well as stream bank cultivation, all can very well contribute to changes in runoff.

5.2.4 Potential Catchment Yield

5.2.4.1 Analysis

	Q10(10^3m^3)	Q4(10^3m^3)
Dam A	**172364**	**151653**
Dam B	**269385**	**239677**
Yield at 4% risk level(Q4)=0.95Q10*-0.05*(MAR)		

Table 5.8: Catchment yields at 10% and 4% risk levels.

Catchment yield for Dam A (Assumed Sub zone O4) was found to be 172364 *10^3 m^3 at 10% risk factor. At 4% risk factor, it was found to be 151653 *10^3m^3. Catchment yield for Dam B (Assumed Sub zone O5) was found to be 269385 *10^3 m^3 at 10% risk factor. At 4% risk factor, it was found to be 239677 *10^3m^3. The Save catchment yield value (old blue book) is given as 0.75*10^9 m^3. Figure 5.9 below shows the percentage yield ratios of Dams A and B to the Save yield and percentage comparisons of catchment areas between Save and the Catchment areas for Dams A and B. Save has a Catchment area of about 7834 Km^2.

Comparison with Save Catchment yield			
Yield Save=	750000	10^3m^3	
Dam A/Save*100=	22.981802	%	
Dam B/Save *100=	35.918064	%	
Catchment Area (Save)	7834	km^2	
Catchment area ratios			
Dam A Catchment area/Save Catchment area*100		2.9797	%
Dam B Catchment area/ Save Catchment area*100		4.12803	%

Table 5.9: Yield and Catchment Area Comparison between Dams A, B and Save.

The percentage ratios of yield between Dam A and Save shows that yield in Dam A was about 23% of that of Save. In other words, it is contributing 23% of the total Save yield. In terms of area, Dam A Catchment area was found to be about 3% of that of Save Catchment. Dam B yield was about 36% of that of Save. In other words, it is contributing 36% of the total Save yield. In terms of area, Dam B Catchment area was found to be about 4% of that of Save Catchment.

Comparing Yield values from old blue book with calculated values				
E04	88200	10^3m^3		
E05	178210	10^3m^3		
Area E04=	1117	Km^2		
Area E05=	1393	Km^2		
Area coverage for Stations E32 and E72-Supplying Dam A=			233.43	km^2
Area coverage for Stations E73, E127 and E129- Supplying Dam B=			323.39	Km^2
Q10(E04)/Q10(Area A)	0.511709			
Q10(E05)/Q10(AreaB)	0.661543			
Area Ratios				
Area E04/AreaA=	4.78516			
AreaE05/Area B=	4.307493			

Table 5.10: Comparison of calculated and old blue book results

The ratios of yield between Dam A and EO4 (new) show that yield in EO4 was about 51 % that of Dam A. In terms of area, EO4 Catchment area was found to be about 5 times that of Dam A. The area used was therefore much smaller than that of sub region EO4, though the yield was about 49% larger than that of EO4. EO5 yield was about 66% that of Dam B. In terms of area, EO5 Catchment area was found to be about 4 times that of

Dam B. The area used for calculations was therefore much smaller than that of sub region EO5, though the yield was about 34% larger than that of EO5.

Comparing Yield values from New blue book with calculated values				
E04	145116	10^3m^3		
E05	217730	10^3m^3		
Area E04=	1073	Km^2		
Area E05=	1414	Km^2		
Area coverage for Stations E32 and E72-Supplying Dam A=			233.43	km^2
Area coverage for Stations E73, E127 and E129- Supplying Dam B=			323.39	Km^2
Q10(E04)/Q10(Area A)	0.841918			
Q10(E05)/Q10(AreaB)	0.808247			
Area Ratios				
Area E04/AreaA=	4.596667			
AreaE05/Area B=	4.37243			

Table 5.11: Comparison of calculated and new blue book results

The ratios of yield between Dam A and EO4 (new) show that yield in EO4 was about 84 % that of Dam A. In terms of area, EO4 Catchment area was found to be about 5 times that of Dam A. The area used was therefore much smaller than that of sub region EO4, though the yield was about 16% larger than that of EO4. EO5 yield was about 81% that of Dam B. In terms of area, EO5 Catchment area was found to be about 4 times that of Dam B. The area used for calculations was therefore much smaller than that of sub region EO5, though the yield was about 20% larger than that of EO5.

5.2.4.2 Calculating and analyzing Life line satisfaction index

Per capita water requirement assessment		
Q(Total yield of sub catchment)	441748.99	10^3m^3
Percapita water requirement(Lifeline)	18.25	m^3/annum
Number of persons getting Lifeline water /yr	24205.424	
Population density=	60	persons/km^2
Total area of sub catchment	556.82	Km^2
Average subcatchment population	33409.2	

Table 5.12: Per capita life line water requirement assessment

Lifeline water requirement is the amount of water that is required by an individual to for the purposes of drinking, sanitation, bathing and food preparation. This however, excludes water required to grow food for one person which is estimated at about 1*10^3m^3/annum (Gleick, 1996). Calculations above prove that the Sub Catchment itself has an estimated population of 33409. It was calculated that 24206 persons of an estimated total population of 33409 could be sustained with life line water in the sub catchment. Therefore, these results show that the water situation in the sub-catchment is stressed. About 9000 out of about 34000 persons cannot be sustained (life line) by the available surface water. With the increase in population and the factoring in of water requirements by food grown, the above figure could be seen going up.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Rainfall, Runoff and Temperature

Results over that area have shown that rainfall is both decreasing (Mukandi at the rate of -0.00068) as well as increasing (Nyanga at the rate of +0.00069). Other stations have shown a no trend scenario. The modulus of the rate of change of rainfall on station Mukandi is more or less equal to that for Nyanga. Thus, the effect of one is offset by the other. That could probably explain why runoff showed a no significant trend scenario. Further study into the rainfall patterns of this catchment is therefore recommended so as to ascertain the cause of this contrast.

Runoff according to literature, is affected by rainfall among other factors like land use. Runoff analysis results show that in principle climate change could not be justified hence the study's Null hypothesis of no change is retained. Looking at the decline in runoff for station E32 and also looking at the land use map associated with that station, it was shown that that station data were most probably affected by land use change more than climate change.

The area influencing flows to this station is no longer pristine. Hence, it is recommended that a further study into the flow regime of this and other river systems within this subcatchment be done, especially the naturalization of flows so as to get a better picture of the more or less once original flows. This study also recommends that issues of current land use patterns and water abstractions be thoroughly understood. This will help better the results obtained in the Trend analysis so that the situation on the ground could be better understood. It is also known that land use activities have an impact on the water resources affecting both the quantity and quality of catchment water. Thus, it is also strongly recommended that water resource management be integrated with land use management.

Literature has shown that mean temperatures across the globe have risen by 0.3-0.6 ºC since the late 19^{th} century and global sea levels have also risen between 10 and 25 cm (IPCC, 1995, 2001). The consequences of such increases are the advent of extreme climatic conditions among other issues like disease increases. Therefore, though the results given of rainfall and runoff have not truly proved the presence of climate change, these declared temperature signals are enough to cause the water experts and managers to seriously look into means and ways of curbing this impending problem. It is there to stay. On this note, this study recommends that a closer analysis of temperature patterns in this micro catchment be done. Temperature and rainfall are direct indicators of existence or absence of climate change.

The higher the temperatures, the higher the evaporations on dams with in the catchment. Thus building of more dams to increase yield, though it is a good idea is not the best under the given circumstances. Engineering plus integration which includes sustainable development are the best solutions to help the environment adapt to the changing climate as judged by the increase in temperature.

6.2 Water Availability

Results have shown that the micro catchment had a total yield value of about 441749 * 10^3 m^3. This is about 59% of the total yield of the Save catchment based on calculations. Study area catchment size was about 7% that of Save, yet the net contribution of the yield from the study area is about 59%. This shows therefore, that the greatest amount of rainfall most probably falls in that part of the Save catchment. It was also shown that the micro catchment yield was about 1.2 times that of sub regions EO4 and EO5 combined. This shows that the calculated yield compares very well with that of the sub regions combined.

However, calculations also showed that the sub catchment's available surface water can not sustain its population in terms of providing it with life line water only. Thus, it is strongly recommended that other aspects like water harvesting, water use efficiency and exploration of ground water be looked into.

Climate change results did not justify the existence of climate change. This would mean that future available water resources could easily be estimated (predictability high) and also that the available developed water storage facilities (dams) within the catchment can still achieve their purpose.

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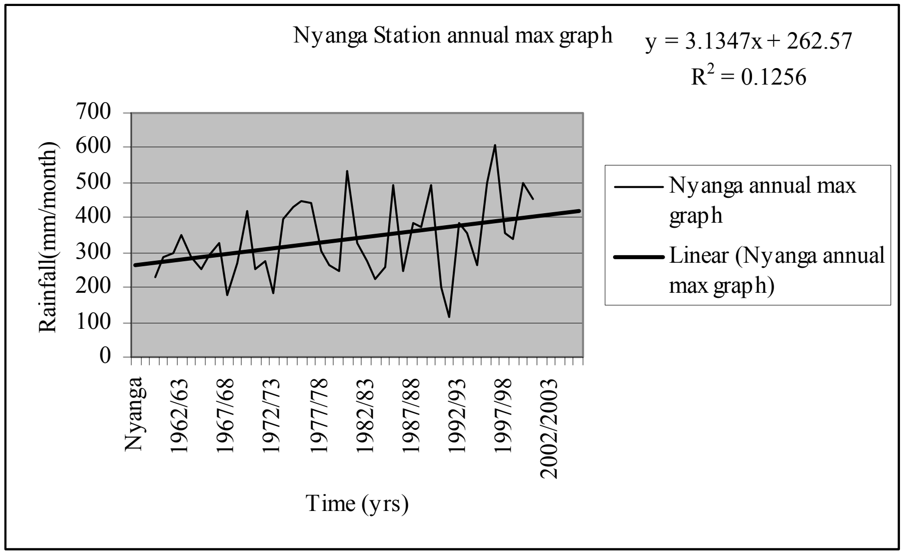
APPENDIX A
RAINFALL AND RUNOFF ORIGINAL DATA

Nyanga Exp. Stn Lat 18 13 Long 32 44													
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Total**
1959/60	1.8	3.3	0.0	44.2	61.0	229.1	88.6	125.7	29.0	51.6	22.4	26.2	682.9
1960/61	1.0	0.0	26.2	54.4	72.4	217.9	288.8	216.4	66.8	94.7	43.4	22.1	1104.1
1961/62	1.5	11.2	5.8	10.2	86.9	53.3	300.5	122.4	185.4	51.6	1.0	0.0	829.8
1962/63	5.8	2.0	0.0	11.2	191.0	350.5	135.1	289.8	47.0	51.6	1.8	15.0	1100.8
1963/64	0.0	0.0	5.3	30.7	89.4	88.9	288.8	65.5	22.1	0.0	0.0	10.2	600.9
1964/65	0.0	0.0	0.0	21.6	137.4	255.3	203.5	53.8	63.0	6.9	2.0	0.0	743.5
1965/66	2.3	0.5	30.5	31.0	78.5	186.4	134.1	293.1	127.3	27.9	31.5	34.3	977.4
1966/67	0.0	5.3	8.9	9.9	44.2	228.9	327.2	288.0	229.1	8.4	13.5	0.0	1163.4
1967/68	0.0	41.4	15.5	18.3	49.0	72.4	40.6	179.8	10.2	68.6	2.5	2.0	500.3
1968/69	0.0	10.2	0.0	2.0	88.1	168.7	268.7	130.6	177.0	83.3	1.0	0.5	930.1
1969/70	0.8	3.8	3.0	146.1	140.7	419.1	110.0	48.3	23.4	62.5	0.0	15.2	972.9
1970/71	1.5	0.0	7.6	35.8	253.5	194.1	229.6	28.7	94.5	33.0	28.7	0.0	907.0
1971/72	3.0	0.0	15.9	40.3	156.9	250.5	277.8	168.5	191.3	111.9	9.6	9.5	1235.2
1972/73	5.7	3.1	14.2	44.7	79.8	125.3	186.3	56.2	63.9	50.8	2.9	48.1	681.0
1973/74	14.7	18.1	0.0	67.7	222.7	318.8	271.3	397.2	273.8	39.3	65.0	0.5	1689.1
1974/75	26.6	16.8	18.5	18.6	101.9	431.1	270.6	366.2	84.6	50.3	20.0	23.7	1428.9
1975/76	0.9	34.0	0.0	37.0	100.5	204.3	282.8	341.6	448.4	37.8	19.6	12.3	1519.2
1976/77	12.5	1.3	51.5	49.2	91.9	206.8	110.1	440.5	193.2	40.8	2.3	2.6	1202.7
1977/78	42.7	17.4	78.2	46.3	267.6	295.1	305.7	268.7	270.9	145.0	16.9	25.5	1780.0
1978/79	13.8	0.0	0.0	23.9	102.5	265.8	134.7	237.1	95.6	20.2	7.2	43.8	944.6
1979/80	26.9	6.2	3.4	93.0	120.7	245.5	136.6	131.8	142.5	41.5	62.3	1.5	1011.9
1980/81	15.2	23.3	87.8	31.7	67.2	422.3	406.0	530.9	86.6	182.7	25.9	3.2	1882.8

1981/82	19.2	2.9	0.3	38.5	209.9	163.0	256.5	328.3	19.6	82.0	9.4	11.3	1140.9
1982/83	27.1	9.7	5.1	84.0	47.2	116.9	77.2	275.5	248.1	11.7	15.5	12.6	930.6
1983/84	88.3	24.4	0.0	30.3	71.4	137.7	138.7	226.4	174.8	38.3	12.7	16.5	959.5
1984/85	18.3	14.7	72.7	29.8	140.2	187.1	44.2	255.5	217.6	37.8	12.0	4.8	1034.7
1985/86	10.1	7.3	2.5	75.4	135.4	289.3	491.8	250.9	118.5	42.7	10.9	2.5	1437.3
1986/87	28.5	0.0	9.9	66.4	76.4	155.4	245.5	92.1	98.1	31.8	6.1	30.8	841.0
1987/88	0.0	9.4	11.1	44.2	46.8	384.0	330.8	259.6	304.1	164.7	48.9	12.1	1615.7
1988/89	7.4	3.7	3.6	116.1	55.7	122.0	178.1	375.0	83.6	57.5	4.6	18.2	1025.5
1989/90	3.0	12.3	0.9	83.0	90.4	491.0	383.1	168.0	134.5	163.6	35.4	29.1	1594.3
1990/91	1.6	27.1	2.7	3.3	177.0	180.7	199.9	140.1	152.4	12.8	5.9	2.4	905.9
1991/92	5.8	8.1	33.2	5.5	54.4	79.4	113.3	8.0	46.8	27.4	7.7	21.2	410.8
1992/93	17.9	5.7	0.0	45.0	105.0	292.9	382.2	183.3	106.3	48.2	0.0	37.7	1224.2
1993/94	33.3	12.6	3.8	36.8	144.8	166.5	355.0	70.4	16.2	41.1	10.6	1.8	892.9
1994/95	4.4	4.6	22.3	78.6	12.3	231.5	263.3	78.2	56.4	6.5	14.7	58.5	831.3
1995/96	18.6	52.7	6.9	180.2	144.3	252.0	497.7	354.5	68.7	30.3	92.0	44.7	1742.6
1996/97	20.0	6.6	7.4	25.2	89.7	133.5	610.0	387.4	117.4	104.5	4.3	13.1	1519.1
1997/98	51.2	0.0	156.9	45.9	119.9	125.0	353.0	72.8	128.0	27.6	0.0	12.8	1093.1
1998/99	31.9	0.0	0.0	41.6	162.6	164.9	339.2	320.2	261.2	16.3	0.8	0.0	1338.7
1999/2000	21.3	55.1	22.7	39.8	107.4	193.9	322.8	499.0	312.4	125.1	38.6	63.1	1801.2
2000/2001	14.5	14.9	11.5	50.1	201.8	239.2	186.7	452.8	233	119.3	17.3	33.6	1574.7
2001/2002	102.0	2.8	20.8	10.6	112.0		111.7	38.8		103.9	0	63.5	
2002/2003	15.1	27.0	7.5	96.0	101.3	121.9	232.2	140.9	311.4	49.7	62.2	26.7	
2003/2004	8.4	0.4	37.9	11.9	55.2	224.6	361.9	335.7	170.7	91.9	0.0	27.7	
2004/2005	13.1	3.9	11.6	109.3	109.7	255.2	199.9	105.5	92.1	21.1	27.7		
2005/2006	19.1	0.1	20.7	28.1	172.0	293.0		245.7	229.8				

Table A1: Nyanga original data



FigureA1: Nyanga graph of original data

Mukandi Lat 18 41 Long 32 49													
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Total**
1959/60	62.5	36.1	14.7	55.6	62.0	314.5	165.6	419.9	82.3	73.4	33.0	75.2	1394.8
1960/61	11.9	16.3	116.3	83.6	212.6	381.5	343.9	312.9	261.1	119.4	63.2	39.1	1961.8
1961/62	24.6	86.6	67.1	31.5	217.2	169.4	685.8	290.6	530.4	173.5	38.9	0.0	2315.6
1962/63	42.9	22.1	12.7	55.6	311.7	614.2	231.6	491.7	319.8	129.8	26.4	30.0	2288.5
1963/64	24.6	3.6	0.0	120.7	141.2	259.8	405.9	244.3	89.4	13.0	52.6	16.0	1371.1
1964/65	26.9	81.8	2.3	47.5	138.4	464.1	371.6	200.7	213.1	109.7	20.1	34.0	1710.2
1965/66	10.7	5.1	26.4	113.0	271.5	150.1	277.1	598.2	105.4	42.4	91.9	106.4	1798.2
1966/67	1.8	9.1	103.1	30.7	176.6	275.3	525.3	284.2	304.8	33.0	61.5	31.0	1836.4
1967/68	18.8	65.5	11.9	116.8	68.1	233.7	83.6	332.2	103.4	111.5	72.4	32.3	1250.2

1968/69	5.3	27.7	6.6	41.9	194.8	409.2	510.0	106.2	467.4	136.7	24.1	44.7	1974.6
1969/70	18.8	68.6	20.3	200.2	67.8	696.0	135.9	308.1	68.8	158.8	2.8	70.4	1816.5
1970/71	45.5	5.6	8.1	33.8	208.8	335.3	535.4	171.5	102.1	33.3	66.0	10.2	1555.6
1971/72	0.0	2.5	6.1	89.0	413.5	321.0	663.3	128.6	279.2	152.4	26.9	8.3	2090.8
1972/73	6.1	4.5	9.7	72.3	81.8	102.7	227.0	187.3	66.1	130.5	2.3	46.9	937.2
1973/74	45.0	45.0	4.1	144.3	294.9	569.6	473.3	645.7	531.8	152.7	44.5	0.0	2950.9
1974/75	76.6	72.0	83.9	50.6	259.9	284.2	384.7	369.6	178.6	124.8	22.9	47.1	1954.9
1975/76	*	50.2	0.0	43.5	71.5	303.8	487.5	378.5	544.6	33.4	50.5	36.9	2000.4
1976/77	4.3	1.1	140.5	171.7	94.5	333.4	134.4	630.1	370.5	38.1	19.0	17.7	1955.3
1977/78	25.3	55.4	138.2	32.4	124.5	296.5	447.4	490.5	586.0	187.5	41.8	32.2	2457.7
1978/79	16.4	0.0	7.3	74.8	81.7	311.5	141.2	302.4	56.1	18.8	13.8	33.5	1057.5
1979/80	77.6	15.4	12.0	150.0	121.3	250.1	201.0	398.8	173.8	69.2	84.1	0.7	1554.0
1980/81	10.7	38.1	91.4	50.3	65.9	561.4	280.8	446.3	202.1	188.4	70.5	1.6	2007.5
1981/82	11.2	26.0	15.6	54.8	254.2	200.4	284.4	424.2	34.3	53.2	29.8	14.5	1402.6
1982/83	29.7	27.4	20.4	152.1	84.2	108.5	86.4	216.6	246.1	68.5	78.8	17.7	1136.4
1983/84	98.0	39.5	0.0	68.2	95.4	159.2	179.7	235.6	351.0	50.5	59.4	6.2	1342.7
1984/85	25.5	28.5	33.0	13.5	165.7	226.8	641.4	469.2	253.3	27.0	21.8	12.5	1918.2
1985/86	16.5	10.5	11.4	66.4	115.4	294.9	659.4	204.7	167.4	118.2	20.5	0.0	1685.3
1986/87	19.0	0.0	25.5	102.1	100.0	301.8	224.0	154.0	52.0	37.0	4.5	23.7	1043.6
1987/88	0.0	11.0	37.0	158.0	117.0	398.0	251.0	239.2	474.9	25.4	60.0	39.0	1810.5
1988/89	22.5	9.0	8.5	226.5	102.2	201.4	282.3	531.3	132.9	94.7	11.0	10.7	1633.0
1989/90	7.5	26.9	29.1	70.9	137.0	370.0	514.3	199.5	43.5	61.6	21.5	4.0	1485.8
1990/91	10.5	30.1	12.4	35.5	77.0	232.4	102.0	180.7	181.0	11.5	2.5	0.0	875.6
1991/92	3.0	15.0	70.9	6.5	138.5	55.8	57.0	25.3	104.5	46.0	1.0	11.0	534.5
1992/93	18.5	13.8	0.0	114.9	167.9	280.0	353.9	359.0	265.3	47.3	0.0	33.0	1653.6
1993/94	59.3	53.4	22.7	36.6	268.2	181.7	425.7	83.6	81.7	17.1	3.0	5.4	1238.4

1994/95	3.2	0.4	10.1	57.9	8.3	262.7	174.7	75.1	72.2	7.3	32.9	0.0	704.8
1995/96	*	*	*	44.4	140.1	399.7	463.1	371.5	75.4	44.3	0.0	0.0	1538.5
1996/97	35.4	0.0	0.0	21.9	155.4	330.6	717.6	403.9	196.1	*	*	*	1860.9
1997/98	42.4	0.0	70.4	112.8	63.7	162.1	700.1	47.9	147.9	25.2	0.0	11.0	1383.5
1998/99	38.1	4	44	65.4	274.8	302.9	495.6	257.9	352.9	104.4	0	0	1940.0
1999/2000	25.8	27.9	12.7	51.6	109.7	129.6	301.5	490.6	436	78	25.8	74.6	1763.8
2000/2001	23.2	9	17	22.8	183.1	168.9	164.5	452.7	400.1	99.9	20.8	39.7	1601.7
2001/2002	93.4	4.9	23	19.6	80.4	284.8	207.6	52.0	136.4	96	8.2	*	1006.3
2002/2003	15.6	17.1	12.9	169.0	119.6	144.2	207.6	178.4	301.1	30.3	60.1	61.2	1317.1
2003/2004	13.7	0	51.9	97.1	183.6	77.0	653.6	451.5	357	106.5	17.5	40.8	2050.2
2004/2005	19.5	3	28	75.0	102.0	221.6	353.3	85.5	79.2	61.2	12.5	16.2	1057.0
2005/2006	10.5	2.2	4.8	52.0	278.1	248.7	389.7	397.7	460.2	*	0.0	0.0	1843.9

Table A2: Mukandi Original Station data

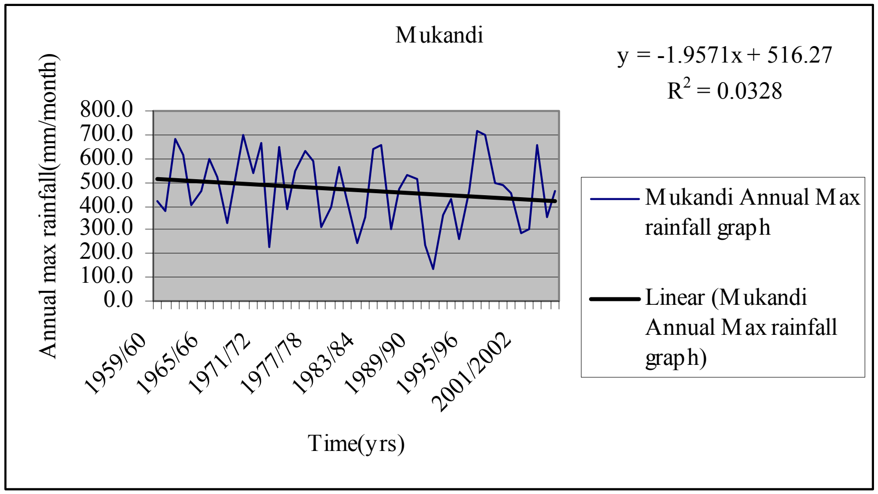


Figure A2: Mukandi annual max graph

Rusape Lat 18 32 Long 32 08

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
1959/60	1.8	1.5	1.0	14.7	92.2	214.6	120.1	144.5	55.4	61.2	65.0	11.4	783.4
1960/61	1.5	0.0	2.8	81.0	114.6	200.9	129.5	132.1	136.1	99.6	20.1	18.3	936.5
1961/62	5.8	9.1	0.0	29.2	75.4	68.3	248.9	119.6	80.0	61.7	1.0	0.0	699.0
1962/63	1.0	1.5	0.0	1.0	149.6	374.1	154.4	184.9	33.5	90.9	2.5	9.4	1002.8
1963/64	4.6	0.0	0.0	54.9	27.4	124.7	155.4	7.6	21.6	2.3	0.3	8.1	406.9
1964/65	7.4	2.3	0.0	32.0	106.7	348.5	197.6	65.3	57.7	7.1	7.9	3.0	835.5
1965/66	0.0	0.0	67.1	26.4	117.6	107.4	159.3	233.7	46.7	44.7	35.6	23.1	861.6
1966/67	0.0	3.6	3.0	0.0	89.2	61.7	332.0	134.6	112.5	46.2	52.8	6.1	841.7
1967/68	4.8	27.2	20.8	46.5	51.3	140.0	15.7	102.9	13.5	96.8	1.8	2.3	523.6
1968/69	0.0	12.4	0.0	6.4	106.9	113.5	198.4	106.9	238.0	63.8	8.9	2.0	857.2

1969/70	5.1	2.8	1.8	83.6	38.6	412.2	53.6	40.6	35.1	41.7	0.0	20.8	735.9
1970/71	8.1	0.0	0.0	17.5	288.0	100.8	177.0	52.1	29.0	28.7	38.1	4.1	743.4
1971/72	0.0	0.0	0.5	28.5	137.1	143.6	272.6	138.0	140.6	22.4	5.1	1.5	889.9
1972/73	0.5	0.0	22.5	7.0	87.7	57.3	174.5	107.6	10.8	10.2	0.0	4.2	482.3
1973/74	7.1	0.9	0.3	21.0	251.9	215.0	151.5	322.6	99.3	24.4	44.9	0.0	1138.9
1974/75	32.3	1.3	7.3	6.0	156.7	299.9	146.6	136.0	48.9	75.6	21.5	7.1	939.2
1975/76	0.0	11.7	0.0	18.7	141.3	116.0	188.3	231.3	221.0	52.7	21.1	45.9	1048.0
1976/77	0.6	0.0	0.0	65.5	109.5	121.8	134.5	386.7	215.8	0.5	0.0	0.9	1035.8
1977/78	24.7	15.2	39.7	32.7	123.6	180.9	145.7	238.7	198.3	62.9	29.7	12.2	1104.3
1978/79	1.2	0.0	0.0	76.8	61.8	128.2	103.7	83.3	29.9	9.6	2.3	7.4	504.2
1979/80	1.4	15.0	0.1	52.1	85.5	217.9	134.8	155.1	10.8	42.7	12.2	0.5	728.1
1980/81	2.8	1.2	72.8	25.0	198.9	230.9	333.6	338.4	98.3	63.3	11.9	0.0	1377.1
1981/82	1.3	0.2	8.6	25.8	170.2	118.4	175.0	122.7	12.3	30.5	17.6	1.4	684.0
1982/83	5.3	0.0	0.0	56.9	38.7	49.0	29.2	100.7	76.2	11.7	18.2	1.6	387.5
1983/84	5.7	9.8	0.0	10.6	96.3	99.9	61.9	136.6	64.4	2.5	8.9	6.5	503.1
1984/85	0.7	3.2	0.9	42.1	83.5	227.3	206.8	179.5	64.2	11.2	4.4	3.2	827.0
1985/86	9.2	1.0	14.4	58.1	62.4	197.3	307.2	121.1	93.5	62.6	1.8	0.0	928.6
1986/87	0.3	0.0	0.0	62.2	71.1	121.8	138.0	10.4	8.5	0.0	2.1	1.3	415.7
1987/88	0.0	0.0	6.2	82.1	93.7	237.1	91.4	105.3	148.9	73.6	6.5	16.5	861.3
1988/89	4.7	0.0	0.0	166.6	37.9	161.5	70.3	248.0	26.3	6.1	1.7	7.9	731.0
1989/90	0.0	19.2	4.4	92.0	77.1	103.5	300.2	113.9	43.2	56.8	3.7	1.9	815.9
1990/91	0.0	4.1	5.1	3.7	39.8	168.9	106.6	111.7	84.4	0.1	4.3	0.0	528.7
1991/92	0.0	1.0	5.4	4.6	101.8	47.7	70.6	16.6	85.9	25.8	4.0	4.2	367.6
1992/93	0.0	0.0	0.1	1.1	145.3	154.0	154.2	229.6	107.9	49.7	0.0	4.0	845.9
1993/94	10.1	6.0	2.3	1.1	137.8	100.4	154.2	37.6	1.3	42.9	0.8	0.0	494.5
1994/95	0.0	2.6	20.4	45.5	24.0	238.1	129.4	39.3	6.2	15.8	3.5	8.4	533.2

1995/96	2.6	7.4	0.3	91.6	62.4	223.4	334.4	111.5	54.2	1.5	73.5	17.8	980.6
1996/97	8.6	0.1	0.0	3.8	127.1	52.6	355.8	164.2	86.1	176.4	2.5	0.0	977.2
1997/98	14.5	0.0	105.3	23.3	133.9	14.5	277.6	115.0	99.1	1.7	0.0	0.0	784.9
1998/99	6.0	0.0	0.0	5.9	132.6	233.0	508.0	233.8	47.5	5.4	0.0	0.0	1172.2
1999/2000	4.7	20.6	3.9	35.3	105.6	143.8	210.0	352.0	165.1	63.2	39.3	11.5	1155.0
2000/2001	3.3	1.5	0	64.6	195.5	74.2	110.4	232.5	137.7	44.0	0.5	7.1	871.3
2001/2002	13.7	0.6	7.6	1.0	62.8	216.5	26.1	12.5	56.7	111.8	0	0	509.3
2002/2003	18.7	5.8	1.7	57.7	101.9	80.8	57.8	87.8	131.0	7.0	20.1	54.9	625.2
2003/2004	0.0	0.0	2.9	51.6	39.5	206.9	180.9	166.0	303.1	42.0	2.1	4.8	999.8
2004/2005	12.0	0.0	13.7	70.2	46.6	160.2	67.8	45.7	58.2	11.9	0.8	3.9	491
2005/2006	3.4	0.0	5.0	0.4	77.3	403.7	207.3	218.9	162.0	9.7	0.0	0.0	1087.7

Table A3: Rusape Original Station data

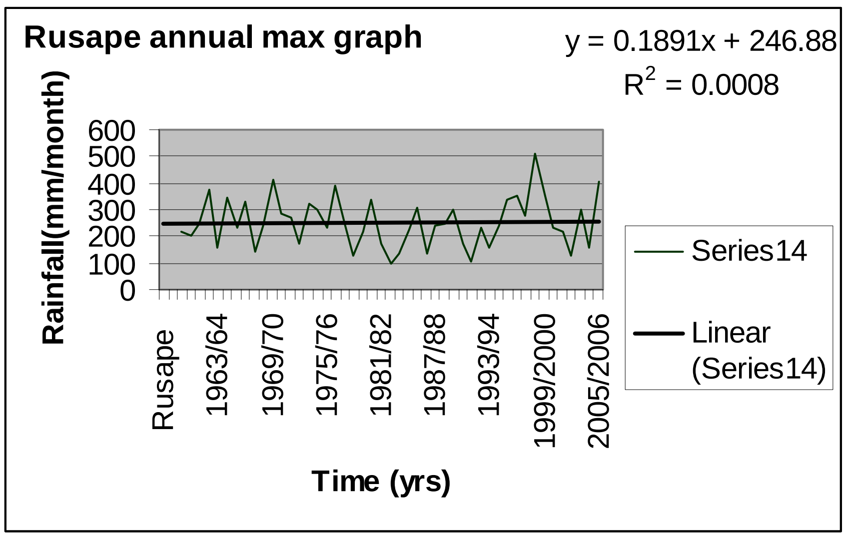


Figure A3: Rusape annual max graph

Odzi Police/ Rail Lat 18 58 Long 32 24												
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
1959/60	4.3	0.0	1.0	17.0	47.0	190.8	78.5	105.4	2.5	0.0	0.0	0.0	446.5
1960/61	0.0	0.0	6.9	50.5	56.9	174.5	115.8	87.6	52.8	46.0	4.8	21.6	617.4
1961/62	0.0	5.3	0.0	11.2	74.4	47.5	191.0	88.4	127.8	30.7	0.0	0.0	576.3
1962/63	0.0	0.0	0.0	0.0	190.5	279.1	170.7	429.0	63.5	48.0	1.3	0.0	1182.1
1963/64	0.0	0.0	0.0	35.6	26.2	143.3	146.1	21.8	0.0	0.0	0.0	0.0	373.0
1964/65	0.0	0.0	0.0	82.6	56.6	161.0	95.3	67.3	40.6	15.2	0.0	0.0	518.6
1965/66	0.0	0.0	0.0	19.6	133.6	74.9	129.5	332.7	46.2	14.0	38.1	29.0	817.6
1966/67	0.0	0.0	14.7	9.9	41.4	77.5	219.7	131.8	96.0	0.0	0.0	0.0	591.0
1967/68	6.4	24.4	0.0	37.6	57.9	81.3	13.0	136.4	37.8	55.9	0.0	4.1	454.8
1968/69	0.3	5.3	0.0	7.6	80.0	179.6	165.4	42.7	213.1	58.4	29.2	5.8	787.4
1969/70	0.0	0.0	2.0	159.8	78.0	291.8	42.7	19.8	61.7	46.7	0.0	27.4	729.9
1970/71	4.1	0.0	0.0	23.4	218.7	45.0	210.8	67.8	48.0	31.2	24.6	1.3	674.9
1971/72	0.0	0.0	0.0	16.0	218.2	126.2	346.7	171.0	120.0	34.8	17.0	2.8	1052.7
1972/73	0.0	0.0	4.0	69.5	81.7	50.3	132.8	69.9	9.5	2.0	0.0	0.0	419.7
1973/74	0.0	7.3	0.0	26.5	98.5	231.5	76.0	119.0	99.5	81.5	33.7	0.0	773.5
1974/75	32.5	0.0	16.7	13.0	71.7	499.9	84.5	131.0	58.0	70.0	0.0	4.2	981.5
1975/76	0.0	5.5	0.0	0.0	90.0	153.4	130.2	79.8	225.8	55.0	32.5	40.0	812.2
1976/77	3.4	0.0	71.0	21.4	58.9	222.8	47.6	445.6	241.9	0.0	0.0	0.0	1112.6
1977/78	0.0	0.0	133.6	26.9	48.6	281.1	172.7	161.5	105.3	87.1	15.0	4.8	1036.6
1978/79	2.0	0.0	0.0	82.2	52.7	196.6	145.0	68.5	30.3	17.7	4.5	0.0	599.5
1979/80	0.0	0.0	1.0	115.8	130.6	203.2	176.1	85.0	16.0	57.0	17.5	0.0	802.2
1980/81	0.0	1.8	111.4	43.0	116.0	243.8	248.0	276.0	131.5	8.0	4.0	0.0	1183.5
1981/82	0.0	3.5	10.0	17.5	159.0	93.5	88.0	128.0	4.0	23.5	18.0	0.0	545.0
1982/83	7.5	0.0	0.0	71.5	8.0	56.0	108.5	28.0	122.1	3.0	4.5	0.0	409.1
1983/84	23.0	7.0	0.0	8.5	40.3	75.0	48.0	102.0	86.7	6.5	24.5	3.5	425.0
1984/85	0.0	6.0	3.1	76.5	117.6	122.0	273.1	125.5	75.5	6.0	0.0	0.0	805.3
1985/86	0.0	1.5	3.0	27.0	57.5	190.5	141.6	141.5	80.9	80.5	22.5	0.0	746.5

1986/87	0.0	0.0	0.0	34.5	7.0	155.0	130.0	11.9	32.5	0.0	3.5	0.0	374.4
1987/88	0.0	0.0	3.0	20.0	25.0	275.9	90.0	104.5	201.0	11.0	0.0	12.0	742.4
1988/89	3.5	0.0	0.0	95.0	87.0	127.5	76.5	335.0	79.4	15.1	0.0	0.0	819.0
1989/90	0.0	36.5	0.0	144.5	48.5	123.0	178.5	106.0	50.0	15.0	0.0	27.0	729.0
1990/91	0.0	6.0	0.0	6.0	56.0	112.5	61.0	108.5	46.8	2.0	13.5	0.0	412.3
1991/92	0.0	3.5	6.5	0.0	65.6	25.8	26.5	22.5	43.5	10.5	0.0	0.0	204.4
1992/93	0.0	0.0	0.0	6.0	32.4	163.0	70.5	161.8	31.8	27.0	0.0	0.0	492.5
1993/94	11.8	5.9	0.5	2.5	110.7	112.5	175.5	47.5	12.0	14.0	0.0	0.0	492.9
1994/95	1.7	1.5	4.5	26.0	10.0	244.6	119.8	56.0	25.0	10.5	14.0	1.0	514.6
1995/96	0.0	0.0	0.0	39.6	40.5	214.5	293.0	186.5	67.0	5.0	84.0	*	930.1
1996/97	5.0	0.0	0.0	0.0	93.9	107.3	385.0	219.0	62.0	0.0	0.0	0.0	872.2
1997/98	0.0	0.0	0.0	20.0	149.0	13.0	257.0	258.0	113.0	7.0	0.0	0.0	817.0
1998/99	0.0	0.0	0.0	0.0	128.0	306.0	263.0	208.0	90.0	19.5	0.0	0.0	1014.5
1999/00	0.0	33.0	1.0	37.5	82.5	194.5	274.0	347.5	130.0	21.5	6.0	0.0	1127.5
2000/2001	1	0	0	27.0	186.5	123.9	98.0	243.5	256.7	*	*	*	936.6
2001/2002	0.0	0.0	0.0	0.0	253.5	258.5	3.5	15.0	*	*	*	*	530.5
2002/2003	0.0	0.0	0.0	35.5	87.5	18.5	36.3	14.5	42.7	*	*	*	235.0
2003/2004	0.0	0.0	0.0	98.5	*	*	138.5	198.0	191.0	40.0	0.0	0.0	*
2004/2005	0.0	0.0	0.0	54.5	*	161.0	105.0	*	*	14.5	0	0	*
2005/2006	0.0	0.0	5.0	0.0	2.0	323.0	218.5	89.5	138.5	*	*	*	*

Table A4: Odzi Police Rail Original Station data

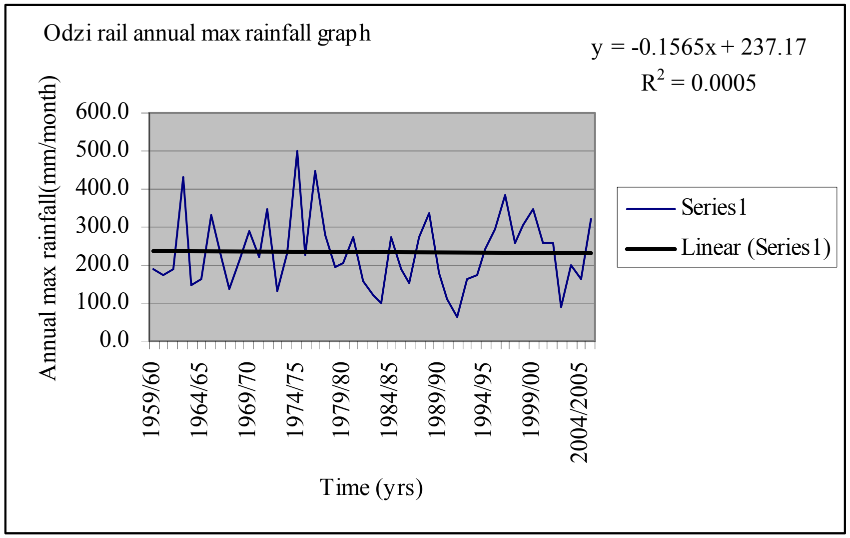


Figure A4: Odzi Rail Annual max graph

b.Runoff Original data

Station_code E32M		**Measured in 10^3 $*m^3$/month**											
Month	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Yearly Total
Year													
1957/1958	46	567	2590	33600	42600	16900	4070	2280	1590	1110	707	944	107004
1958/1959	1760	1010	1300	19500	17400	8590	1840	961	941	1310	651	261	55524
1959/1960	240	432	3120	3290	10800	1890	1370	983	1430	686	296	342	24879
1960/1961	614	1460	5410	24000	26800	8110	5650	2270	1570	1340	1370	884	79478
1961/1962	284	1120	2870	20000	12800	31600	10300	5060	3070	2560	1920	988	92572
1962/1963	565	2920	21700	14800	38600	34200	11900	5200	3190	2200	1570	919	137764
1963/1964	652	563	4510	8380	6950	2500	858	688	448	475	551	252	26827
1964/1965	171	305	6030	8150	3070	2120	1390	715	596	319	154	180	23200
1965/1966	519	1590	546	837	10800	31400	3240	2680	1750	1030	501	321	55214
1966/1967	207	690	716	11800	13700	36900	9040	3770	2110	1650	1150	697	82430
1967/1968	404	469	2030	559	5350	941	1640	494	206	227	197	164	12681
1968/1969	181	402	1220	11400	2420	4990	3000	1500	952	695	465	210	27435
1969/1970	415	686	18900	3470	4260	2400	2560	648	697	459	146	119	34760
1970/1971	163	620	1520	5130	2172	1104	410	400	71	12	19	2	11623
1971/1972	0	1138	1529	5283	5119	3531	5729	1948	515	451	323	142	25708
1972/1973	341	306	229	515	1110	197	99	85	92	74	70	67	3185
1973/1974	0	753	6618	8384	9864	14429	17805	7828	4668	4679	2900	2349	80277
1974/1975	495	1273	13215	11217	16272	10739	6614	4480	4059	1758	1353	234	71709
1975/1976	142	403	4650	9163	17160	36374	14725	6522	5287	4333	2579	2031	103369
1976/1977	2114	1427	4187	3300	41648	23259	8784	5200	3638	3319	3115	3060	103051
1977/1978	2067	1332	7259	14266	17472	52141	19197	7846	5691	4392	2589	1747	135999
1978/1979	1727	1197	13968	4515	2564	7870	534	*	*	*	*	*	32375
1979/1980	550	531	1768	5297	5029	12692	4351	2594	1311	801	713	688	36325

1980/1981	667	630	8005	18211	56413	22525	8767	8757	5096	3601	2770	1360	136802
1981/1982	1087	1898	3654	9276	17744	4973	2722	1717	1050	777	398	392	45688
1982/1983	928	753	819	396	1045	3566	409	543	94	355	239	185	9332
1983/1984	190	10	361	207	2428	5231	4587	1496	310	284	212	20	15336
1984/1985	7	35	1520	8782	22057	13635	6795	4086	2244	1596	843	753	62353
1985/1986	574	893	3470	15488	16498	7804	6275	3794	1525	699	961	700	58681
1986/1987	1703	3023	943	535	348	245	95	94	52	1	0	244	7283
1987/1988	256	62	831	1171	1656	14598	5188	3463	985	986	1039	452	30687
1988/1989	869	871	1903	2301	27532	13697	5604	3036	1527	1542	1790	893	61565
1989/1990	980	1376	3776	11995	17158	5087	4327	1849	1682	1389	1290	935	51844
1990/1991	773	461	1428	1068	1226	1523	951	692	249	89	26	0	8486
1991/1992	0	0	0	0	0	0	0	0	0	0	0	0	0
1992/1993	0	0	0	680	1985	350	0	0	0	0	0	0	3015
1993/1994	0	0	7	3894	392	10	0	0	0	0	0	0	4303
1994/1995	0	0	124	0	0	0	0	0	0	0	0	0	124
1995/1996	*	*	*	*	*	*	*	*	*	*	*	*	0
1996/1997	0	2	740	29239	56031	11918	10010	2561	1466	1121	244	336	113668
1997/1998	857	829	857	1401	1161	1094	867	698	484	302	100	49	8699
1998/1999	15	119	1709	16443	27751	26316	8247	3923	1674	1452	653	606	88908
1999/2000	736	962	652	7139	32330	33353	19640	6846	*	*	*	*	101658
2000/2001	*	*	*	*	*	*	*	*	*	*	*	*	0
2001/2002	*	*	*	*	*	*	*	*	*	*	*	*	0
2002/2003	854	2016	670	807	1652	5669	2360	1237	999	715	47	520	17546
2003/2004	674	375	187	184	150	161	143	134	130	111	107	53	2409
2004/2005	190	16	4106	4334	1771	3090	2639	1223	161	*	*	*	17530

Table A5: E32 Original Station data

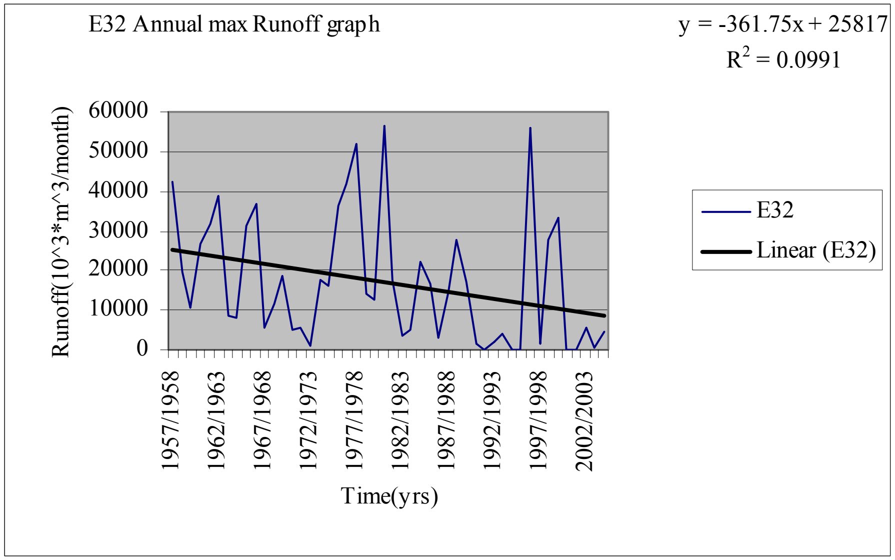


Figure A5: E32 Original Station data graph

Station_code E72M		**Measured in 10^3 *m^3/month**											
Month	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Yearly Total
Year													
1961/1962	0	0	1170	2224	1596	2893	2010	1123	765	587	478	378	13224
1962/1963	355	449	983	1181	2046	1970	1606	1178	889	609	471	359	12096
1963/1964	340	300	597	897	1159	852	415	380	306	295	328	311	6180
1964/1965	213	224	528	459	394	560	542	363	330	260	250	228	4351
1965/1966	217	312	274	269	1239	1262	546	471	458	373	289	283	5993
1966/1967	231	259	264	916	974	2079	1065	684	505	434	384	317	8112
1967/1968	271	282	364	288	375	301	317	283	228	227	205	150	3291
1968/1969	146	233	462	796	339	630	548	349	271	241	238	188	4441
1969/1970	210	197	1002	459	607	450	465	299	279	278	199	145	4590
1970/1971	156	460	629	969	655	432	287	280	224	187	145	100	4524
1971/1972	149	536	287	568	541	586	762	381	260	236	184	137	4627
1972/1973	129	131	188	190	250	168	190	143	152	133	137	93	1904
1973/1974	125	400	428	419	1099	1391	1812	760	409	380	333	306	7862
1974/1975	232	212	628	539	744	794	737	429	347	287	285	182	5416
1975/1976	173	150	407	573	983	2536	1345	676	506	430	330	251	8360
1976/1977	331	340	525	376	2608	1708	945	586	462	396	472	353	9102
1977/1978	300	276	569	1217	1618	2498	1526	883	665	581	448	371	10952
1978/1979	289	321	1093	621	785	995	496	402	364	422	294	244	6326
1979/1980	220	279	556	680	452	724	429	403	295	263	265	291	4857
1980/1981	264	245	920	1223	2905	1809	1119	870	564	476	446	343	11184
1981/1982	394	362	588	918	1777	948	613	488	374	364	306	277	7409
1982/1983	429	565	383	261	511	767	357	348	245	439	342	247	4894
1983/1984	256	189	286	280	774	1112	1124	610	408	334	285	257	5915
1984/1985	214	300	611	1177	2205	1419	1049	638	488	424	341	266	9132

1985/1986	252	280	530	1280	1328	955	824	583	426	370	309	238	7375
1986/1987	248	243	445	329	252	231	218	175	174	144	131	0	2590
1987/1988	168	125	443	537	841	1756	957	796	414	333	296	200	6866
1988/1989	59	*	*	111	1282	2392	1151	665	486	406	372	302	7226
1989/1990	304	396	1778	4435	2991	1655	1073	639	495	376	327	231	14700
1990/1991	196	189	365	280	375	611	371	285	250	211	175	161	3469
1991/1992	130	144	158	137	115	79	70	49	66	76	76	55	1155
1992/1993	54	54	99	238	462	478	196	148	113	191	139	119	2291
1993/1994	112	140	367	1282	579	386	272	229	196	174	154	143	4034
1994/1995	153	128	232	438	195	165	144	131	126	146	122	102	2082
1995/1996	*	*	*	*	*	*	*	*	*	*	*	*	*
1996/1997	222	249	738	2813	5399	2243	1429	823	511	518	331	327	15603
1997/1998	377	324	320	1394	1550	667	564	425	322	310	283	216	6752
1998/1999	228	358	681	1874	1157	1664	1330	990	622	503	379	306	10092
1999/2000	292	257	369	499	2198	3072	2360	1685	1186	1042	772	528	14260
2000/2001	393	588	919	759	2924	3431	1755	990	663	613	421	367	13823
2001/2002	267	267	463	400	312	412	403	305	318	245	242	168	3802
2002/2003	160	264	176	251	265	429	557	381	328	295	224	422	3752
2003/2004	60	230	450	637	609	1981	1421	746	577	453	353	291	7808
2004/2005	314	299	512	641	498	619	394	328	307	319	213	192	4636

Table A5: E72 Original Station data

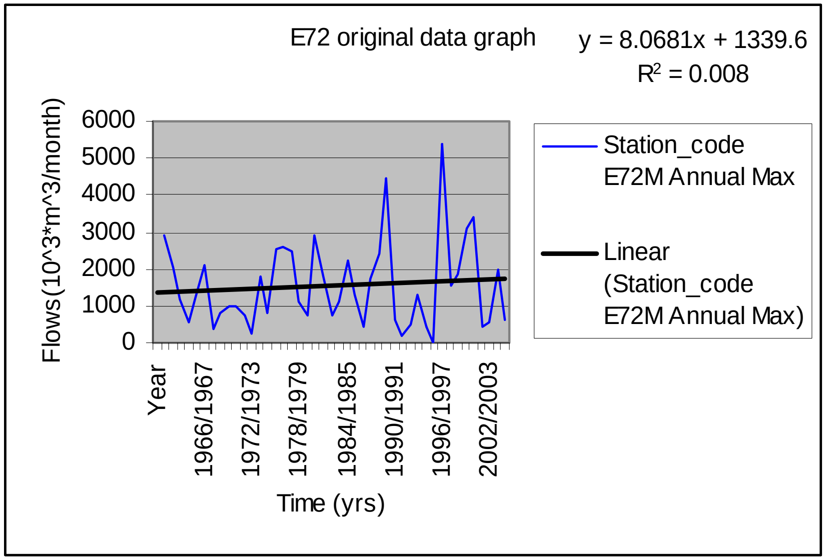


Figure A5: E72 Original Station data graph

Station_code E73M		**Measured in 10^3 *m^3/month**											
Month	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Yearly Total
Year													
1961/1962	3700	4110	11100	13400	14200	29200	16300	13900	8080	6840	5520	4330	130680
1962/1963	3700	4090	11300	11100	21300	19500	14400	9740	7070	5880	4640	3420	116140
1963/1964	3300	3010	5660	9200	8200	4600	3110	2540	2200	2130	2230	1500	47680
1964/1965	1120	1490	4210	12100	5350	4600	3970	2700	2450	1890	1440	1230	42550
1965/1966	20	1540	2590	4310	11200	14800	6210	5120	4620	4020	3350	2860	60640
1966/1967	2634	2615	2827	12857	10942	23070	11651	8782	6490	5550	4831	4089	96338
1967/1968	2035	3309	3684	3187	4273	3271	3755	3209	2561	2489	2284	1861	35918
1968/1969	1716	2416	4974	13915	4880	7355	5877	4075	3329	3041	2912	2198	56688
1969/1970	2654	3038	11945	10552	10355	5738	4992	3765	3366	3301	2696	2046	64448
1970/1971	2042	3642	7706	14364	8241	5501	4265	4076	3251	2755	2248	1852	59943
1971/1972	1933	3518	6747	14749	9564	11069	10745	6152	4674	4077	3338	2653	79219
1972/1973	2901	2570	3381	7240	5473	4321	3847	3011	2978	2447	2465	1839	42473
1973/1974	1942	4822	6420	13332	22544	21881	20123	11579	7514	6365	5734	4780	127036
1974/1975	3405	3605	11809	10135	11410	11764	8468	6044	5054	4291	3829	2977	82791
1975/1976	2941	2429	5430	8037	16265	31928	16979	10177	7854	6356	5141	4459	117996
1976/1977	4726	4567	4750	5136	21016	16823	9632	6990	5493	4919	5654	3676	93382
1977/1978	3612	3034	5486	20383	14743	27963	16102	10433	8212	7193	5519	4411	127091
1978/1979	3540	4108	10513	7112	10171	10859	5978	4950	4546	5090	3486	2838	73191
1979/1980	2831	3333	4705	4446	5034	5894	3733	3384	2755	2612	2583	2675	43985
1980/1981	2303	2109	9520	10891	36251	17018	11301	11199	6810	5711	4940	4053	122106
1981/1982	4042	4619	6179	13658	20407	9714	7181	5803	4742	4157	3524	3151	87177
1982/1983	4346	3276	2921	2133	4545	4893	2376	2546	1840	2919	2267	1638	35700
1983/1984	1440	1389	3054	2306	6230	8391	7857	3899	2724	2714	2329	1843	44176

1984/1985	1667	2807	4620	15970	19992	13360	9774	6271	5239	4292	3495	2791	90278
1985/1986	2807	2872	5155	19277	15050	11571	8078	5727	4728	4332	3187	2719	85503
1986/1987	3019	2647	5515	5397	3785	2623	2153	1349	1598	1548	1605	1349	32588
1987/1988	1339	814	*	*	9143	15181	7327	5897	4064	3703	2835	2634	52937
1988/1989	3622	3592	6495	6342	24483	13845	8970	6059	5209	3978	3354	2530	88479
1989/1990	2334	3189	4818	20209	15928	9473	6603	5494	4528	3677	3159	2428	81840
1990/1991	2010	1864	2579	4276	5015	5875	3273	2251	1872	1696	1592	1252	33555
1991/1992	1185	832	1261	1236	672	630	677	720	771	795	771	506	10056
1992/1993	457	948	1680	4384	6120	5288	2465	1587	1285	1791	1388	939	28332
1993/1994	681	1708	2622	6693	255878	4030	2066	1648	1289	1362	1138	1038	280153
1994/1995	1111	725	1303	2922	2126	1304	982	875	741	839	882	520	14330
1995/1996	580	1193	6369	9179	15722	11056	5391	5666	4388	3699	3046	2300	68589
1996/1997	1902	1822	4231	20998	34700	17043	15083	8625	6434	5878	4227	4780	125723
1997/1998	4538	3873	5653	14693	10476	7011	5139	3967	3247	392	2798	2310	64097
1998/1999	2332	2411	6210	26694	17489	20069	13656	9833	7559	1049	5525	3987	116814
1999/2000	3696	3944	4658	8181	12331	11587	16592	10191	8967	1337	5889	4517	91890
2000/2001	3431	3136	3110	3924	19734	26437	16576	10463	9085	1439	7650	4686	109671
2001/2002	3790	3304	7865	5579	4081	4318	4338	3234	3191	749	2373	1925	44747
2002/2003	1831	2650	3098	5122	7082	15391	10016	4641	986	3606	2641	2357	59421
2003/2004	2269	2137	3100	4596	8262	14293	7952	5003	4372	3855	2465	2326	60630
2004/2005	2885	2318	4133	7675	5808	5365	3897	2669	2361	3118	1558	1155	42942

Table A6: E73 Original Station data

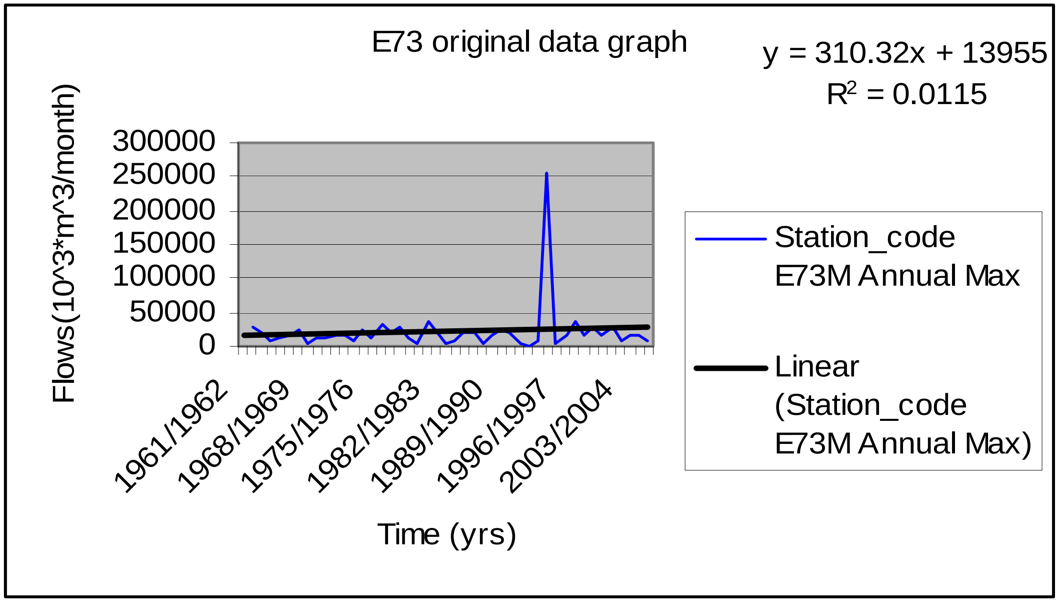


Figure A6: E73 Original Station data graph

Station_code E127M-			**Measured in 10^3 $*m^3$/month**										
Month	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Yearly Total
Year													
1969/1970	487	478	2800	2980	2030	1330	1050	865	795	764	626	497	14702
1970/1971	465	992	1600	2400	1330	1070	813	881	703	647	538	455	11894
1971/1972	451	795	1410	3209	3442	2622	2962	1844	1343	1199	992	808	21077
1972/1973	845	716	905	1436	1207	829	652	578	533	506	438	332	8977
1973/1974	305	927	947	1992	6000	2936	2714	2431	1610	1528	1190	906	23486
1974/1975	726	892	3222	3464	3860	4593	2695	1884	1505	1208	1120	799	25968
1975/1976	667	635	1551	1896	3544	6909	4698	3042	2137	1647	1291	1126	29143
1976/1977	1104	883	1007	897	7529	4911	3206	2210	1662	1417	1357	943	27126
1977/1978	807	719	1193	3922	2743	4948	3898	2797	2031	1670	1296	1022	27046
1978/1979	1036	927	2001	1395	1616	2175	1332	1021	870	857	699	569	14498
1979/1980	628	791	1337	1505	1461	1243	1100	863	706	636	560	538	11368
1980/1981	458	433	1953	5509	9540	5468	3568	3205	2144	1750	1450	1119	36597
1981/1982	1109	1378	1984	5601	5076	3682	2595	1876	1438	1320	1035	836	27930
1982/1983	951	811	722	453	984	1083	542	436	390	573	417	306	7668
1983/1984	335	520	1012	518	1510	1147	1004	781	522	459	396	365	8569
1984/1985	326	564	1275	4673	6401	3706	2677	1911	1659	1204	996	807	26199
1985/1986	700	742	1216	3868	4494	2951	2093	1659	1290	1193	944	712	21862
1986/1987	873	552	2078	1182	880	801	537	430	426	378	442	331	8910
1987/1988	282	223	1668	1294	2197	3090	1838	1277	937	818	657	504	14785
1988/1989	565	459	907	692	3205	3056	1942	1333	1111	898	768	605	15541
1989/1990	527	547	1277	3361	4878	2528	1898	1419	1182	961	792	628	19998
1990/1991	539	471	605	663	846	697	448	403	319	295	263	195	5744
1991/1992	172	359	185	203	175	94	89	109	164	119	134	99	1902

1992/1993	67	69	846	1484	1629	901	447	285	233	324	238	175	6698
1993/1994	92	291	468	2086	1074	521	312	260	233	242	216	151	5946
1994/1995	211	139	292	962	438	248	172	123	119	144	191	95	3134
1995/1996	119	224	1092	3095	4307	2558	1445	1602	1293	1014	797	617	18163
1996/1997	449	691	758	7100	11623	5336	4078	2771	2023	1685	1238	1561	39313
1997/1998	1237	1254	1359	2208	2271	1788	1232	952	786	728	672	490	14977
1998/1999	426	473	2217	10366	6144	5123	3361	2444	1821	1659	1460	1072	36566
1999/2000	977	882	677	1810	2442	3841	3004	2463	1946	1638	1410	1001	22091
2000/2001	804	1046	969	901	6218	5451	3416	2554	2052	1510	2256	1032	28209
2001/2002	965	1435	2221	1856	1047	1147	1150	765	717	639	537	426	12905
2002/2003	417	648	626	518	1350	2348	1655	1001	831	614	518	411	10937
2003/2004	412	382	507	664	866	2040	1353	1013	766	669	536	389	9597
2004/2005	640	349	443	1426	855	622	357	304	277	338	213	140	5964

Table A7: E127 Original Station data

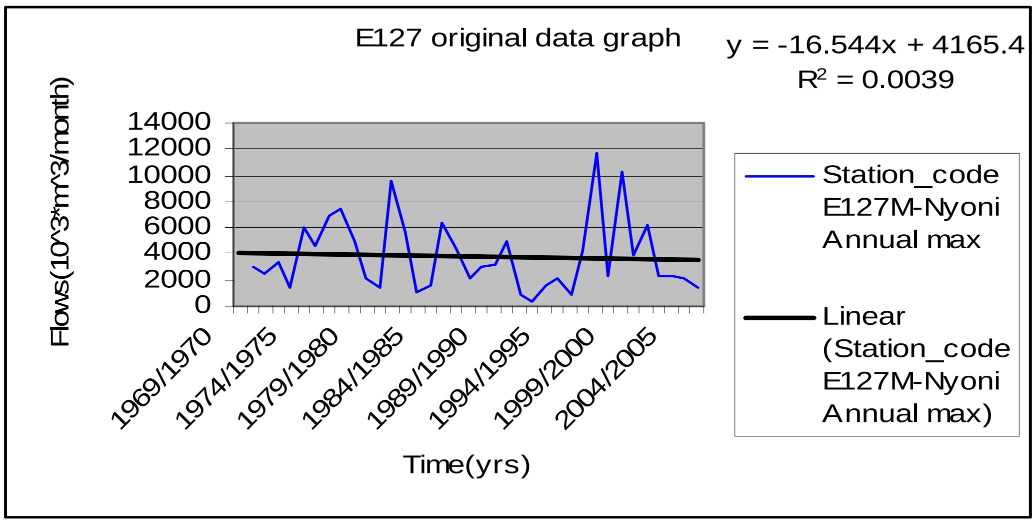


Figure A7: E127 Original Station data graph

Station_code E129M-			**Measured in 10^3 *m^3/month**										
Month	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Yearly Total
Year													
1970/1971	716	1494	3218	2222	1573	1379	1208	1071	955	941	766	663	16206
1971/1972	692	997	1994	4288	3614	3304	3350	2290	1819	1541	1312	1068	26269
1972/1973	1123	907	921	1660	1502	1222	1017	851	867	768	703	560	12101
1973/1974	517	1413	1636	3535	5995	6081	5054	3449	2520	2344	1944	1495	35983
1974/1975	1213	1259	4605	3665	4003	4239	3093	2391	2022	1708	1608	1176	30982
1975/1976	1084	840	1429	1990	3917	7380	5137	3558	2728	2199	1861	1524	33647
1976/1977	1573	1378	1463	1406	6703	5195	3333	2537	1996	1781	1748	1284	30397
1977/1978	1235	1058	1847	3936	3806	7113	5689	3856	3018	2511	2057	1610	37736
1978/1979	1497	1306	2852	1976	2435	3337	2230	1828	1624	1603	1263	1063	23014
1979/1980	1098	1468	1726	1673	1582	1926	1316	1220	979	955	921	869	15733
1980/1981	736	759	2904	3701	11860	6580	4903	4512	2996	2578	2178	1737	45444
1981/1982	1718	1736	2141	743	*	*	*	*	*	*	*	*	6338
1982/1983	1369	1198	1041	787	1337	1400	807	783	668	964	730	524	11608
1983/1984	533	642	957	710	1702	1953	1691	1188	1078	955	769	645	12823
1984/1985	564	862	1319	4654	6824	4543	3524	2590	2114	1771	1497	1204	31466
1985/1986	1150	1077	1878	5110	5156	3882	3193	2549	2039	1856	1582	1244	30716
1986/1987	1350	1020	1770	1920	1440	1110	898	754	706	702	709	547	12926
1987/1988	558	488	1470	2278	2513	4737	2661	2182	1594	1423	1211	948	22063
1988/1989	1032	920	1396	1841	5020	3564	2724	2043	1600	1454	1248	1152	23994
1989/1990	988	977	2969	4877	5209	3243	2624	2140	1760	1525	1332	1079	28723
1990/1991	878	854	1228	1339	1644	1610	1158	904	768	719	588	584	12274
1991/1992	547	539	572	620	259	359	289	294	265	336	327	222	4629
1992/1993	287	294	688	1505	1459	1238	689	499	415	532	443	350	8399
1993/1994	238	379	762	2262	1452	918	666	551	459	435	402	323	8847

1994/1995	407	264	395	1067	529	377	292	257	241	261	300	171	4561
1995/1996	287	443	1357	3388	4884	4015	2067	2448	1762	1460	1208	931	24250
1996/1997	766	692	1344	6995	12896	7307	5854	4020	3131	2661	1979	1943	49588
1997/1998	1679	1566	1915	3733	3643	2585	1978	1636	1374	1302	1212	952	23575
1998/1999	*	*	*	*	*	*	*	*	*	*	*	*	*
1999/2000	1604	1322	1728	2593	2928	5808	6454	4429	3431	505	2340	1801	34943
2000/2001	1567	1912	1796	1604	6868	8012	5384	3977	3138	902	2388	1827	39375
2001/2002	1500	1487	3458	2440	1598	1585	1642	1159	1191	1032	991	747	18830
2002/2003	750	726	750	750	677	750	726	750	726	750	750	725	8830
2003/2004	*	*	*	*	*	*	*	*	*	*	*	*	*
2004/2005	918	752	1340	2292	1943	1721	1310	1008	835	840	640	526	14125

Table A8: E129 Original Station data

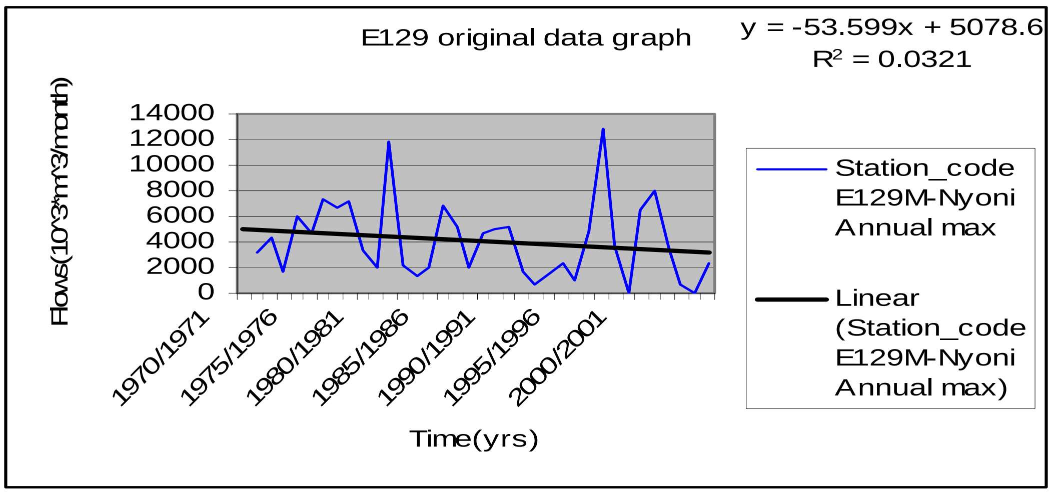


Figure A8: E129 Original Station data

APPENDIX B

Testing for Normality

		E32	E72	E73	E127	E129	RUSAPE	MUKANDI	ODZI	NYANGA
N		420	420	420	420	420	432	432	432	432
Normal Parameters	Mean	14.896405220031 74	60.543773651123 10	31.023893356323 24	20.443323135375 98	26.132303237915 0	63.484	131.130	58.863	99.951
	Std. Deviation	25.466396331787 11	52.765415191650 40	26.414978027343 75	18.999347686767 58	21.559143066406 3	80.054	156.150	78.385	116.317
Most Extreme Differences	Absolute	.279	.188	.183	.176	.181	.214	.201	.226	.195
	Positive	.243	.188	.183	.176	.181	.179	.192	.195	.181
	Negative	-.279	-.145	-.138	-.153	-.139	-.214	-.201	-.226	-.195
Kolmogorov-Smirnov Z		5.724	3.850	3.753	3.603	3.718	4.446	4.168	4.704	4.055
Asymp. Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.000	.000	.000

Table B1: Results of Kolmogorov-Smirnov Test for Normal distribution

APPENDIX C

Correlation Analysis results

i.Correlation between Station E127 (Runoff) with Rusape (Rainfall)
@corr X2, X3
Correlation Station, Rusape = 0.6604
Testing hypothesis that rho = 0
t value corresponding to correlation is 5.128 with 34 d.f.
Significance level (2 sided) is 0.00%
Approximate 95% confidence interval for rho is 0.41 to 0.82

ii. Correlation between Station E127 (Runoff) with Mukandi (Rainfall)
@corr X2, X4
Correlation Station, Mukandi = 0.5875
Testing hypothesis that rho = 0
t value corresponding to correlation is 4.233 with 34 d.f.
Significance level (2 sided) is 0.02%
Approximate 95% confidence interval for rho is 0.31 to 0.77

iii. Correlation between Station E127 (Runoff) with Mukandi (Rainfall)
@corr X2, X5
Correlation Station, Odzi_Police rail = 0.5549
Testing hypothesis that rho = 0
t value corresponding to correlation is 3.890 with 34 d.f.
Significance level (2 sided) is 0.04%
Approximate 95% confidence interval for rho is 0.27 to 0.75.
iv. Correlation between Station E127 (Runoff) with Nyanga (Rainfall)
@corr X2,X6
Correlation Station, Nyanga = 0.6782
Testing hypothesis that rho = 0
t value corresponding to correlation is 5.382 with 34 d.f.
Significance level (2 sided) is 0.00%
Approximate 95% confidence interval for rho is 0.44 to 0.83

Mukandi –E127 relationship

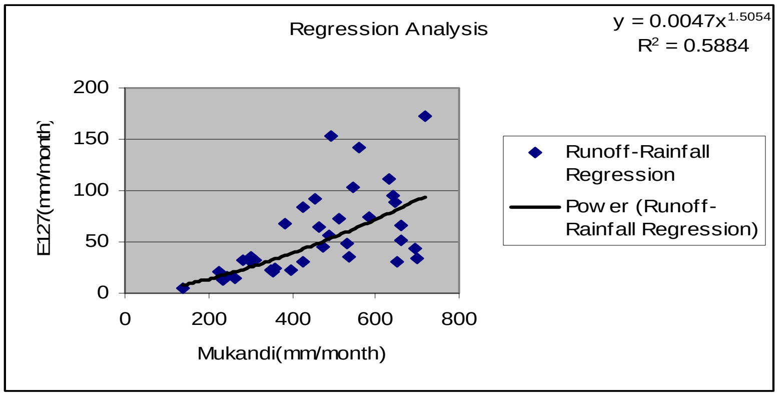


Figure C1: Rainfall-Runoff relationship

The coefficient of determination (R^2) is 59%, meaning that 59% of variation of runoff can be explained by rainfall. Thus the following model was used to complete data for rainfall:

$Y=0.047X^{1.505}$

Where: Y: Predicted Runoff data

X: Rainfall data

Rusape-E127 Relationship

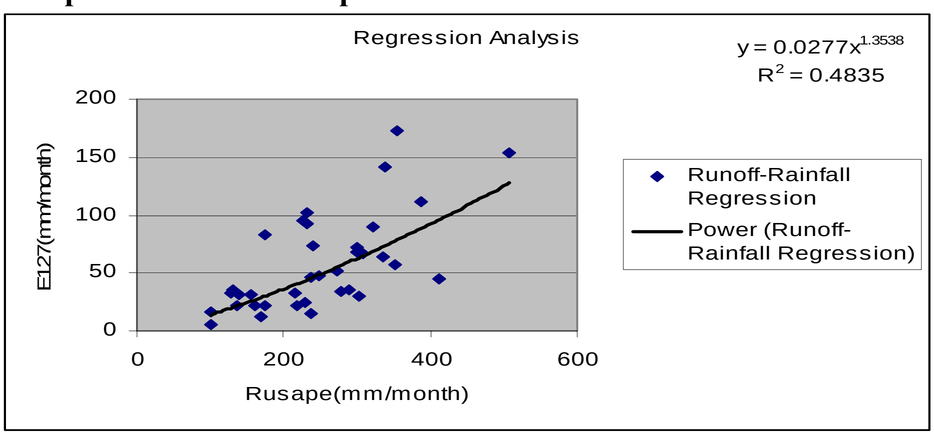


Figure C2: Rainfall-Runoff relationship

The coefficient of determination (R^2) is 48%, meaning that 48% of variation of runoff can be explained by rainfall. Thus the following model was used to complete data for rainfall:

$Y=0.0277X^{1.354}$

Where: Y: Predicted Runoff data

X: Rainfall data

Odzi-E127 relationship

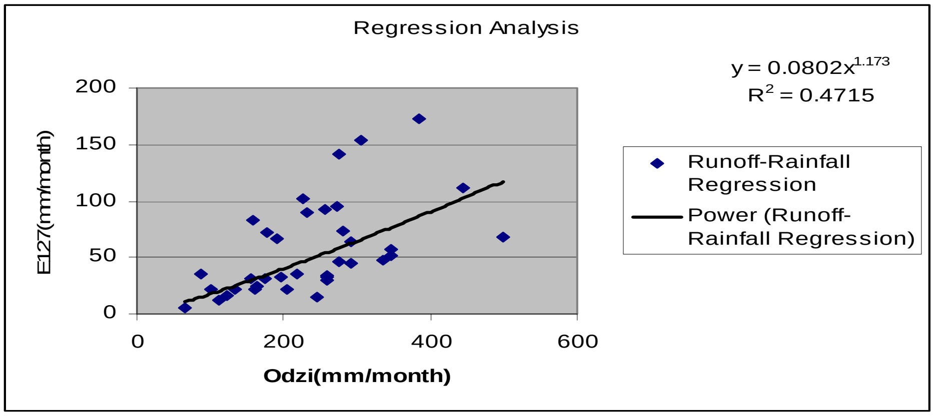


Figure C3: Rainfall-Runoff relationship

The coefficient of determination (R^2) is 47%, meaning that 47% of variation of runoff can be explained by rainfall. Thus the following model was used to complete data for rainfall:

$\mathbf{Y=0.008X^{1.173}}$

Where: **Y: Predicted Runoff data**

X: rainfall data

Nyanga-E127 relationship

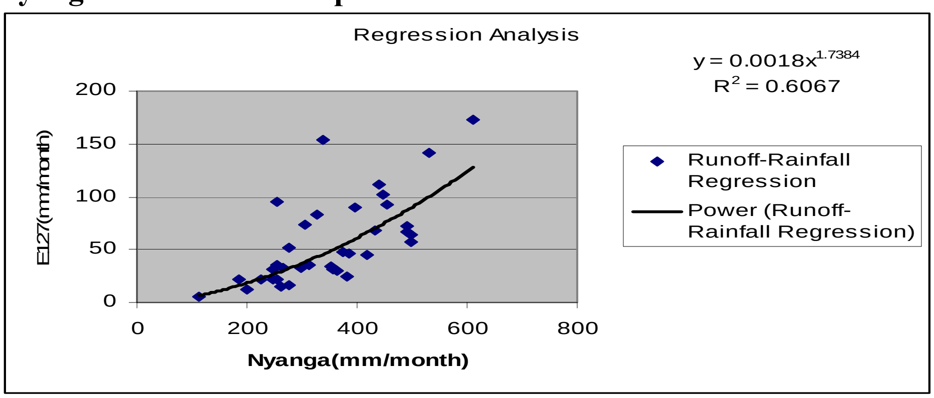


Figure C4: Rainfall-Runoff relationship

The coefficient of determination (R^2) is 61%, meaning that 61% of variation of runoff can be explained by rainfall. Thus the following model was used to complete data for rainfall:

$\mathbf{Y=0.0018X^{1.74}}$

Where: **Y: Predicted Runoff data**

X: rainfall data

APPENDIX D
Catchment yield analysis

Catchment yield analysis of Subzones O4 and O5					
Assume Va=2*MAR		Va	483701	10^3m^3	
Assume Vb=2*MAR		Vb	649550	10^3m^3	
Aa(ha)=	4668.6	Assumed(about 20% of catchment Area)			
Ab(ha)=	6467.8	Assumed(about 20% of catchment Area)			
Standard MAR for subzones O4 and O5					
MARa=180mm	0.18	m			
MARb=173mm	0.173	m			
Min catchment rainfall=400mm/yr					
Evaporation=4mm/day					
e=4*365mm/yr-400mm/yr					
e=	1.06	m			
Catchment Area A	2E+08	m^2	23343	ha	
Catchment Area B	3E+08	m^2	32339	ha	
Two dams(A and B) are assumed in the area. For subzone O4, Area is 233.43KM^2					
For subzone O5, Area is 323.39KM^2					
Calculated MARs					
Total MARa	1036.07	mm	2.4E+08	m^3	CVa=78%
Total MARb	1004.28	mm	3.2E+08	m^3	CVb=52%
EF=(eA)^3/(0.7V)^2					
EFa	1.06				

EFb	1.56				
Dam A Full supply capacity(m^3) :Va	483701				
Dam B Full supply capacity(m^3):Vb	649550				
	Dam A	**Dam B**			
MAR	241851	324775	10^3m^3		
V/MAR	2	2			
MAR/EF	228781	208361	**10^3m^3**		
Yield Q	172364	269385	**10^3m^3**		
Therefore 10% yield (Q10)	172364	269385	**10^3m^3**		
Yield at 4% risk level(Q4)=0.95Q10*-0.05*(MAR)					
Q4	151653	239677	**10^3m^3**		
Comparing Yield values from old blue book with calculated values					
E04	88200	10^3m^3			
E05	178210	10^3m^3			
Area E04=	1117	Km^2			
Area E05=	1393	Km^2			
Area coverage for Stations E32 and E72-Supplying Dam A=			233.43	km^2	
Area coverage for Stations E73, E127 and E129- Supplying Dam B=			323.39	Km^2	
Q10(E04)/Q10(Area A)	0.5117				
Q10(E05)/Q10(AreaB)	0.6615				
Area Ratios					

Area E04/AreaA=	4.7852				
AreaE05/Area B=	4.3075				
Area ratios show that the areas taken for assessment were smaller than those of E04 and E05 However, yields obtained for Areas A and B were above 50% bigger than those obtained in the blue book caculation.					
Comparing Yield values from New blue book with calculated values					
E04	145116	10^3m^3			
E05	217730	10^3m^3			
Area E04=	1073	Km^2			
Area E05=	1414	Km^2			
Area coverage for Stations E32 and E72-Supplying Dam A=			233.43	km^2	
Area coverage for Stations E73, E127 and E129- Supplying Dam B=			323.39	Km^2	
Q10(E04)/Q10(Area A)	0.8419				
Q10(E05)/Q10(AreaB)	0.8082				
Area Ratios					
Area E04/AreaA=	4.5967				
AreaE05/Area B=	4.3724				
Area ratios show that the areas taken for assessment were smaller than those of E04 and E05 However, yields obtained for Areas A and B were about 80% bigger than those obtained in the blue book calculation.					

Comparison with Save Catchment yield			
Yield Save=	750000	10^3m^3	
Dam A/Save*100=	22.981802	%	

Dam B/Save *100=	35.918064	%	
Catchment Area (Save)	7834	km^2	
Catchment area ratios			
Dam A Catchment area/Save Catchment area*100		2.9797	%
Dam B Catchment area/ Save Catchment area*100		4.12803	%
Per capita water requirement assessment			
Q(Total yield of sub catchment)	441748.99	10^3m^3	
Per capita water requirement(Lifeline)	18.25	m^3/annum	
Number of persons getting Lifeline water /yr	24205.424		
Population density=	60	persons/km^2	
Total area of sub catchment	556.82	Km^2	
Average subcatchment population	33409.2		

Table D1: Catchment yield analyses and per capita (lifeline) water requirement analysis of Subzones O4 and O5