ABSTRACT

Poverty, hunger and malnutrition amongst rural people in semi-arid areas where small scale farming is dominant are widely recognized as major problems. The fact that rural communities of southern Africa reside in marginalized areas which are characterized by low and highly variable rainfall that is poorly distributed exacerbates these problems. Most of their attempts at farming activities result in yields that are way below the expectation of farmers. Sometimes these dryland farmers experience complete crop failure leaving them with nothing to live on, or let alone sell and earn the much needed income. So how then, can a growing community whose main means of survival is at the mercy of nature feed itself? The challenge at hand is to determine how crop productivity can be improved in semi arid areas in the wake of erratic and low rainfall. This research is in line with both the Millennium Development Goal (MDG) number 1, which is to eradicate extreme poverty and hunger and the Poverty Reduction Strategy (PRS) which aim to increase national food security. Also the fight against the negative impacts of HIV/Aids cannot be won without the necessary basic nutrition.

This investigation tried to investigate the effect of rainfall variability on crop yield under semi-arid conditions at meso-catchment level.

Ten portable raingauges were installed at ten locations within Zhulube meso-catchment based on direction of prevailing wind and soil type. In addition to this, seven 10m*10m experimental maize plots were cultivated and a household survey was carried out to assess the farming practices that prevail in the area in order to understand their possible impacts on crop yield.

Results have revealed that while there was temporal variability of rainfall in the study area, it was significant in the long-term and insignificant in the short-term. Spatial variation of rainfall was significant in Zhulube meso-catchment in the short-term. It was however not significant enough to cause significant differences in yield. Results from the household survey indicated that despite the villages cultivating common crops with maize being the most common, they exhibited variation in most of the critical farming practices.

Keywords: meso-catchment, Rainfall variability, semi-arid, yield

DECLARATION

I hereby declare to the Senate of the University of Zimbabwe, that, this dissertation is a product of my own investigation except whereby acknowledged, and that it is being submitted for the degree of Master in Integrated Water Resources Management (IWRM). I also declare that the interpretations of results from the collected data are entirely mine and based on the period that I collected the data. Additional data collection and analysis by a different person may result in different interpretations.

BRENDA CHIBULU MWAMBA ……………… …………………….

Name and signature Date

DEDICATION

This work is dedicated to my beloved parents for making me the person that I am today.

To my loving husband; my friend, my comforter, my rock, for the strength and support through out the duration of my study and for encouraging me to soldier on even when I was at my lowest, emotionally.

To my lovely children: Mwamba and babies Natasha and Mulenga for their patience and love.

Lastly, but not the least to my eldest brother, Mulenga Chibulu for giving the educational foundation that enabled me to undertake this programme through his huge financial sacrifices.

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First and foremost, I would like to thank Jehovah God for giving me yet another chance at education. Lord, indeed you still sit on the throne.

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LIST OF ACRONYMS

B: Boron
Ca: Calcium
Cl: Chloride
FAO: Food and Agricultural Organization
Fe: Iron
IIRR: International Institute of Rural Reconstruction
Mg: Magnesium
Mo: Molybdenum
Na: Sodium
N: Nitrogen
O.C: Organic Carbon
P: Phosphorous
WHC: Water Holding Capacity

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

The majority of the worlds hungry are found in the rainfed regions of the developing world, particularly in sub-Saharan Africa (SSA) (Ngigi, 2003). Despite major investment in irrigation throughout the world over the last 40 to 50 years, only 20% of the total agricultural land worldwide is irrigated (Ngigi, 2003). In Africa, this figure drops to between 2 to 5% depending upon the region (Ngigi, 2003). This means that over ninety-five percent of the food producing land in SSA is rainfed. Majority of the ninety five percent of the world's 1.1billion farmers live in developing countries of which the majority are smallholder farmers who depend on rainfed agriculture. Their share of global agriculture is very large, amounting to 60% of world currently practiced agriculture (Savenije, *et. al*, 2003). However, it is still in these developing countries where hunger and poverty are the order of the day in most cases.

Of the surface of the earth used for agriculture, two thirds are in the tropics and sub-tropics. Almost 4 billion people live in these regions accounting for three quarters of the world's population (Sigmund and Gustav, 1991). Most of Southern Africa has a tropical climate which is semi-arid in nature making it prone to prolonged dry spells and drought. Suffice to say that rainfed agriculture is the source of the bulk of world food, and will continue to be so for the foreseeable future (Ngigi, 2003).

Unfortunately, rainfall variability has a significant impact on crop production, making it risky with high chances of crop failure in the semi-arid areas of the continent that are already marginal for crop production. Drought is a common feature of most agro-ecosystems, both within and between seasons, and contributes to food insecurity and rural poverty. It is therefore essential that proactive approach to managing rainfall variability is promoted within rural communities most at risk; a step in the right direction as far as achieving the Millennium Development Goal of eradicating extreme poverty and hunger is concerned.

Inspite of the shortcomings highlighted above, agriculture is still and will continue to be the backbone of most African economies. The challenge, therefore, is for researchers to find ways and means of making it a reality. One way of doing this is to make the ordinary small scale farmer living in a marginalized area which is prone to drought self reliant in terms of food production. This study is aimed at determining the extent of rainfall variability and its potential impact on crop yield at meso-catchment level in an effort to identify portions within the meso-catchment (15-45km^2) with a relatively high potential for crop production where crop production can be intensified.

1.2 Problem Statement

Rainfed agriculture accounts for more than 95% of the land used for staple food production in Sub-Saharan Africa (FAO, 1995). In semi-arid regions, erratic rainfall pattern is regarded as the most limiting factor to dry-land crop production. It is actually regarded as the main determinant of agricultural activities (Duckham and Masefield, 1985). These areas experience low rainfall which is highly variable and yet people still want to grow staple food crops. Other factors such as soil type, temperature, lack of agricultural inputs and management practice also contribute to a reduction in crop yield.

Various improvements for these other factors have been developed, but can only be effective if the required minimum moisture is available to the soil. Although it is known that rainfall variability in semi-arid areas is high, the extent of variability at meso-catchment scale is hardly understood. At catchment level, the main challenge therefore, is to identify meso-catchments which have minimum rainfall variability where water can be conserved for maximum crop production.

1.3 Rationale

The agriculture sector highlights perhaps more clearly than any other the extent and severity of potential impacts of rainfall variability on food production, food security and lost livelihoods. One of the great achievements of the 20th century was the successful expansion of food production to keep pace with the growing demand caused by growing populations. The Food and Agricultural Organization (FAO) estimates that as these two factors continue to push demand upwards, the world will require about 50% more food by 2030, compared to 1998 (FAO 2005a). Rainfall variability will be an important factor in determining whether this can be achieved. This variability, along with the uncertainties of very long - term weather forecasting, especially at the regional level, makes discussions of effects of rainfall variability on crop production tentative at best.

Changes in precipitation coupled with characteristic high rates of evapotranspiration exhibited by semi-arid areas may lead to further water shortages and affect soil moisture in some regions of the world. Access to water is a key factor to ensuring food security (UNEP, 2006)

The problem of rainfall variability is worsened in Sub-Saharan Africa (SSA) which is a semi-arid area characterized by erratic and low rainfall. SSA is the only region in the world where average food production per capita has been declining over the last 40 years; yet agriculture continues to be the dominant economic activity, accounting for 70% of total employment, 40% of total exports and 34% of the gross domestic product (GDP) (Ngigi, 2003). Despite the technological advances in agricultural research in recent years, poverty, food insecurity and mal-nutrition still remain major challenges in sub-Saharan Africa (Sanchez and Swaminathan, 2005).

It is estimated that at least 25% of the population will be undernourished and living in the dryland areas of sub-Saharan Africa, which already accommodate 70% of the world's poorest communities (Ryan and Spencer, 2001).

1.4 Research Hypotheses

The alternate hypotheses (H_u):

- Significant rainfall variability exists within the meso-catchment
- Rainfall variability affects crop yield at meso-catchment scale.
- Rainfall variability results in significant differences in crop practices at household level and consequently yield.

The null hypotheses (H_o):

- There is no significant rainfall variability within the meso- catchment.
- Rainfall variability does not affect crop yield at meso-catchment scale.
- Rainfall variability does not result in significant differences in crop practices at household level and consequently yield.

1.5 Objectives of the study

1.5.1 General objective

The overall objective of the study is to show the extent of rainfall variability in the catchment and assess whether this variability gives rise to differences in crop yield at meso-catchment level in a semi-arid area.

1.5.2 Specific objectives

- ➢ To show the extent or degree of rainfall variability at meso catchment level and establish whether the difference in rainfall is significant.
- ➢ To show whether rainfall variability is significant enough to cause significant differences in crop yield.
- ➢ To establish whether farmer practice is influenced by rainfall variability.

1.6 Report outline

The report is divided into seven chapters.

- Chapter one gives a description of the problems addressed by the study, the justification for undertaking the research, the objectives of the study, the activities undertaken in addressing the problems and an outline of the report.
- Chapter two presents a review of available literature on rainfall variability, hydro climatic challenges faced by semi-arid areas relating to rainfall, crop yield, farmer practice and livelihoods.
- Chapter three gives a description of the study area.
- Chapter four presents methods, materials and parameters being investigated
- Chapter five presents an analysis of results.

- Chapter six discusses the results and gives a highlight of gaps not covered by this study.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction.

Rainfall variability refers to a range of values of rainfall between a particular maximum and minimum over a certain time period. Risk from rainfall is a major limiting factor to agricultural production in Sub-Saharan Africa. This problem is exacerbated in the semi-arid regions where rainfall extremes like droughts can lead to famine and result in acute food insecurity for millions of people. The probability of occurrence of unfavorable rainfall events affecting crop performance is the risk associated with rainfall variability (Rotter, 1993). For the resource poor farmer in SSA, the implications of outstandingly good or bad years can be profound thus, for these farmers; the impact of extreme rainfall conditions far outweighs its apparent probability of occurrence (Amissah-Arthur, 2000). Increasingly, adaptation to climate (rainfall) change and variability has become a focus for research and policy in Africa. By using weather forecasts of expected seasonal rainfall, it is possible to determine if the season would be a low, normal or high rainfall season (Rotter, 1993) thus, enabling assessment of the cropping potential of the period or area and risks of yield variability. Such information could also enable tactical intra-seasonal crop management planning, decision making and increase the capacity to adapt to climatic variability by reducing vulnerability to rainfall risks. Thus, climate forecasts can support farmers in reducing risk by allowing them to alter their production strategies by taking advantage of opportunities in good years and reduce losses in poor years. However, the abilities to use climate forecasts could be constrained by the options (e.g., draft power, sources of income, crop types/cultivars, fertilizer use etc) available to the farmers.

2.2 Rainfall variability and livelihoods

The number of kilograms per hectare that can be obtained through crop production may increase or decrease due to crop responses to rainfall variations. Similarly, the amount of food a household can purchase is influenced by affordability. Affordability is influenced by price fluctuations created by rainfall related variations in production and therefore of food supply.

Rainfall variations can affect livelihoods through impacts on trade, such as in the case of livestock trade bans imposed by Middle Eastern countries on the Greater Horn of Africa due to rainfall-related outbreaks of Rift Valley fever, a mosquito-borne virus. Epidemic malaria triggered by climate.

A household with a high dependence on rain- fed subsistence crop production is vulnerable to drought (agricultural drought). If that same household is in a region of high rainfall variability, the combination of probable exposure to drought with the household's vulnerability to drought from dependence on rain-fed crops creates risks of the household becoming food insecure. A household with a high dependence on income from mining is not vulnerable to drought. In this latter case, however, fluctuations in the prices of mineral commodities on international markets could constitute a food security hazard. In many parts of the semi-arid tropics climate is highly variable, fluctuating according to quasi-periodic changes in global sea surface temperatures and atmospheric patterns, such as El Niño and the Southern Oscillation. In Africa, areas of highly variable rainfall include the Sahel, the Greater Horn and Southern Africa. All of these areas have been at risk, or have realized the risks, of widespread, prolonged famine associated with drought in combination with the vulnerabilities of household and national economies (Hansen, *et. al*., 2004)

2.3 Factors influencing crop productivity

The rapidly increasing population in the tropics and sub-tropics has resulted in increased land use pressures. Agriculture is the major economic activity for the countries of the SSA, engaging between 75% and 85% of the people of those countries. A survey of 277 societies in SSA by Hunt-Davis (1986) showed that approximately 86% depended primarily on agriculture. Thus the livelihood in this region is based on small holder rural agriculture, which in most cases is dominated by resource poor farmers, with low levels of productivity and simple tools, making them over-dependent on the status of the natural environment.

With land supply being inelastic, farmers are being faced with the problem of inadequate land on which to grow their crops and feed their families. This has called for researchers and farmers alike to find better ways of intensifying crop production, increase yields and improve household food security and incomes. The challenge facing Africa today is to clearly find a way of achieving these especially for farmers in marginal areas if Africa is to meet the target set by millennium goal number one which states that the proportion of people who suffer from hunger should be halved by 2015.

The aim in the past has been on developing new technology, on the assumption that this will lead directly to improvements in crop productivity, food security, and rural welfare. This has not occurred for various reasons; hence the need (goal) to develop and promote practical methods by which resource poor smallholder farmers can improve crop productivity in areas with limited rainfall and poor soils. Technological approach must aim to incorporate agronomic and germplasm approaches and must aim to lead to better agronomic practices that suit the rainfall patterns and soil types of specific areas to ensure sustainability of the cropping system (Rusike and Heinrich, 2001).

2.4 Climatic pattern of Southern Africa

The term climate refers to long-term weather statistics. Climate is how weather acts over many years. Several methods of grouping areas with similar climatic conditions exist. One method uses the factors that in addition to the sun shape the climate of a region and hence describes climatic regions as being polar, temperate, tropical, and marine among others.

In view of the above, most of the Southern African climate is described as being tropical in nature and is either arid or semi-arid. It is characterized by two distinct seasons: the hot wet season (rainy season) from mid-October/November to mid-March and a dry cold season in the winter with countries near the Indian Ocean receiving higher rainfall than those on the Atlantic Ocean. Hence, rainfall in the region is not uniform and is highly variable in both space and time and erratic at the same time (Twomlow, *et. al*., 2006). Seasonal Precipitation patterns hence the climate in Southern and Eastern Africa are predominantly controlled by the following:

- Regional circulation patterns and the Inter-Tropical Convergence Zone (ITCZ).
- Latitude which affects the timing of rainfall minima and maxima.
- Topography and aspect, which influence the intensity of the ITCZ and the amount of rainfall; and
- Inland lakes such as Lakes Malawi and Tanzania which provide local sources of moisture (Parry, *et. al*., 1989; Buckle, 1996).

Rainfall is a function of climate. It follows then that any change in climatic patterns results in a change in rainfall patterns. For many tropical zones, the overall effect of climate change looks more negative as there maybe increased rainfall variability, increased incidence of extreme weather events, and reduced crop yields. Improvements in crops, techniques of cultivation, and soil and water management may be able to compensate, but increasing food production in these zones will be made much harder (FAO, 2002).

2.4.1 Rainfall variability and crop production.

Most of the countries in SSA are characterized by a semi-arid climate and important to note is the fact that in the dry areas, water, not land, is the limiting factor in improving agricultural production (Pala and Studer, 1999). It is a well known fact that semi-arid areas tend to experience lower rainfall and high annual rainfall variability resulting in reduced amounts of reliable rainfall between years. Under rainfed conditions, crop growth is subject to the random variability of rainfall in both space (spatial) and time (temporal). As a rule of thumb, the variability of rainfall over time increases with decreasing annual and seasonal rainfall levels. Rainfall variability has an impact on crop production as it is strongly related to crop yields in rainfed agriculture, particularly in semi-arid and dry sub-humid areas where water is a major constraint in food production (Hansen, *et. al*., 2004).

Rainfall is one of the climatic variables that is most critical to measure with regard to crop production. However, it is important to note that there are other agronomic factors like: soil type, temperature, length of growing period, availability of inputs and management (farmer) practices like type of tillage practice, time of planting, variety of crop, plant density, weeding, pest control, fertilizer application; that affect the environment of a crop.

2.4.2 Hydro- climatic challenges in semi-arid regions

Hydro-climatic challenges are considered to be the most limiting in terms of crop production in semi-arid areas because they reduce the amount of water available to the crop in order for it to reach maturity and are in most cases very difficult and expensive to manipulate. They are essentially responsible for setting the boundary conditions of potential yields (Savenije, *et. al*., 2003).

Hydro-climatic challenges are the water-related problems in rain-fed agriculture in the water-scarce tropics that often relate to high-intensity rainfall with large spatial and temporal variability, rather than to low cumulative volumes of rainfall (Wallace and Batchelor, 1997; Rockström, 2000; Hatibu, *et. al.*, 2003). Coefficients of variation range from 20 to 40%, increasing as seasonal rainfall averages decrease. The overall result of unpredictable spatial and temporal rainfall patterns indicates a very high risk for meteorological droughts and intra seasonal dry spells. The annual (seasonal) variation in rainfall can typically range from a low of one-third of the long-term average to a high of approximately double the average; meaning that a high-rainfall year can have some six times higher rainfall than a dry year. Generally, the hydro-climatic focus in semi-arid and dry sub-humid tropics is on the occurrence of meteorological droughts. Meteorological droughts are defined on the basis of the degree of inadequacy of precipitation, in comparison to a normal or average amount and the duration of the dry period. Their impact on rain-fed agriculture is complete crop failure, which statistically, for semi-arid lands, occurs about once every 10 years (Stewart, 1988).

However research from several semi-arid tropical regions show that the occurrence of dry spells, i.e. short periods of 2–4 weeks with no rainfall, by far exceeds that of droughts. Stewart (1988), based on research in East Africa, indicated that severe yield reductions due to dry spells occur once or twice in 5 years, and Sivakumar (1993) showed that the frequency of seasonal dry spells lasting 10–15 days was independent of long-term seasonal averages, which range from 200 to 1200 mm in West Africa. Rockstrom, *et. al.*, (2003), studying the frequency of dry spells in semi-arid locations in Kenya and Tanzania, showed a minimum probability (based on statistical rainfall analysis) of 0.2–0.3 for a dry spell lasting more than 10 days at any time of the growing season of a crop, and a probability of 0.7 for such a dry spell to occur during the sensitive flowering stage for maize.

Occurrence of dry spells can be categorized depending on the threshold value being used to define a period which can either be a day, week or months depending on parameters being investigated.

Mitigation of intra-seasonal dry spells is a key to improving water productivity in rainfed agriculture in semi-arid and dry sub-humid tropical environments. Rockström, *et. al*., identified three major avenues to achieve this:

- Maximize plant water availability (maximize infiltration of rainfall, minimize unproductive water losses(evaporation), increase soil water-holding capacity and maximize root depth)

- Maximize water uptake capacity of plants (timeliness of operations, crop management and soil fertility management).
- Dry spell mitigation using supplemental irrigation.

2.5 Water-soil- plant relationships

Although water may be primarily limiting for agricultural production and crop growth (Zingore, *et. al*., 2006), the instant soil water is available nutrient deficiency will be the limiting factor. Obviously the two states will alternate during crop season and in the end determine the final yields (Gregory, *et. al*., 2000). Lack of available soil nutrients and low input of fertilizer in small holder farmers have been thoroughly researched upon and discussed in studies by Zingore, *et. al*., 2006 and Pool, 2001)

Several studies have showed the interaction of soil water and nutrients for semi-arid farming conditions (Klaij and Vachaud, 1992; Boumar, et. al., 1982; Rockstrom, *et. al*., 1999; Fox and Rockstrom, 2000) which emphasize the need to secure water availability in order to improve crop nutrient uptake.

The size, shape, and arrangement of the soil particles and the associated voids (pores) determine the ability of a soil to retain water. It is important to realize that large pores in the soil can conduct more water more rapidly than fine pores. In addition, removing water from large pores is easier and requires less energy than removing water from smaller pores. Soil texture is one of the most important properties of soil that helps to determine the nutrient-supplying ability of soil solids and the supply of water and air that support plant life. Silt and clay soils are finely textured and sustain slow water and air movement. They have a high water-holding capacity because they consist of a high percentage of pores. Silt and clay soils are referred to as heavy soils, with clay being the heavier of the two. Soil compaction on the other hand reduces the size of pores that hold air and water resulting in significantly reduced plant growth. Another important factor that tends to have a bearing on availability of water to plants is the soil organic fraction which serves as a nutrient source and helps to maintain soil moisture (Miller, 1971**).** The proportions of clay, silt and organic matter are different depending on soil type.

Soil pH is one of the most important characteristics of soil fertility because it has a direct impact on nutrient availability and growth. It also affects the adaptability of plants to a given soil. Although there are exceptions, the preferred pH range for most plants is between 5.5 and 7.5. Legumes prefer higher pH (pH values of 6.2 - 7.0) than do grasses (pH values of 5.8 - 6.5) (Bandel and John, 2002). Phosphorous tends to be available between pH 6.0 and 7.5. Elements such as iron; aluminium and manganese are especially soluble in acid soils. Above pH 7.0, calcium, magnesium and sodium are increasingly soluble (Miller, 1971).

The range of water available to plants is between field capacity (FC) and the permanent wilting point (PWP). The soil is at field capacity when all the gravitational water has been drained and a vertical movement of water due to gravity is negligible. Further water removal for most of the soils will require at least 7 kPa tensions. The PWP is defined as the point where there is no more water available to the plant and depends on plant variety, but is usually around 1500 kPa (15 bars). This means that in order for plants to remove water from the soil, it must exert a tension of more than 1500 kPa (15 bars). This is the limit for most plants and beyond this they experience permanent wilting. Therefore, soils which hold significant amounts of water at tension in the range plants are able to exert (up to 1500 kPa (15 bars) of tension) will provide better water supply for plant growth.

2.5.1 Major processes determining crop yield

Water, soil and plant deficiencies affect two main crop processes which determine crop yield and growth. These are:

- Crop water availability
- Crop water uptake capacity.

It is therefore very important to address these processes as we attempt to improve crop yield, assess water required in crop production and in estimating what water management options to adopt.

Water availability is a function of the interaction between amount of rainfall received and potential evapotranspiration (PET). Potential evapotranspiration rates that are two to four times the annual mean rainfall makes an area vulnerable to prolonged droughts. On the other hand, lower evaporation and transpiration rates tend to increase the effectiveness of the rain received; although this may not be enough to recharge the soil moisture reserves in the rooting zone.

Crop water availability is the amount of plant available soil moisture in the root zone at any given moment in time during crop growth. It is determined by the following factors:

- Rainfall depths (mm) and distribution
- Amount of rainfall that infiltrates the soil
- Amount of rainfall that has infiltrated that can be held in the soil and made available to the plant.

Crop water uptake is defined as the capacity of the crop to take up water and is determined by factors such as:

- Crop variety
- Soil fertility management
- Soil structure
- Timing of operations
- Weeding

Crop water availability should be secured during the entire period of the crop growing cycle and crop water uptake kept at a maximum if full potential of crop in terms of yield is to be achieved.

2.5.2 Water supply and crop yield

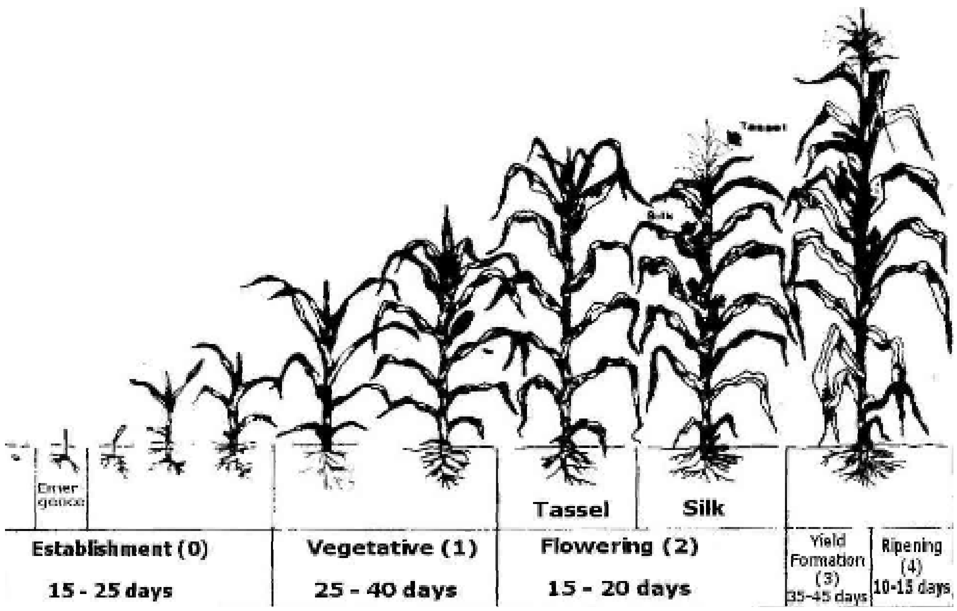

Figure 2-1: schematic graph of the growth stages of maize)
(Source: FAO AGL, 2002)

Frequency and depth of rain and irrigation have a pronounced effect on grain yield. Maize appears relatively tolerant to water deficits during the vegetative (1) and ripening (4) periods. Greatest decrease in grain yields is caused by water deficits during the flowering period (2) including tasselling and silking and pollination, due mainly to a reduction in grain number per cob. This effect is less pronounced when in the preceding vegetative period (1) the plant has suffered water deficits. Severe water deficits during the flowering period (2), particularly at the time of silking and pollination, may result in little or no grain yield due to silk drying. Water deficits during the yield formation period (3) may lead to reduced yield due to a reduction in grain size. Water deficit during the ripening period (4) has little effect on grain yield (Al-Kaisi, *et. al*., 2005)

2.5.3 Water uptake

When evaporative conditions correspond to ET_m of 5 to 6 mm/day, soil water depletion up to about 55 percent of available soil water (Sa) has a small effect on yield (p = 0.55). To enhance rapid and deep root growth a somewhat greater depletion during early growth periods can be advantageous. Depletion of 80 percent or more may be allowed during the ripening period.

Although in deep soils the roots may reach a depth of 2 m**,** the highly branched system is located in the upper 0.8 to 1 m and about 80 percent of the soil water uptake occurs from this depth. Normally 100 percent of the water is taken up from the first 1 to 1.7 m soil depth (D = 1 to 1.7 m). Depth and rate of root growth is, however, greatly affected by rainfall pattern and irrigation practices adopted. In addition to soil water and nutrient status, root development is strongly influenced by textural and structural stratification, salts and water table.

2.5.4 Essential Plant Nutrients

Many dry-area soils are inherently low in fertility, as was pointed out before, and the correct application of fertilizers is therefore essential. Extensive work in Syria (Pala, *et. al.*, 1996) demonstrated the benefits of appropriate fertilization for Water Productivity (WP) and therefore for production and yield stability. Water plays a significant role in fertilizer-use efficiency. Improved fertility improves WP and can therefore stabilize production and enable crops to exploit favorable rainfall in good years. Given the inherent low fertility of many dry-area soils, judicious use of fertilizer is particularly important. Under rainfed conditions, the application rate of N fertilizer is not high. In northern Syria, 50 kg N ha_$^{-1}$ was sufficient under rain-fed conditions. However, with water applied by supplementary irrigation, the crop responded to nitrogen up to 100 kg N ha^{-1} after which no benefit was obtained. This rate of N greatly improves WP.

There are 16 identified elements that are essential to plant growth. Three of these elements are obtained mostly from air and water: they are carbon (C), hydrogen (H), and oxygen (O). The other 13 essential elements come from soil solids and are the elements we tend to focus on in plant fertility management. The 13 essential plant nutrients are divided into three categories based on the amount of the element required for plant growth. The nutrients and their categories are as indicated in the table below:

Table 2-1: Essential elements

Essential Plant nutrients	**Primary nutrients**	**N**	**P**	**K**				
	Secondary nutrients	**Ca**	**Mg**	**S**				
	Micronutrients	**Fe**	**Mg**	**B**	**Mo**	**Cu**	**Zn**	**Cl**

Plants require primary nutrients in high amounts, secondary nutrients in lesser amounts, and micronutrients in only small amounts. Whether a nutrient is primary, secondary, or a micronutrient, it is essential to plant growth. A deficiency in any one of the essential nutrients will restrict plant growth.

2.5.5 Measure of crop productivity

Yield is usually measured in kilograms per hectare and can either be biological or Economical. Biological yield refers to the total biomass produced by a plant where as economic yield refers to the component of the plant which is of economic value to the producer or consumer. Yield may be measured using the following methods:

- Biomass analysis-which measures how a crop accumulates dry matter and
- Harvest Index (H.I**)-**which is the ratio of economic yield to the biological yield and is always a fraction. Where only certain part of the plant is

harvested the H.I will be less than one. In the case of forages the H.I is one (100%).

2.6 Conclusion

The literature above shows that it is a well known fact that Southern Africa in which the study area is located is characterized by low and erratic rainfall which exhibits high spatial and temporal variation; and that this impacts negatively on crop production. However, this literature only gives a general picture of the whole concept of rainfall variability. It is not site specific and has been silent on the degree of the variability or the degree of its associated impacts regarding crop yield and failure to specific areas; previous studies on rainfall variability involved long term weather focusing usually at a global or regional level. Such studies makes discussions of rainfall variability at a local scale not be conclusive. Thus this study aims to address the degree of rainfall variability, the degree of its effect on crop yield and the resulting effects arising from these at a smaller scale (meso-catchment).

CHAPTER THREE

3.0 STUDY AREA

3.1 Introduction

Mzingwane catchment is one of the seven catchment areas as demarcated by the new water legislation that was promulgated in 1998. It is located in the semi arid region of Zimbabwe and is divided into four sub-catchments. Mzingwane is part of the Limpopo basin, located in South-eastern Africa. The Limpopo basin covers 1.3% of the continent and spreads over four countries: Botswana, Mozambique, South Africa and Zimbabwe.

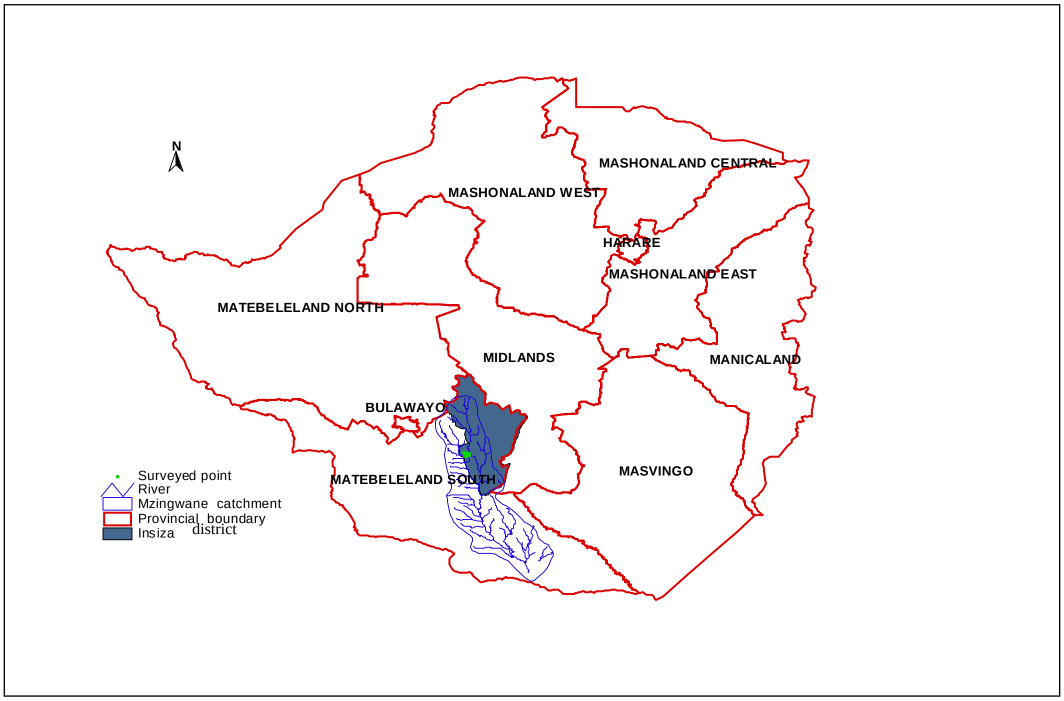

Figure 3-1: Provincial map of Zimbabwe showing location of study area
(Source: ICRISAT, Bulawayo)

In Mzingwane catchment, annual rainfall ranges from 300mm in the south to 635mm in the north of the catchment and the temporal distribution of rainfall follows the general pattern of the southern African region (Kahinda, 2004)The dry months between April and October provide the coldest month in July when minimum temperature below 0^{o}C are experienced, and as well as the hottest month in October when maximum temperature in the upper thirties are observed, with the hottest areas being around Beitbridge.

Soils in the area vary from sandy loams (red soils) in the north to sandy soils in the south. Small holder farmers are generally confined to marginal soils (predominantly sandy) which are of poor quality as they are infertile and deficient in nitrates, phosphates and sulphur (Burt. *et .al*., 2001).This, coupled with rising populations have placed an increasing burden on the already poor soils (Moyo, 2004).In addition to the above, these soils are referred to as light soils as opposed to being heavier soils and have lower water holding capacities because they consist of a low percentage of pores. Soils in this area also tend to exhibit low proportions of clay and silt further exacerbating their ability to hold water. In view of the above, chances of residual moisture at planting are negligible and even if there was any it would be in quantities that would not even be available for use by the plant and would be outside the root zone. The root zone is considered to be the 2mm depth from soil surface.

3.1.2 Farming systems

The types of farmers found in SSA are mostly the small-scale farmers (rainfed) and smallholder irrigation scheme farmers. The majority of farmers are the small holder farmers who depend on rainfall which is rather erratic and highly variable and unpredictable. In addition, agro-climatic information for smallholder farmers to enhance their productivity is not just limited but mostly unknown by the people Therefore, food production is low and household food insecurity is common (IIRR 1998).

The main crops grown during the wet season are maize, groundnut and beans. Wheat and vegetables are grown during the dry season under irrigation.

The five major crops grown by both commercial and small holder farmers in southern Africa in 1998 were groundnuts (*Arachis hypogaea L*), maize(*Zea- mays*), sorghum (*Sorghum bicolour L*), pearl millet (*Pennisetum glaucum L*) and cotton (*Gossypium hirsutum*) (FAO, 1999a). Maize is by far the most dominant crop, favored by both large and small scale farmers alike, with more than 13million hectares in 1998, 70% of the total area cropped. Despite the inadequacies of the rainfall and a marginal resource base, maize continues to be the dominant crop and accounts for the caloric intake of most urban and rural populations in the region. This is so due to the following reasons:

- Many households, both urban and rural prefer the taste of maize over their traditional small grain crops;
- In many countries maize is given out in drought relief programs, both as food and seed(Rohrbach and Kiala,2002)
- Current pricing policies in much of sub-Saharan Africa and underdeveloped rural grain markets make maize more economically attractive (Tripp and Rohrback,2001)
- Traditional small grain crops, particularly sorghum are attacked by birds;
- Maize is less labor intensive than other crops, a major consideration for many households with labor shortages, and last but not least.
- Improved maize varieties developed by the International Maize and Wheat Improvement Center (CIMMYT) and their partners in Africa consistently out yield other cereals (Johnson,1992 and Twomlow et al., 2006)
- Maize can be eaten green

3.2 Description of specific study area

The study area (Zhulube meso-catchment) is located in the upper Mzingwane Catchment in Insiza District which is one of the six districts in Matebeleland South Province. It is in southern rural Zimbabwe where water is a vital and scarce commodity. Insiza district comprises 18 wards. Eleven of these including ward one where the study area is located within the Mzingwane Catchment.

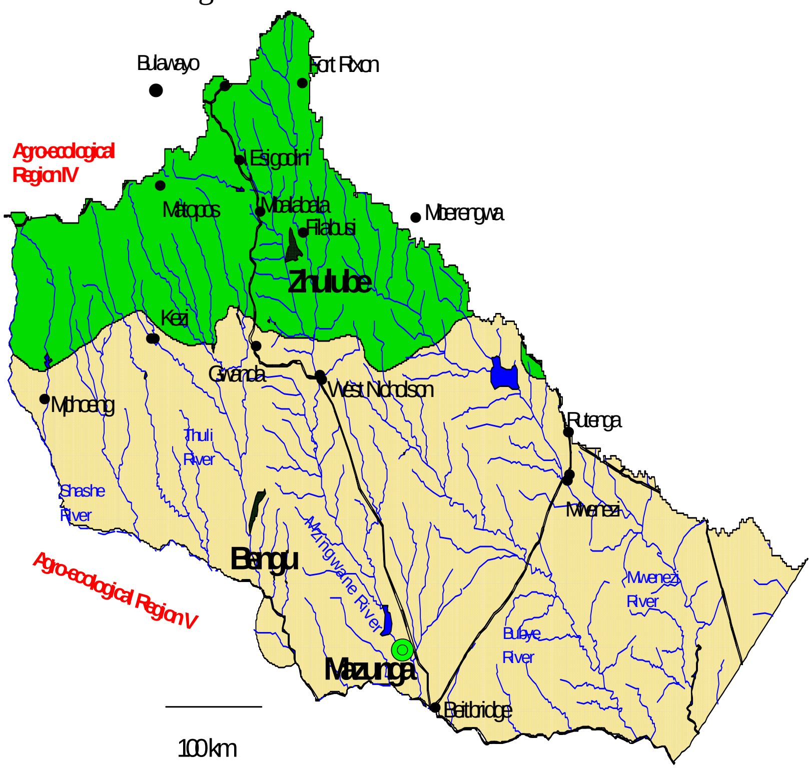

Figure 3-2: **Mzingwane catchment showing location of study area**
(Source: Description of Zhulube, David Love)

3.2.1 Climate

The area can be classified as being semi-warm, sub-humid, with a summer rainfall regime occurring in convectional storms of short duration and high intensity. Mean annual rainfall is around 550 mm and mean annual temperatures range between 12^{o}C and 29^{o}C (meteorological records of Filabusi: 1931-2001). Temperatures are minimum and maximum in June-July and October respectively. Summer temperatures can be as high as 40^{o}C.

3.2.2 River system

The principal river of the catchment is the Zhulube River whose source is in a seasonal wetland in granite terrain around Mahole village, in the southeast of the catchment, and flows westwards, then southwest to the Mzingwane River. It is fed by one major right bank tributary (variously designated Geneva or Tshazi River), which flows from the mountains in the north, and several smaller streams. The Zhulube River is sub-perennial, but most of the tributaries are highly ephemeral, flowing only for a few hours after a storm (description of Zhulube, Love).

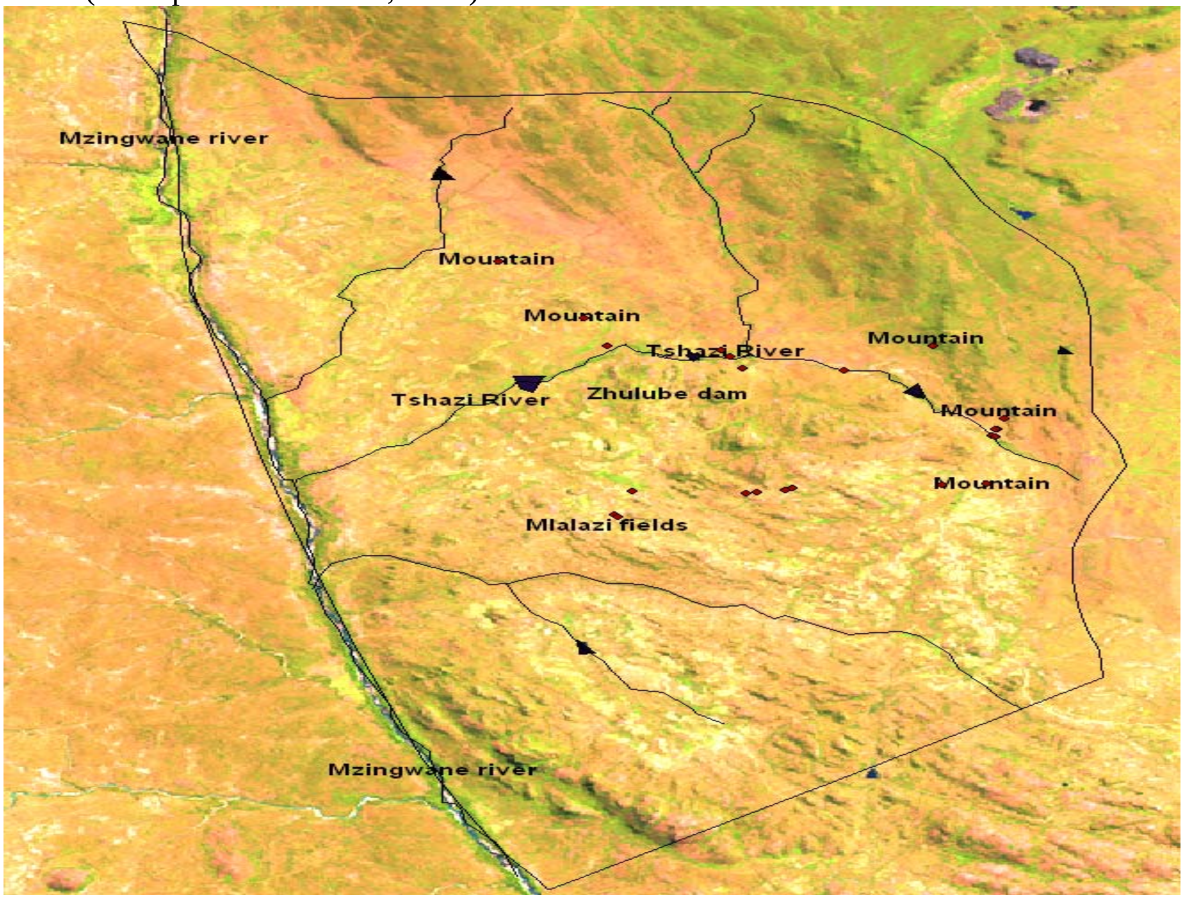

Figure 3-3: **Land sat image of study area showing distribution of experimental plots points.**
(Source: ICRISAT, Bulawayo)

The study area has a small dam built for irrigation purposes by World Vision in 2003, but used as a multi-purpose reservoir by the local community. It is downstream of an older dam, which is now completely silted up. It is typical for such structures to fulfil various uses like drinking water, domestic use, livestock watering and irrigation (Sawunyama, *et. al.*, 2005)

3.2.3 Soil

The soils in the area are predominantly sandy in nature. These soils are classified as being light soils as opposed to being heavy soils and generally have low water holding capacities. In view of the above, chances of residual moisture at planting are negligible and even if there was any it would be in quantities that would not even be available for use by the plant and would be outside the root zone.

3.3 Land use

The area comprises a mixed land use system consisting of cropland, pastureland and woodland (Hearn, et. al., 2001).Small scale rainfed agriculture is the most prevalent type of cropping. Irrigation farming facilitated by the presence of irrigation schemes such as the Zhulube irrigation scheme is also practiced.

CHAPTER FOUR

4.0 MATERIALS AND METHODS

The parameters being investigated and the tools used to investigate them including statistical software packages are outlined in this section.

4.1 Desk study-long term rainfall

This study involved the study of rainfall using existing rainfall data collected over a period of at least 25 years so as to show whether it is variable or not. This data was important for the establishment of trends which could then be incorporated in to the planning processes for agricultural related activities. Since Zhulube had no long term data required for such a study, a nearby station was used.

4.1.1 Sampling protocol

Existing daily rainfall data from 1965 to 1994(source: meteorological department of Zimbabwe) for the neighbouring area of Filabusi was used to study the long term rainfall trends of Zhulube meso-catchment. This station was selected on the basis of proximity to the study area and data availability.

4.1.2 Data analysis

Rainfall data was analyzed for trends in variability and occurrence of dry spells in two parts: firstly for the entire 30 year period and secondly at five year intervals. The analysis was partitioned in this way in order to allow for comparison based on the duration of the datasets.

Effective rainfall was used as a threshold for determination of rain days and / or dry days in order to allow for the estimation of dry spells. A dryday was described as a day with zero or negative effective rainfall and a spell was defined as a specified period with zero or negative rainfall. For the purpose of this study only dry spells lasting 10 days or more were considered as dryspells because these are the ones that tend to have a profound effect on the survival of most crops including maize.

Effective rainfall is defined as that part of rainfall which can be used for crop growth including rainfall intercepted by plant foliage, rainfall that can enter and be stored in the root zone. It is generally the only water source for rainfed crops (Moyo, 2005). Effective rainfall was calculated using equations 1 and 2 (Brouwer and Heibloem, 1986) considering that not all the received rainfall is available to plants.

Effective rainfall = 0.8* P-25 if rain > 75mm/month **Equation 1**

Effective rainfall = 0.6* P-10 if rain < 75mm/month **Equation 2**

where P = total rainfall per month

First recommended planting dates were identified using the AREX criterion (Raes, et. al., 2004). Two criteria are currently in use in Zimbabwe, the AREX criterion of the Agricultural Research Extension (25mm rainfall in 7 days) and the MET criterion of the department of Meteorological Services (40mm in 15 days). The AREX criterion was found to be appropriate for this study because of the amount of rainfall that it receives and the distribution pattern. Following this a threshold of 25mm rainfall over a period of seven days was used to determine the earliest planting dates (Raes, et. al., 2004**).**

Data handling and processing was done using micro-soft excel in which t-tests and Analysis of Variance (ANOVA) were carried out. Descriptive statistics was also employed using instat version 3.33 statistical software package (Instat Plus v 3.33, 2005).

4.2 Short term rainfall comparison

This involved field work in which daily rainfall data was recorded in a record book and later analyzed for trends in that particular season. A comparison was also done in which this data was compared with data for the previous season which was collected in a similar way.

4.2.1 Sampling protocol

Initially 10 raingauges were to be stationed in the catchment and the criteria for choosing the location of these was based on the following: Geographic location of the catchment in terms of direction of prevailing wind. In view of this the following sites were identified as being suitable: Windward side-Mahole business center, Zhulube Clinic, Tshazi Secondary School and Tshazi Primary School; Midveld -Nkomo, N'cube, Mlalazi and Moyo; Leeward side Khumalo, St. Matthews Primary School and Mafu. However, two of these sites namely Nkomo and Ncube were found to be in possession of rain gauges which were installed by another researcher earlier.

The soil type was another factor that was considered and as such gauges were placed in such a way that they would cover the principle soil types of the catchment which were identified as sand, sandy loam and loamy sand. In addition to these, security was also identified as an important aspect of the sampling protocol. The raingauges had to be at a place which was not isolated so as to reduce on chances of them being vandalized; and for a place to be secure it had to have people around and enclosed to avoid both human and livestock interference. Based on this, public places such as schools, business centers, clinic and private places such as people's homesteads were identified as being relatively secure; thereafter, the final decision was now based on willingness of people occupying the so called secure area to allow the researcher to put up a rain gauge, willingness and ability to read rain gauge and distance and ease of access to area. The above mentioned locations were then identified as being suitable.

4.2.2 Placement of Rain gauge

The raingauges were placed well away from buildings, trees, shrubs and other obstruction on level or nearly level ground at a height of between 0.7m and 1.2m above the ground (Manual of the Department of Meteorological Services of Zimbabwe, 1974).

4.2.3 Recording of data

Daily rainfall readings were taken and recorded in a record book by the researcher with the help of field assistants. Results of the recordings are as indicated in appendix A. The readings were taken before eight o'clock in the morning of each day. Readings had to be read in the morning when the effect of evaporation was considered to be minimum or negligible.

4.2.4 Data analysis

Missing data for some stations was calculated using nearby stations. This was done using Microsoft excel data analysis tools in which correlation analysis was done to establish if two stations were related. Correlation involves comparing two stations (an independent and dependent). The dependent station refers to the station with missing data. If a correlation exists then missing data is calculated using regression analysis function in excel. After regression analysis, an x-variable is obtained and used to calculate the missing values. A correlation of greater than 70% between two stations is sufficient.

A form of quality control check was performed on the observed rainfall data in which inhomogeneities (particularly jumps) in the time series were investigated using the principle of double mass analysis in which accumulated values of the station under investigation were plotted against accumulated values of another station, or accumulated values of the average of other stations, over the same time period. A monthly time series spanning over a period of seven months (October to April) was used. Inhomogeneities were indicated by inflections in the straight line of a curve of a double mass plot.

Daily rainfall data was analyzed for trends in variability and occurrence of dryspells. Seasonal comparison was done between 2004/05 and the 2006/07 cropping seasons. Spatial and temporal variability of rainfall was shown graphically and statistically.

Data handling and processing was done using excel in which t-tests and Analysis of Variance (ANOVA were carried out. Descriptive statistics was also employed using instat version 3.33 statistical software package.

4.3 Maize performance

Maize being the widely grown crop was used in the establishment of crop yield. Both as food for man and feed for animals, maize is one of the most important crop in world agricultural economy. It has yield potential far higher than any other cereal. Maize performance was assessed in terms of the biomass produced. Biomass measures how a crop accumulates dry matter and was determined using bio-mass analysis based on total dry weight. The main purpose of evaluating maize performance was in order to relate it to rainfall trends in the area so as to show whether rainfall variability results in significant differences in yield.

4.3.1 Cropping calendar

A seeding rate of 3 maize seeds (SC 403) per station was employed and the other requirements were as indicated below:

Table 4-1: Cropping calendar of experimental plots

Crop	Tillage practice	Spacing	Weeding	Compound D	Ammonium nitrate
Maize(SC403)	**Conventional Hand hoeing**	**90cm*30cm**	**Twice at 2&6wks after planting**	**Applied at planting at a rate of 250kg/ha**	**Applied at 6weeks at a rate of 100kg/ha**

Thinning of the weaker plants was done during the second weeding at six weeks so as to achieve a population of one plant per station. The reason for a uniform cropping calendar for all maize plots was in order to have all the above as constants so as to be able to investigate the effects of rainfall and soil on the yield. Monitoring for germination dates and percentages was done. Plant height was also measured 30 days after planting (refer to table)

4.3.2 Sampling protocol

Seven experimental plots were cultivated using conventional tillage methods. These experimental plots were located within the areas where seven of the raingauges were placed and were chosen based on amount of rainfall received, soil type and willingness of farmers to have them on their fields, seriousness of farmer in terms of ability to follow instructions and also ability to implement these instructions and easiness of monitoring. The plots were being monitored by farmers themselves under the supervision of the researcher.

Sampling for height was done as part of field monitoring by randomly selecting 20 plants per plot. An average was calculated to give the average height per plot Sampling for biomass was done twice; at flowering and grain filling stages respectively. It involved a random selection of five plants per plot. The sample was weighed to determine the fresh weight. Thereafter it was oven dried in an oven at sixty degrees Celsius for 48 hours. Biomass was then determined by weighing the dried sample to give a crop biomass based on its dry weight (**Table 5.8**). The difference between the fresh and dry weights is the moisture contained in the plant.

Sampling for soil involved sampling randomly at five locations per maize plot at a depth of 0.30m.After sampling the soils from the different points on the plot were mixed to give one sample per plot. The samples were then taken to University of Zimbabwe soil science laboratory for testing and analysis (**refer to appendix E).**

4.3.3 Data analysis and processing.

The effects of rainfall, soil type and soil type and rainfall on maize yield were investigated. In order to determine the influence of rainfall on biomass, a comparison was done in which areas with similar soil type were grouped and their biomass plotted against rainfall received. This was done in order to standardize soil type and sampling time so that the biomass could be investigated on the basis of rainfall alone. An assumption that rainfall prior to planting had no effect on amount of biomass produced was made.

Secondly, the role of soil type in crop yield was looked at. In this analysis, biomass and rainfall were the variate and covariate respectively where as soil type was the factor being investigated.

Lastly, the effect of the interaction of soil type and rainfall on biomass was investigated. This analysis incorporated location as well as the day of sampling within a location (as a random term) bearing in mind that location and date of sampling can bring about variability in terms of biomass.

Data handling and processing was done in excel to illustrate the relationship that exists between rainfall and biomass. In the second and third instances, data was managed and processed using an analysis of covariant (ANCOVA) and the residual maximum likelihood (REML) variance components analysis statistical model respectively. These two were facilitated by Genstat Release 9.1 statistical software package.

4.4 Survey on households

Interviews were held with farmers by use of household questionnaires. The major purpose was to assess the farming practices that prevail in the area in order to understand their possible impacts on crop yield.

4.4.1 Sampling protocol

The catchment of interest comprises six villages namely Siyapambili, Asibambanani, Mpumelelo, Thuthuka, Thandanani and Masiyepambili. The villages were being considered for the study based on their spatial location and expected differences in soil type, total rainfall received and farming techniques. Following this, ten small scale farmers were interviewed per village resulting in a total of sixty cases. The individual farmers who were interviewed were randomly selected.

4.4.2 Data analysis

Variables were formulated from survey questions. The variables and responses from variables were then coded and subjected to Statistical Package Social Scientists (SPSS) for analysis and narrative information was directly transcribed. Frequencies were performed on cases to see if there were any significant differences between the cases or villages. Thereafter, cross tabulations (two-way tables) were run to view frequencies of cases at different levels. This was followed by the use of descriptive statistics which was employed to give a comparison of means, standard deviations and sums.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

5.1 Analysis of long term rainfall trends and variability

Filabusi station located in a semi-arid area close to Zhulube meso-catchment was undertaken to assess long-term trends and changes in rainfall characteristics. The historical rainfall data gave an indication of variability in annual rainfall for the different years as indicated below (**Figure 5.1**). The rainfall varied around a mean of 533mm between 1965 and 1994. The longest low rainfall period was observed between 1983 – 1983 and 1987- and 1989. A similar cluster of low rainfall years was reported between 1992 -1994. There was a continuous three year period of rainfall below the long term annual mean of 533mm (**Figure 5.2**)

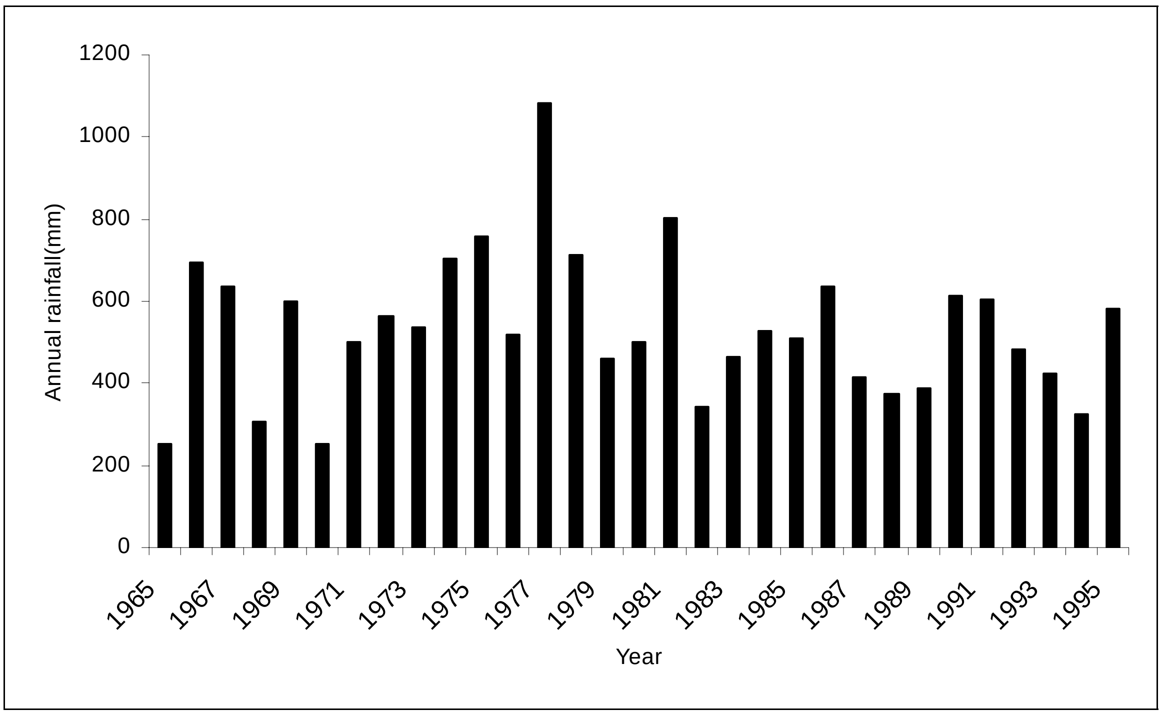

Figure 5-1: **Seasonal rainfall graph for Filabusi station**
(Source: Harare Meteorological Department**)**

The coefficient of variation of 34% for the entire period of 30 years indicated highly variable rainfall for the station (**table 5.1**).

Table 5-1: **Descriptive statistics of years based on total amount of rainfall received.**

No. of observations	Min	Max	Range	Mean	Std.dev.	s.s	CV
30	251	1083	832	533	179	930188	34%

A t- test for significance revealed that p = 4.36E-28(< 0.01), two tailed at 95% confidence level meaning that the means of rainfall for the different years of interest were highly significantly different from each other and the difference could not be attributed to chance alone (**see table 5.2**). In this relationship, the association of variables is very weak and yet it is strongly significant; this usually happens in large samples where even weak associations maybe found to be significant. Also two variables maybe strongly ,but not significantly associated; this may happen in small samples .It is important to note that significant coefficients not only reflect the strength of association, but also sample size. This is why researchers should report measures of both significance and association.

Table 5-2: T-test for means of rainfall and years

	Rainfall	Years
Mean	533	1980
Variance	32075	78
Observations	30	30
Pearson correlation	- 0.12	
d. f	29	
t. stat	-43.9	
P(T < =1) one- tail	2.18E-28	
t critical one- tail	1.70	
P(T < =1) two- tail	4.36E-28	
t critical two- tail	2.05	

The historical data shows that 17 years out of 31years had rainfall below the long term average of 533mm/annum. Annual rainfall figures were subtracted from the long term mean so as to show their degrees of departure from it and consequently the rainfall variability (**figure 5.2 below**). In this analysis the x-axis represented the annual mean. Thirteen years had rainfall above the long term average. The lowest and highest annual rainfall was 251mm in 1970 and 1083mm in1977, respectively.

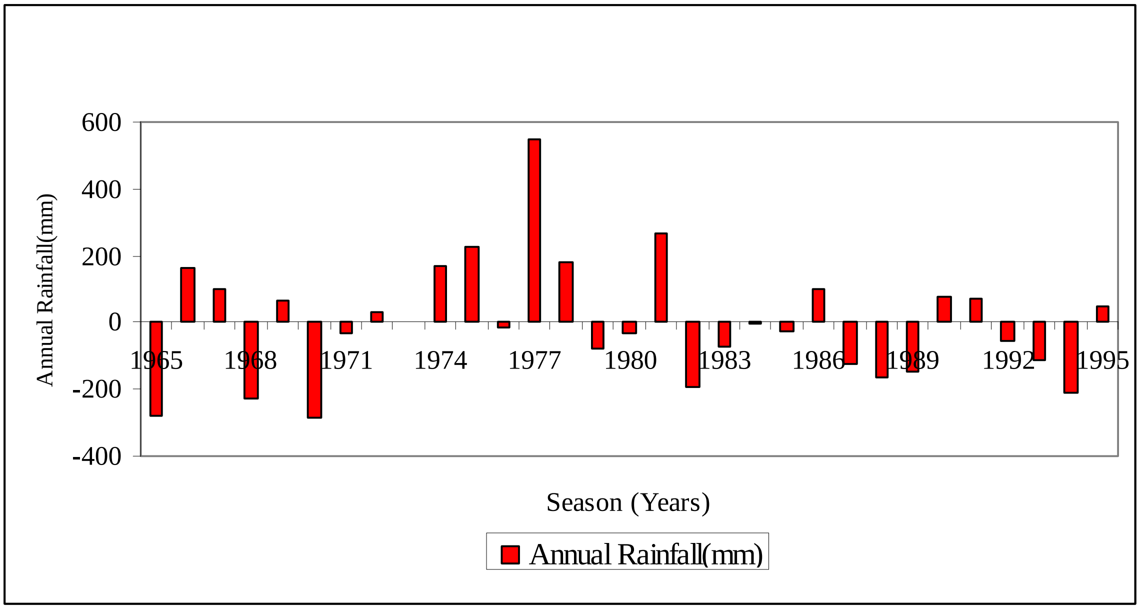

Figure 5-2: **Seasonal fluctuations of rainfall indicating variation of rainfall from the long term annual mean.**
(X-axis to represent seasonal annual mean= 533mm)

Results showed a high variation in rainfall at five year intervals. This was indicated by the CV which was found to be 24% as shown in the table below.

Table 5-3: **Descriptive statistics of rainfall at five year intervals**

No. observations	Min	Max	Range	Mean	Std.dev.	s.s	CV
5	373	637	264	464	110	48785	24%

The calculated F value of 1.26 was less than the critical F of 2.62 value meaning that there were significant differences in rainfall received among the five year intervals (**see table 5.4**)

Table 5-4: **ANOVA table for rainfall at five year intervals**

Source of variation	s.s	d.f	ms	F.calculated	P-value	F.critical
Between groups	193631	5	38726	1.26	0.31	2.62
Within groups	736557	24	30690			
Total	930188	29				

Above results of long term rainfall trends indicated a generally very high temporal variation both over the entire 30 year period and at five year intervals respectively for the area. The annual (seasonal) variation ranged from a low of approximately 0.3 of the long term average to a high of approximately double the average. This means that a high rainfall year can have approximately seven times rainfall higher than a dry year. The year 1977 shows that the area exhibited an annual rainfall way above the normal for the area probably due to the presence of cyclone Emilie which passed through Bulawayo in January of that year. Other cyclone months and years include Jan, 1976; January, 1986; February, 1997; February, 2000 and February, 2003. These years received rainfall of 79mm, 176mm, 63mm, 153mm and 204mm during the specified months. Cyclones can cause above normal rainfall or a drought depending on their nature. An example of a drought causing cyclone is the elnino (year) which hit most parts of Southern Africa. Consecutive low rainfall years are observed in 1983 -1986, 1987- 1989 and 1992-1994. Annual rainfall oscillated between a high and a low value every 2-3 years. The high temporal variability and lack of a clearly defined rainfall cycle illustrate the unpredictability of the rainfall.

5.1.1 Analysis of planting dates and dry spells for long-term rainfall data

Planting dates varied between the months of October, November and December respectively during the entire 30 year period and the specific earliest planting dates as described by the AREX criterion were as indicated in table 5.5 below. The frequency and duration of dryspells before and after planting are also indicated in the same table. The cropping season was described as being good, fair or bad based on the frequency of dryspells and number of drydays after planting. These two factors are very important because they give an indication of the duration of dryspells and specific number of drydays. Generally a maize plant requires a minimum of 90 days as growing period. Currently there certain maize varieties which have been bred and improved so much that they can have a minimum of less than 90 days as growing period; but for the purpose of this research 90 days will be considered as the minimum requirement. It was therefore, used as the basis for defining an acceptable number of drydays in a growing season which were then used to characterise a season as being good or bad in as far as growing of maize was concerned. The following bands were used:
Good: Less than 45 drydays
Fair: 45 – 60 drydays
Bad: Greater than 60 drydays.

The periods from 1965 – 1969, 1970-1974, 1975 – 1979, 1980 -1984 and 1990 – 1994 had one good year each with the exception of the period 1985 – 1989 which had no record of a good season at all. However, the 1970s in addition to having two good years also had four fair seasons unlike the eighties which had only one good season and no fair season at all. From this it can be seen that the 1970s were better than the 1980s. Bad seasons occur characteristically in runs of 2-5 seasons rather than singly. This results in severe food shortages.

Table 5-5: Analysis of planting dates and dryspells of long term cropping season

Year	No. of dryspells	No. of drydays	Planting date	drydays after planting	dryspells after planting	Description of cropping season
1965	4	102	21/11	69	3	Bad
1966	6	111	13/11	74	4	Bad
1967	4	89	2/11	64	3	Bad
1968	5	121	18/11	80	4	Bad
1969	3	36	8/10	36	3	Good
1970	4	157	18/11	126	3	Bad
1971	4	99	11/11	89	3	Bad
1972	3	114	17/12	44	3	Good
1973	7	129	10/11	95	6	Bad
1974	5	89	15/11	52	4	Fair
1975	4	107	3/12	45	3	Good
1976	4	60	12/10	60	4	Fair
1977	6	110	1/12	60	4	Fair
1978	4	103	8/11	70	3	Bad
1979	5	83	4/11	58	3	Fair
1980	6	105	28/11	70	5	Bad
1981	5	77	30/10	46	1	Good
1982	4	148	19/10	123	1	Bad
1983	5	102	21/10	94	3	Bad
1984	6	125	6/11	96	5	Bad
1985	4	128	20/12	64	2	Bad
1986	5	122	4/11	105	4	Bad
1987	4	138	1/12	86	2	Bad
1988	6	128	24/10	100	4	Bad
1989	7	101	29/10	79	5	Bad
1990	3	89	9/12	23	2	Good
1991	5	121	26/11	68	3	Bad
1992	5	139	9/11	107	4	Bad
1993	5	131	30/11	79	3	Bad
1994	5	119	6/11	95	3	Bad

5.2 Results of short term rainfall comparison

These were centered on rainfall data for Zhulube meso-catchment for 2006/07 cropping season. It also included a comparison between 2006/07 and 2005/06 cropping seasons.

5.2.1 Homogeneity of Zhulube rainfall data

The double mass curves for the 18 rainfall stations revealed that the stations had generally consistent variation of the rainfall data over time except for one (Mguni) whose data proved to be heterogeneous (**see figure 5.11**) and was thus not used in the final analysis. The heterogeneity at Mguni station could have resulted from a change in observer, raingauge type or a disturbance in the position of the raingauge or taking of wrong readings by the observer.

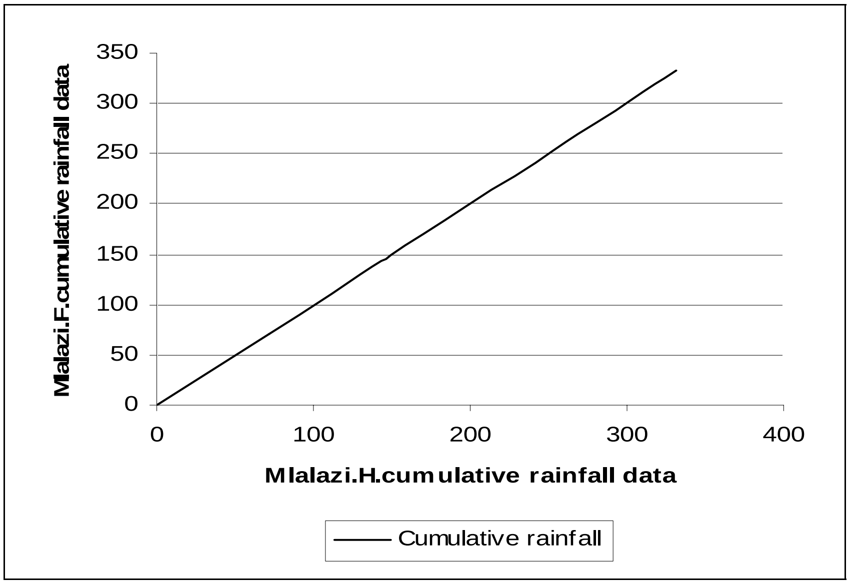

Figure 5-3: Double mass analysis curve for Mlalazi. H/Mlalazi.F

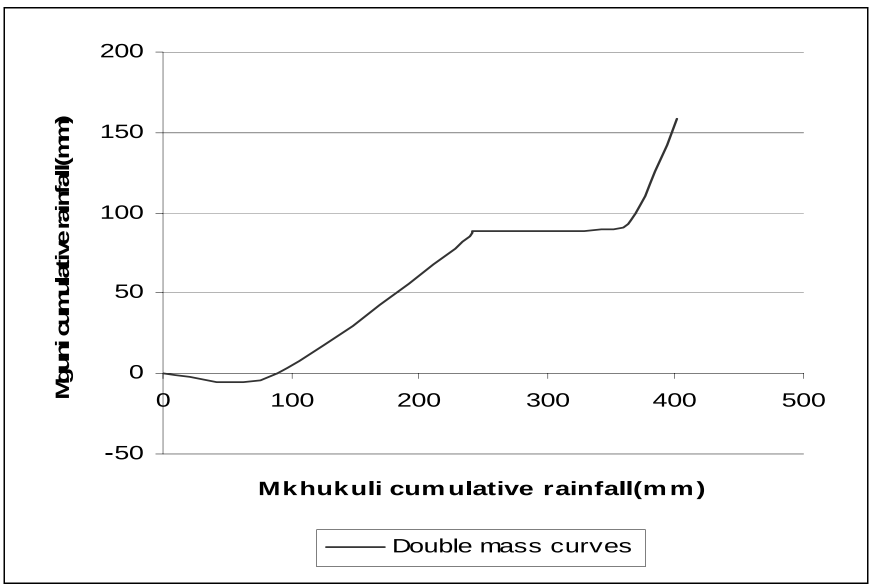

Figure 5-4: Double mass analysis curve for Mkhukuli/Mguni

5.2.2 Spatial analysis in Zhulube

Rainfall totals were plotted against specific locations to show the spatial variability during the 2006/07 cropping season.

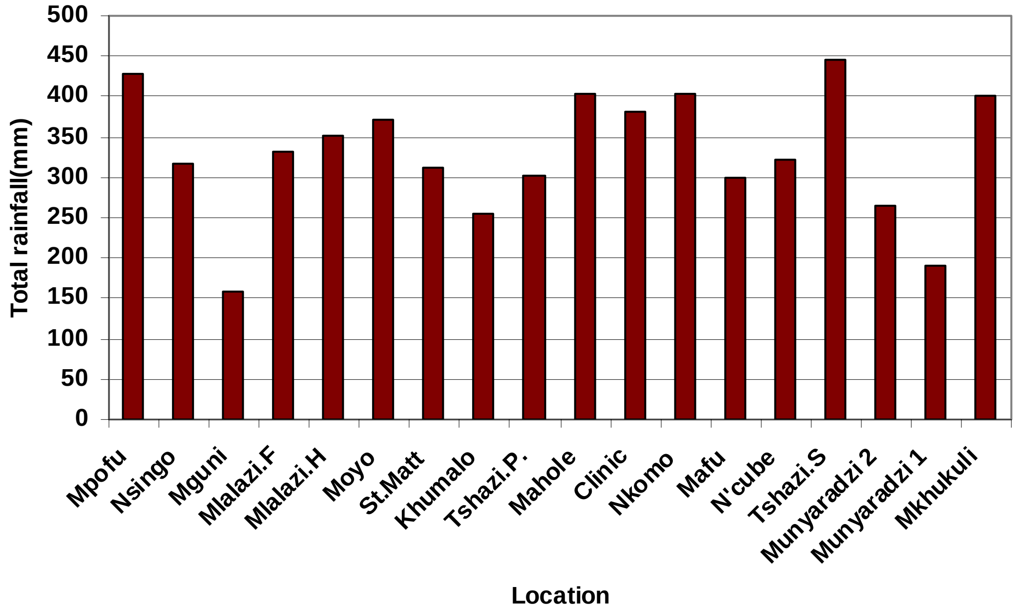

Figure 5-5: Spatial distribution of rainfall in the 2006/07 cropping season (Zhulube)

Spatial rainfall variability in terms of total rainfall on location during the cropping season existed in the catchment and its extent was depicted in the CV which was greater than 20% (**see table 5.6**). The spatial variation ranged from a low of 0.4 of the long term annual average to a high of approximately equal to the long term average. This means that a relatively high rainfall area can have approximately two times rainfall higher than a relatively dry area. The variation in rainfall was mainly due to location of areas in terms of direction of prevailing wind and topography. Areas located in the wind ward direction tended to experience relatively higher rainfall than those on the leeward side. Also an area bound by mountains may experience more rain since as the air attempts to pass through them, it is forced to rise upward as its path gradually narrows down forcing it to release warm air resulting in a rainfall event. The area therefore oscillates from semi-arid to arid conditions.

The farmers are, however, unable to take advantage of the wetter areas owing to their unpredictability in terms of temporal variation. Resource-poor farmers have no choice but to invest in low input production systems to minimize their losses in bad years. Hence low and erratic rainfall is one of the main factors influencing the type and amount of farmers' investments in these semi-arid conditions.

Table 5-6: Descriptive statistics of Total rainfall at location

No. of observations	Min	Max	Range	Mean	Std.dev.	Median	Std.e.m	CV%
18	158	445	287.	325	76	325	19	23

Results of the t-test for level of significance were as indicated in table 5.7 below in which p=8.78E-13(< 0.01), two tailed at 95% confidence level meaning that the means of rainfall at the locations of interest were highly significantly different from each other. All the locations received rainfall that was below the long term average of 533mm (**see figure 5.6**).

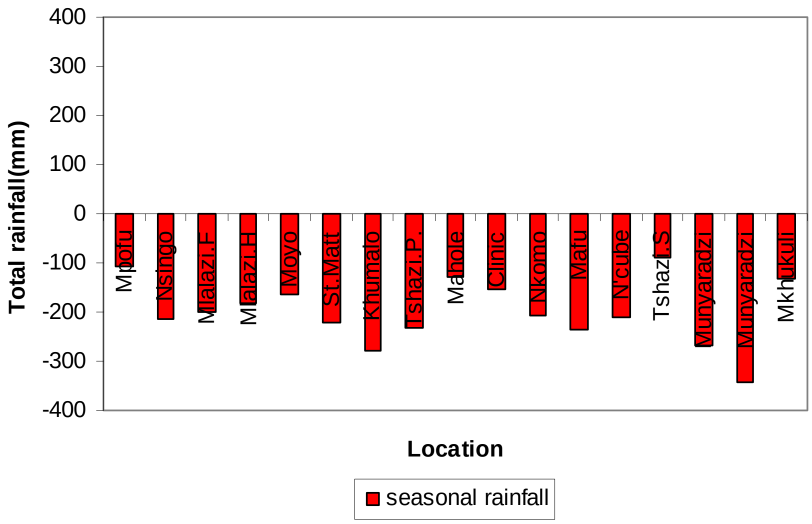

Figure 5-6: Seasonal fluctuations of rainfall indicating the variation of rainfall from the long term annual mean
(X-axis = 0 =long term annual mean = 533mm)

Table 5-7: **T-test paired two sample means for location and rainfall**

	Variable 1	Variable 2
Mean	335.2	9
Variance	4316	25.5
Observations	17	17
d. f	16	
t. stat	20.1	
P(T < =1) one- tail	4.39E-13	
t critical one- tail	1.75	
P(T < =1) two- tail	8.78E-13	
T (critical two- tail	2.12	

5.2.3 Temporal variability in Zhulube

The graph below indicates temporal rainfall variability within the study area during the 2006/2007 cropping season. This was indicated by the CV which was greater than 20%. However, this variability was found to be insignificant. Highest rainfall was received in the month of December while the lowest was in October (**figure 5.7**)

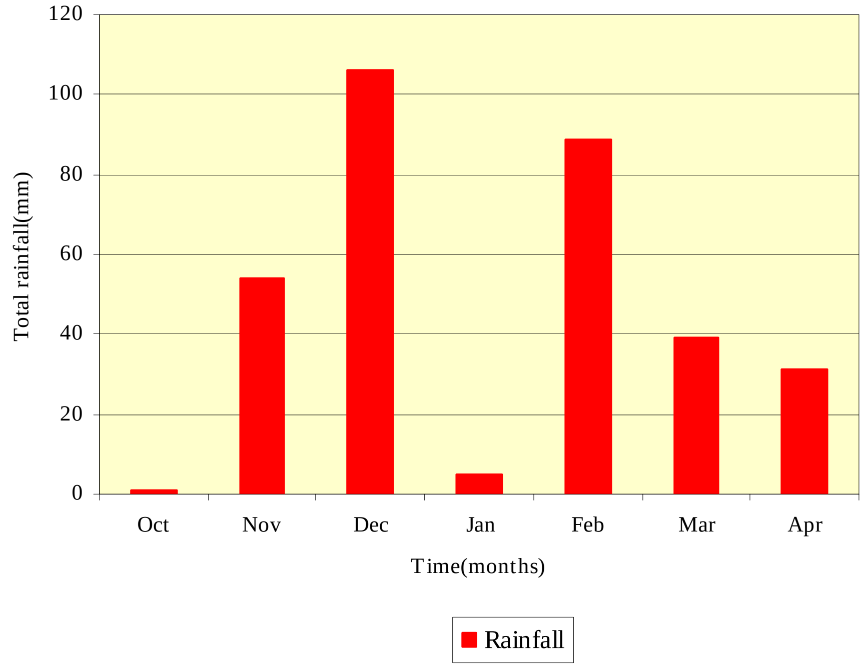

Figure 5-7: Temporal distribution of rainfall in the 2006/07 cropping season in (Zhulube)

The variability depicted above however, proved not to be significant statistically since the p=0.03 (> 0.01), two tailed at 95% confidence level meaning that the means of rainfall for the different months were not different from each other and the observed differences were due to chance alone.

Table 5-8: **T-test paired two sample means for (month) and rainfall**

	Variable 1	**Variable 2**
Mean	4	46.43
Variance	4.67	1581.95
Observations	7	7
d. f	6	
t. stat	-2.83	
P(T < =1) one- tail	0.015	
t critical one- tail	1.94	
P(T < =1) two- tail	0.03	
T (critical two- tail	2.45	

Monthly totals of rainfall were plotted against cropping season to show the intra - seasonal (temporal) variation and the results were as indicated in the graph below.

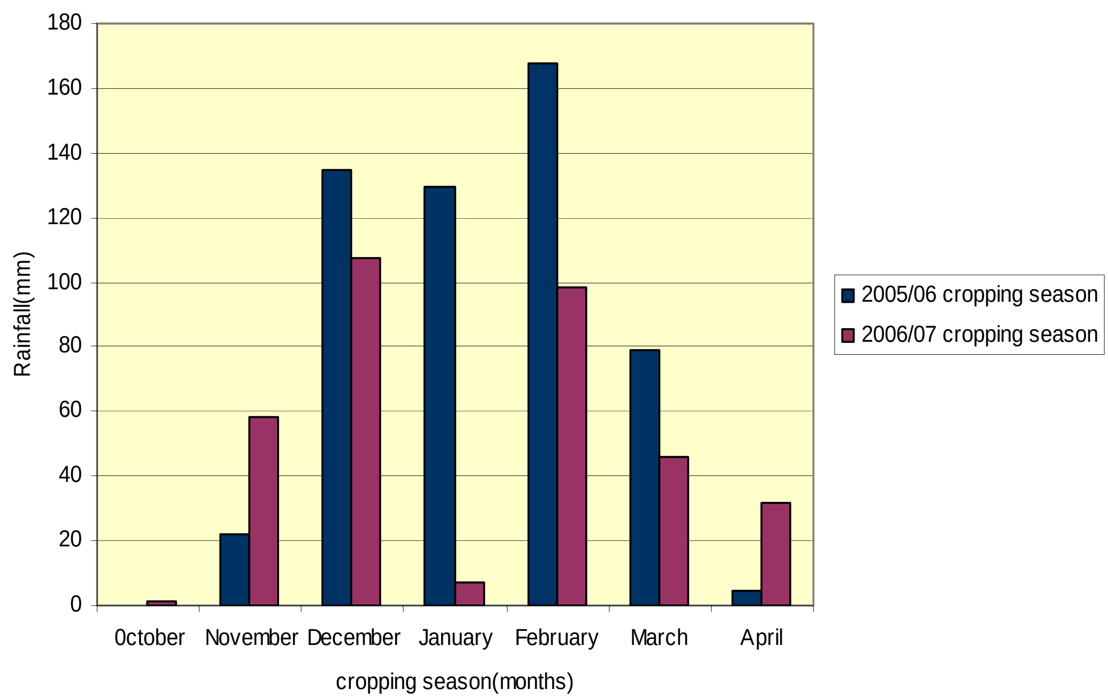

Figure 5-8: Temporal distribution of rainfall in Zhulube

Descriptive statistics for inter-seasonal rainfall variation were performed for the 2005/06 and 2006/07 cropping seasons and the results showed a high variation of rainfall between the two seasons (**see table 5.9**). The resulting CV of 40% showed that inter-seasonal rainfall variation was high but insignificant at p=0.17(> 0.01), two tailed at 95% confidence level meaning that the means of rainfall for the two seasons were not statistically different from each other.

Table 5-9: Descriptive statistics of the 2005/06 and 2006/07 cropping seasons.

No. of observations	Min	Max	Range	Mean	Std.dev.	CV%
12	304	538	233	421	165	40

Table 5-10: **T-test paired means for season and rainfall**

	Variable 1	Variable 2
Mean	1.5	421.10
Variance	0.5	27216.78
Observations	2	2
d. f	1	
t. stat	-3.58	
P(T < =1) one- tail	0.09	
t critical one- tail	6.31	
P(T < =1) two- tail	0.17	
T (critical two- tail	12.71	

5.2.4 Analysis of planting dates and dryspells in Zhulube

The earliest planting dates basically varied between the third week of November and the first week of January within Zhulube meso-catchment. The approximate earliest planting dates for Mlalazi, Moyo, Clinic, Nkomo, Ncube and Khumalo were as indicated in the table below. During the study planting took place on 31st December, 2006. This was rather late for Mlalazi, Moyo, Clinic and Ncube. The late planting could have contributed to the poor yield that was obtained in these areas. Planting at Nkomo and Khumalo was, however, within the calculated range for earliest planting dates. These dates (estimated planting dates) were followed by dryspells in excess of 25 days resulting in poor establishment of crop and consequently in yields below the normal for the area.

Generally all sites were characterized by dryspells in all months and at all stages of plant growth. The duration of the majority of these dryspells was above 20 days which is unacceptable for most food crops. It is such things that make farmers in this area not take farming seriously and not bother to invest in it. They would rather engage themselves in informal businesses or gold panning activities for income generation. The criteria used to describe the cropping season is similar to the one used in the long term rainfall data above. The results indicated in the table below are typical for the area as indicated by the results of the long-term rainfall data.

Table 5-11 : Analysis of dryspells and planting dates.

Location	**No. of dryspells**	**No. of drydays**	**Planting date**	**drydays after planting**	**dryspells after planting**	**Description of cropping season**
Mlalazi	4	122	20/11	87	3	bad
Moyo	4	122	25/11	85	3	bad
Clinic	4	123	24/11	87	3	bad
Nkomo	4	136	4/1	60	2	Fair
Ncube	4	111	25/11	64	2	bad
Khumalo	5	151	3/1	71	3	bad

Generally, the frequency of dryspells ranged between 4 and 5. But for the purpose of this study dryspells that occurred after planting and lasting two weeks or more were considered because these are the ones that had a profound impact on biological yield and consequently the economical yield. In view of this the following results were established: Mlalazi, Moyo, Clinic and Khumalo had 3 dryspells whereas Nkomo and Ncube had 2 dryspells each. Nkomo recorded the least number of drydays after planting. This partly explains why Nkomo also recorded the highest amount of biomass for the area. The frequency and duration of dryspells had a profound effect on crop yield. The crop was exposed to conditions of water stress at flowering at all sites. This negatively affected the plant and consequently the yield.

5.3 Results of maize performance

5.3.1 Effect of rainfall on biomass

Biomass (dry weight) produced per location ranged between 0.16 kg/m^2 to 0.75kg/m^2 (**see table 5.12**). The highest amount of biomass produced was recorded at Nkomo's field where as the least was recorded at the Khumalos. The clinic site and Moyo both had a biomass of 0.75kg/m^2 and yet the former had relatively higher rainfall; this was due to the differences in soil type. The soil at Moyo had a relatively higher water holding capacity which compensated for the lower rainfall that it received at time of sampling in relation to the clinic site. Another interesting result involved Mlalazi and Khumalo where the two had biomass amount which was almost similar at 0.48kg/m2 and 0.47kg/m2 respectively. This was inspite of Mlalazi having a relatively higher amount of rainfall. This also was as a result of differences in soil type and characteristics which related to pH, water holding capacities, organic matter and silt contents(**see appendix E**) Maize requires fertile, deep and well-drained soils. Although, it can be grown on any type of soil, ranging from deep heavy clays to light-sandy ones, it is best adapted to well drained sandy loam to silty loam soils. It is, however, necessary that the pH of the soil does not deviate from the range of 7.5 to 8.5. Laboratory tests revealed that all plots had soils with pH below the stated range (**see appendix E**). This negatively affected availability of nutrients to the plant resulting in an overall low yield for the area during the 2006/2007 growing season. This coupled with the fact that all soils are light –sandy soils(**see appendix E)** which greatly facilitate drainage, but have a relatively poor water-holding capacity and the high frequency of prolonged dryspells made it impossible for the study to obtain any data on economic yield and consequently the harvest index could not be calculated.

Table 5-12: Table of biomass produced.

First Sampling			
Location	**Soil type**	**Biomass(kg/m^2)**	**Rainfall(mm)**
Zhulube clinic	Sand	0.75	323.59
Nkomo	Sand	1.24	368
Moyo	Loamy sand	0.75	274.54
Ncube	Sandy loam	0.63	265.50
Khumalo	Sandy loam	0.47	181.94
Mlalazi	Loamy sand	0.48	252.54
Second Sampling			
Clinic	Sand	0.37	381.09
Nkomo	Sand	0.43	404
Moyo	Loamy sand	0.16	370.35
Mlalazi	Loamy sand	0.20	332.04
Ncube	Sandy loam	Livestock damage	323
Khumalo	Sandy loam	Livestock damage	255.4

The graphical representation of the relationship between rainfall and biomass was done based on the available data sets. In addition to this, the effect of rainfall on biomass was determined firstly across all the available soil types (**figure 5.9**) and secondly on sites with similar soil type so as to rule out the effect of soil interaction (**figures 5.10-5.12).** The comparison of yield among the six fields was based on the first sampling alone because in the second sampling, two of the fields were damaged by livestock resulting in an incomplete data set.

Within the life cycle of an organ, a plant or crop, the total crop growth duration can be divided in to three sub-phases; an early accelerating phase; a linear phase; and a saturation phase for ripening (Goudriaan and van Laar, 1994). Therefore, the growth pattern typically follows a sigmoid curve, and the growth rate a bell shaped curve. However, the bell shaped curve could not be depicted in this case due to the fact that the plants which were being looked at in this case were at the same stage of growth. In addition to this, there was lack of frequent sampling per plot due to logistical problems. Frequent sampling per plot could have captured plant growth at different stages and would have thus made it possible to show the typical bell shaped curve. What can be seen, however is the maize plant at the same stage of growth responding differently depending on amount of rainfall received and soil type(**see figure 5 .9**). It is also quite clear from the graphs (**Figures 5.9-5.12**) that there is a direct relationship between biomass and rainfall.

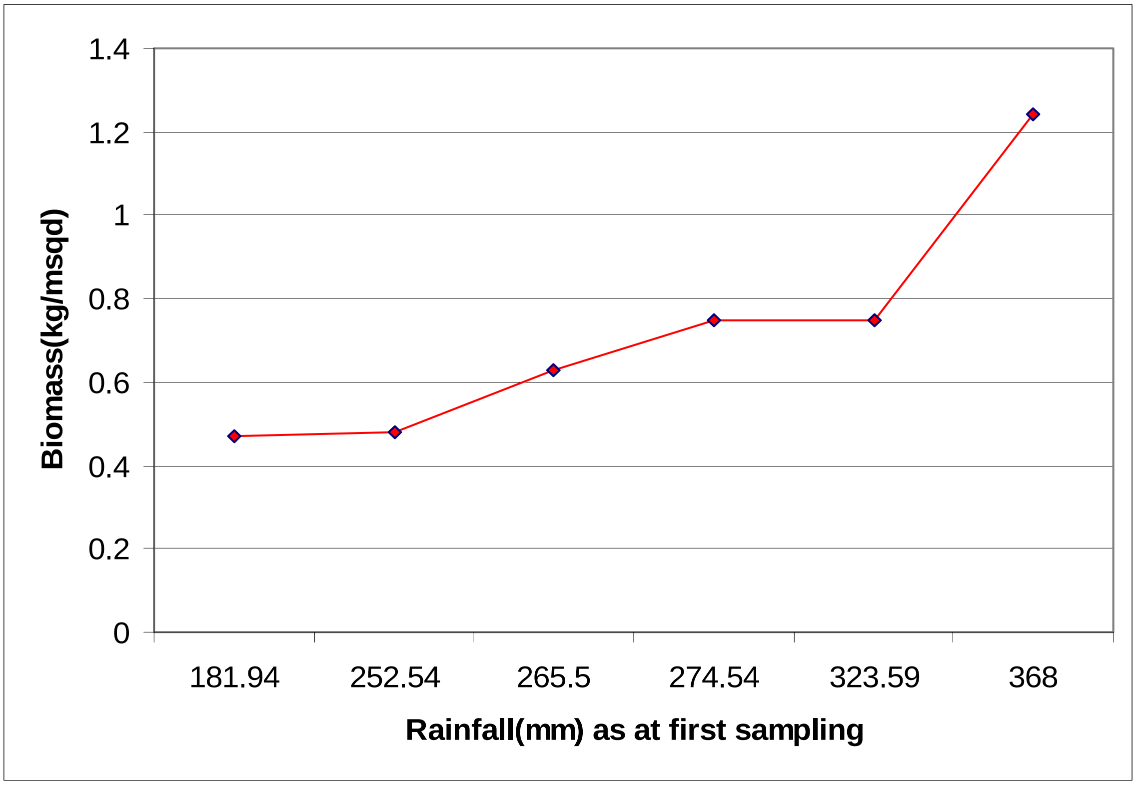

Figure 5-9: Graph of biomass against rainfall across all soil types

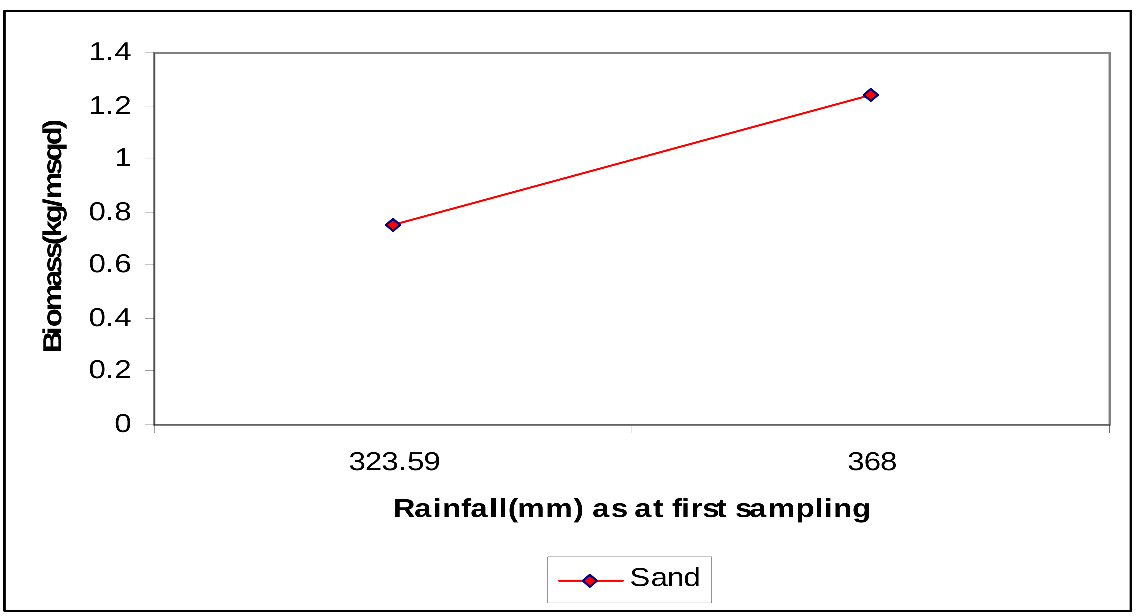

Figure 5-10: Graph of biomass against rainfall

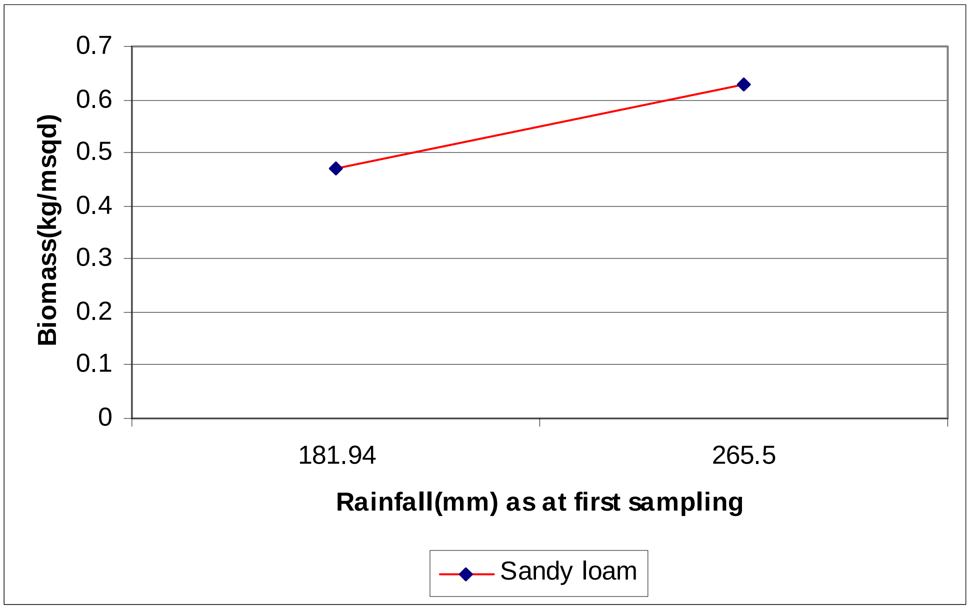

Figure 5-11: Graph of biomass against rainfall

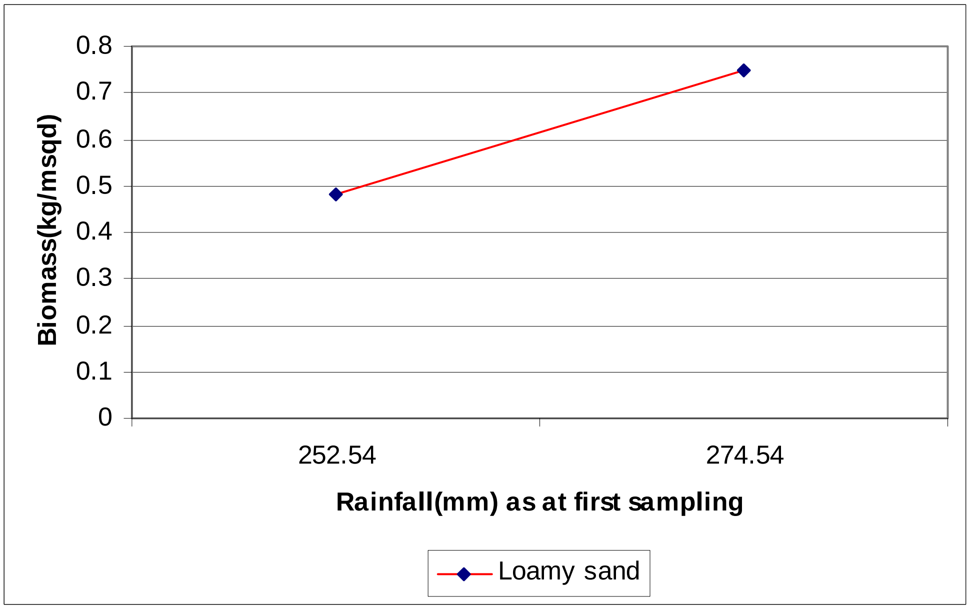

Figure 5-12: Graph of rainfall against biomass

The table below (**Table 5.13**) shows that p=0.02 (> 0.01), two tailed meaning that there were no significant differences in yield. Earlier results have indicated that there is the presence of significant spatial variability in the catchment. This spatial variability was, however, not significant enough to cause significant differences in yield.

Table 5-13: **t-test for biomass**

Variable	biomass
Mean	0.72
Variance	0.08
Observations	6
d.f	5
t. statistic	-3.27
P(T < =1) one- tail	0.01
t critical one- tail	2.02
P(T < =1) two- tail	0.02
T (critical two- tail	2

5.3.2 Effect of soil on biomass

The effect of soil on biomass was found to be relatively highly significant with an F-probability of less than 0.001.Therefore Fpr = <0.001(<0.05) meaning the amount of biomass is a function of soil type. The F-pr. for the covariate (rainfall) was 0.004 and since it was less than 0.05, it was concluded that the effect of rainfall was also significant in this case.

Table 5-14: **ANCOVA table for effect of soil on biomass**

Variate: Biomass
Covariate: Rainfall

Source of variation	d.f	(m.v) s.s.	v.r	Cov.ef	F pr.
Soil type	2	0.25011	0.125056	0.80	<.001
Covariate	1	0.094511	0.094511		0.004
Residual	6(2)	0.027039	0.004506	3.85	
Total	9(2)	0.256160			

Table 5-15: Effect of soil type and rainfall on biomass.

The chi pr = 0.001(<0.05) for both soil type and rainfall. This indicated a high significant influence of the interaction of the two variables on biomass.

Table 5-16: **REML variance components analysis**

Fixed term	Wald statistic	d.f.	Wald/d.f.	Chi pr.
Soil type	19.98	2	9.99	<0.001
Rainfall	41.76	1	41.76	<0.001

The frequency and duration of dryspells had a profound effect on crop yield. The 2006/07 cropping season was not a good season for cropping maize in Zhulube meso-catchment because all the areas experienced rainfall below the normal for the area. This situation was exacerbated by the long duration of dryspells. All areas experienced at least two long dryspells after planting which resulted in three quarters of the growing season having no rainfall events at all. Thus, the crop was negatively affected at all stages of growth. This was probably the reason for the crop not having any economic yield.

The observed differences in yield could have been as a result of differences in soil type, slopes of fields and rainfall intensity because they influence the infiltration of water in to the soil. In addition to this, yield is also affected by farming practices employed by the farmer and timeliness of these practices. Also, high rainfall may not necessarily be synonymous with high yield because of the above mentioned factors.

5.4 Results of household survey

Of the people interviewed 33.3% were female while 66.7% were male. Assuming that the numbers of people who can provide labour were in the age groups of 7 – 17 and 18-40 respectively, the total number of people who were able to work in the fields were 40, 45, 52, 62, 63 and 65 for Masiyepambili, Siyapambili, Asibambanani, Mpumelelo, Thandanani and Thuthuka respectively. The percentages of female headed households per village were 10,20,40,50 and 60% respectively for Masiyepambili, Thuthuka and Mpumelelo, Siyapambili and Asibambanani respectively. Eighty percent of the people in Insiza district ward one regard number of livestock owned as a major indicator of wealth followed by farm equipment at. The frequencies of people owning livestock and other physical assets per village were as indicated in the table below:

Table 5-17: Ownership of physical assets per village

Village	Masiyepambili	Siyapambili	Asibambanani	Mpumelelo	Thandanani	Thuthuka
%age	10	20	50	50	50	60

There were significant differences in terms of formal training whereas with respect to informal training the villages were at the same level as indicated by the values of the Pearson chi-square probability. It was discovered there had been targeted efforts to provide formal training to the community.

There were no significant differences in terms of formal training whereas with respect to informal, there were significant differences as indicated by the values of the Pearson chi-square probability. This means that there had been targeted efforts to provide formal training to the community.

A wide variety of crops were grown during the 2005/06 cropping season. These included maize, sorghum, cowpea, pumpkins, groundnuts, round nuts, beans, and millet and water melons. (**Appendix F**) There were no significant differences in terms of types of crops among the six villages .In addition to this, there were no overall significant differences in yield although the observed differences were not crop specific because of lack of information regarding the specific areas associated with the crops (**see appendix F**)

Methods of land preparation included the use of animal plough, conservation and conventional basins using hand hoes and tractor whereas the time of preparation ranged between September and December. Differences in time and method of land preparation was significant across villages probably due to differences and /or lack of farm equipment and machinery and also due to differences in dates of onset of rains .Method and time of planting was significant across villages since the Pearson Chi-square probability=0.014(=0.01).This could have been due to options that people have in terms of farming equipment coupled with the perceptions that people have about the onset of rains and planting time.

Table 5-18: **Chi square tests for method and time of planting**

	Value	**d.f**	**Asymp.Sig(2-sided)**
Pearson Chi-square	98.476	70	0.014
Likelihood Ratio	101.317	70	0.009
Linear by linear association	1.486	1	0.223
No. of valid cases	60		

There were significant differences in spacing across villages. The community needs to be taught the correct spacing for specific crops despite earlier claims that it knows.

Table 5-19: **Chi-Square tests for spacing**

	Value	**d.f**	**Asymp.Sig(2-sided)**
Pearson Chi-square	53.133	20	0.000
Likelihood Ratio	58.056	20	0.000
Linear by linear association	2.336	1	0.126
No. of valid cases	60		

Farmers exhibited significant differences in weeding times mainly due to the spatial differences in rainfall. Those areas whose weeding time coincided with a rain event weeded on time, but those farmers whose weeding time did not coincide with a rainfall event were hesitant to weed for fear of exposing the roots of the plants to dryness. Farmers need to be made aware of the fact that weeding regardless of the crop’s moisture condition is better than not weeding at all.

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Table 5-20: **Chi-Square tests for weeding**

	Value	**d.f**	**Asympt.Sig.**
Pearson Chi-square	48.388	25	0.003
Likelihood Ratio	52.101	25	0.001
Linear by linear association	2.861	1	0.091
No. of valid cases	60		

The perceptions that people have regarding amount of rainfall received were the same across the villages. They classified rainfall as being medium or low. The whole community thought that rainfall varied in the area. This was indicated by the within village response which was an overwhelming 100%.

Of the total number of villages interviewed, 96.7% thought that maize was the commonest crop grown in the catchment while 16.7%, 5%, 3.3% and 1.8% regarded sorghum, beans, cowpea and groundnuts respectively as being their choice of common crop.

There were variations in responses to the question regarding the basis of intercropping within the villages. These responses were however not significant across villages. The responses in descending order were 60%, 11.7%, 5%, 1.7%, 1.7%, 1.7% and 1.7% for land shortages, shortage of rainfall, land shortage and rainfall, shortage of farm equipment, flooding, security reasons and to safeguard against entire loss of field in times of severe heat stress respectively. A proportion of 16.7% did not seem to know the reasons behind intercropping. All the villages need to be taught major reasons for intercropping. Intercropped plants ripen at different times and therefore allow for staggered harvesting through out the year. The main crop is usually a food crop and is intercropped with a lot of secondary crops, vegetables and fruits (sweet potato, beans, watermelons, pumpkins, etc).Intercropping also increases water use efficiency. This is made possible by intercropping crops with different root systems (that is, shallow versus deep root systems) such that they are able to tap water at different depths of the soil profile thereby maximizing on available water use and consequently land productivity.

Seventy percent of the villages interviewed were familiar with water management techniques and 90% thought there was a positive change in crop growth after employing these techniques. Amount of rainfall and its variability and was regarded as the most limiting factor to crop production followed by soil fertility and unavailability or lack of recommended varieties for the area.

The main survival strategies were agricultural based which included selling of vegetables. Other survival strategies included gold panning, cross border trading and brick moulding.

Ninety eight percent of the villages said that they had experienced three food shortages in the past five years and 100% received help in form of food aid from non-governmental organizations.

Generally, the above results indicate that people need to be educated on the importance of farming practices in relation to correctness and timeliness of application because lack of this may result in reduced crop yield even if other factors are met. Most people lack the proper knowledge on important agronomic practices and they don't seem to understand why they are there or why they practice them. A case in point is the fact that the community of Zhulube considers maize as the most important and common crop and yet rainfall received during this season was way below the long term annual average to support maize production. Notwithstanding the rigid nature of rural communities, there is need for deliberate efforts to try and change the perceptions that people have regarding the cultivation of smaller grains and other drought resistant crops like cassava which when mixed with millet can act as a substitute for maize meal and help improve the nutritional status of people and general well-being.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

From the findings there was evidence of temporal rainfall variation in the study area. This temporal variation was significant in the long-term, but insignificant in the short-term.

Spatial variability of rainfall existed in Zhulube meso catchment and it proved to be significant in the short-term. It was however not significant enough to cause significant differences in yield. Also spatial variability gave rise to differences in some farming practices.

In view of the above, Zhulube meso-catchment can be classified as a heterogeneous unit based on the existence of spatial variability.

6.2 Recommendations

- Investment in real-time climate data.
- Investment in small scale irrigation schemes and water management techniques as way of bridging dry spells.
- Farmers need to be educated on the importance of employing necessary farming practices correctly and timely
- The data set for biomass could be improved by increasing the frequency of sampling i.e., more sampling times (e.g. fortnightly after planting) so as to obtain a more representative relationship between rainfall and biomass. Secondly, measuring of soil moisture at planting and probably fortnightly or monthly thereafter as a way of monitoring soil moisture trends at the different locations would have added more value to this research. Also future research in this area of study should include on site measurement of slope as this would give an indication of infiltration capacity of site (the steeper the slope, the higher the proportion of rain that ends up as runoff and consequently the infiltration is reduced (the opposite is also true). These could not be done in totality during this study due to logistical problems.
- Farmers should opt for drought resistance crops like cassava which in addition to being drought resistance can also perform relatively well on marginal soils like the ones found in Zhulube. Also maybe farmers in this area should try to concentrate on smaller grains like millet and sorghum as opposed to maize.
- Encourage planting of Jatropha trees as a hedge around fields to safeguard against livestock damage instead of the thorny shrubs that are currently used. Soil is exposed to wind and water erosion as people clear land leaving it bare as they cut these thorny shrubs. Jatropha plant is not edible to livestock. This would act as a form of wind break for the field and can also be used as a land reclamation measure. Jatropha can do well on degraded lands. It has a long lifespan after

establishment. Other beneficial effects of jatropha are as follows: Oil from jatropha seed can be used as a lubricant for farm machinery and implements; the resulting cake after extraction of the oil has an NPK value that is equivalent to chicken manure and can therefore be used as organic fertilizer when growing vegetables for example. Oil from jatropha seed can also be used for lighting. It's smoke free and is odorless. Jatropha oil has a high saponification value which can be taken advantage of by small scale farmers; they can easily make soap for personal use and also for sale to earn an income.

- Lastly, but not the least, political will is needed so that amount of investment in agriculture is increased in the face of climate change and consequently precipitation patterns.

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8.0 APPENDICES

APPENDIX A. Tables of results of correlation analyses

Table of correlation between Munyaradzi 2 and Mkhukuli

	Column 1	Column 2
Column 1	1	
Column 2	0.835052	1

Table of correlation analysis between Munyaradzi 1 and Mkhukuli

	Column 1	Column 2
Column 1	1	
Column 2	0.820084	1

Table of correlation analysis between Mahole and Tshazi secondary school

	Column 1	Column 2
Column 1	1	
Column 2	0.912280	1

Table of correlation analysis between Mahole and Zhulube clinic

	Column 1	Column 2
Column 1	1	
Column 2	0.971286	1

Table of correlation analysis between Mkhukuli and Nkomo

	Column 1	Column 2
Column 1	1	
Column 2	0.802735	1

Table of correlation analysis between Mlalazi field and Mlalazi homestead

	Column 1	Column 2
Column 1	1	
Column 2	0.975223	1

Table of correlation analysis between Moyo homestead and Mlalazi homestead

	Column 1	Column 2
Column 1	1	
Column 2	0.95082	1

Table of correlation analysis between Mlalazi between homestead and St. Matthews

	Column 1	**Column 2**
Column 1	1	
Column 2	0.870878	1

Table of correlation analysis between Mafu and Khumalo

	Column 1	**Column 2**
Column 1	1	
Column 2	0.796618	1

APPENDIX B .Tables of regression analyses

Table of regression analysis between Munyaradzi 2and Mkhukuli

	Coefficients	Standard Error	T Stat	P-value	Lower 95%	Upper 95%
Intercept	0.352068	0.470014	0.749059	0.455712	-0.58129	1.285422
X Variable 1	0.577437	0.03945	14.63718	7.23E-26	0.499097	0.655776

Table of regression analysis between Munyaradzi 1 and Mkhukuli

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.236451598	0.516242835	0.458023981	0.64851115	-0.79518	1.268081
X Variable 1	0.43581181	0.038313454	11.37490254	6.4727E-17	0.359248	0.512375

Table of regression analysis between Mahole business center and Tshazi secondary school

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-0.03595	0.365996755	-0.098236	0.9219022	-0.76031	0.688399
X Variable 1	1.051269	0.042214065	24.90329	2.708E-50	0.967722	1.134816

Table of regression analysis between Mahole business center and Zhulube clinic

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.03456	0.206389	0.167451	0.867328	-0.37454	0.443658
X Variable 1	0.946255	0.022303	42.42642	3.55E-69	0.902046	0.990465

Table of regression analysis between Mkhukuli and Nkomo

	Coefficients	Standard Error	T Stat	P-value	Lower 95%	Upper 95%
Intercept	0.36006	0.781598	0.460672	0.646646	-1.20233	1.922452
X Variable 1	0.718061	0.055404	14.86516	4.13E-22	0.712836	0.934337

Table of regression analysis between Mlalazi field and Mlalazi homestead (independent variable)

	Coefficients	Standard Error	T Stat	P-value	Lower 95%	Upper 95%
Intercept	0.048134	0.173749	0.277031	0.782421	-0.29727	0.393537
X Variable 1	0.941016	0.023502	40.88096	3.98E-58	0.914061	1.007502

Table of regression analysis between Moyo homestead and Mlalazi homestead (independent variable)

	Coefficients	Standard Error	T Stat	P-value	Lower 95%	Upper 95%
Intercept	0.113967	0.241288	0.472328	0.637673	-0.36446	0.592396
X Variable 1	1.023711	0.029518	34.66321	2.66E-59	0.964648	1.081704

Table of regression analysis between Mlalazi homestead and St. Matthews Primary school

	Coefficients	Standard Error	T Stat	P-value	Lower 95%	Upper 95%
Intercept	0.555699	0.359577	1.545424	0.125467	-0.15787	1.269268
X Variable 1	0.731548	0.041957	17.36036	1.17E-31	0.645125	0.81165

Table of regression analysis between Mafu homestead and Khumalo.

	Coefficients	Standard Error	T Stat	P-value	Lower 95%	Upper 95%
Intercept	0.4399836	0.44963303	0.978539341	0.3299745	-0.45117441	1.331142
X Variable 1	0.7102062	0.05161853	13.758746	1.411E-25	0.6079	0.812512

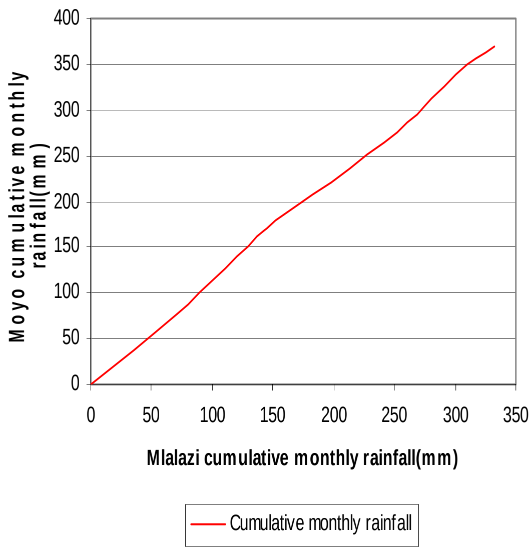
APPENDIX C. Tables indicating observed rainfall data
Table 4. 1: Tables of monthly rainfall readings at locations of interest.

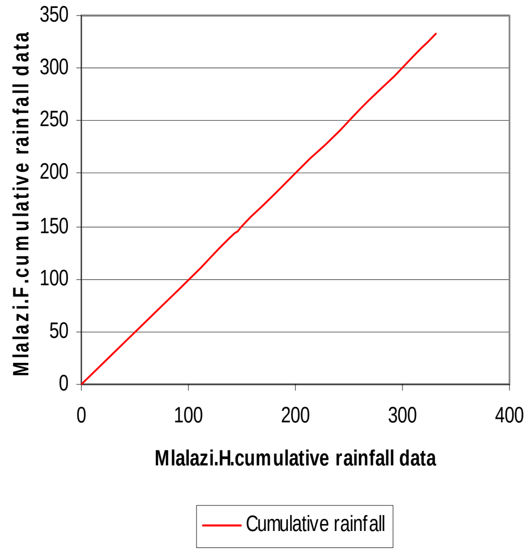
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
Mpofu	3	106	132	0	100	43	43	427
Nsingo	0	73	69	2	91	45	27	307
Mguni	0	0	85	4	1	10	58	158
Mlalazi field	0	71	72	6	104	49	31	333
Mlalazi .H.	0	76	80	6	101	56	34	353
Moyo	0	77	90	7	101	64	15	354
St.Matt.Pr.Sch	0	55	63	6	93	49	45	311
Khumalo	0	2	80	12	87	54	21	256
Tshazi.Pr.Sch	0	49	94	6	85	36	32	302
Mahole	0	65	151	6	83	69	28	404
Clinic	0	58	152	10	88	46	29	383
Nkomo Field	0	44	124	4	112	19	24	327
Mafu	0	10	102	5	100	52	31	300
Ncube	15	39	82	5	110	36	37	324
Tshazi.Sec.Sch	0	95	162	11	118	29	31	446
Munyaradzi 2	0	29	131	2	75	10	19	231
Munyaradzi 1	0	32	87	2	48	7	14	190
Mkhukuli	0	90	150	1	110	17	33	401

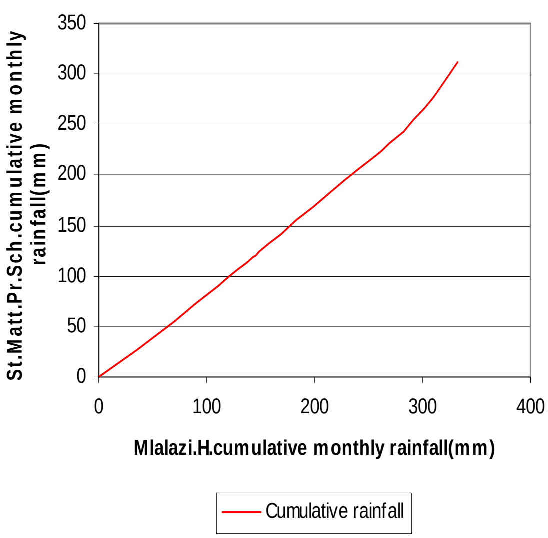
Table of monthly cumulative rainfall for Zhulube meso-catchment 2006/07 cropping season.

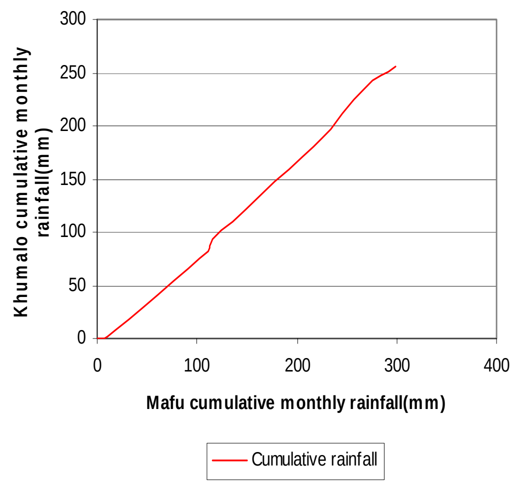
Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Average rainfall(mm)	1.56	58.17	107.65	6.90	98.27	45.65	31.66
Cumulative average(mm)		59.73	167.38	174.28	272.55	318.2	349.86

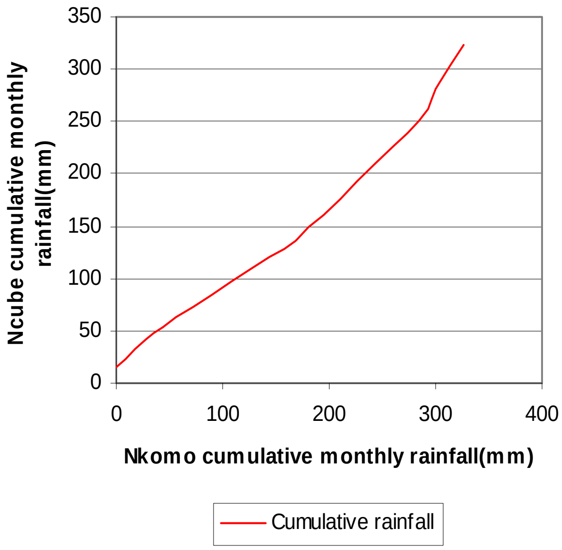
APPENDIX D: Double mass analysis curves

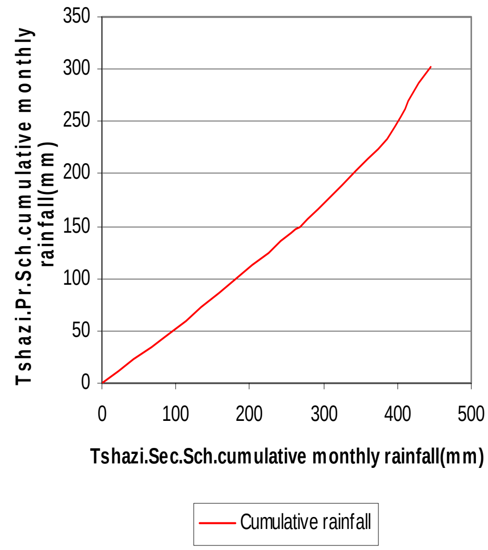


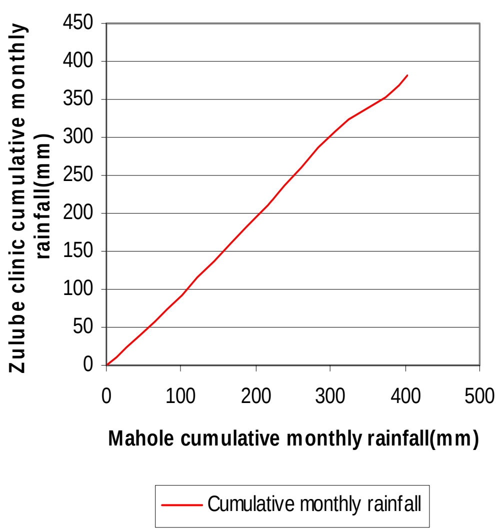


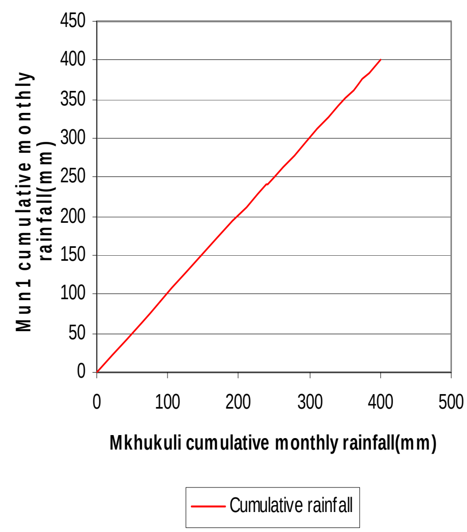


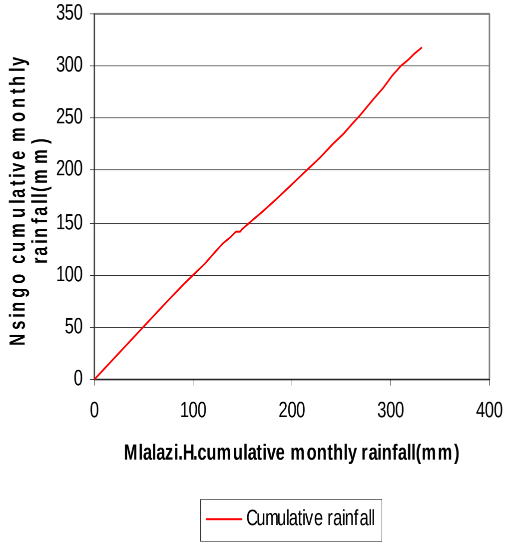


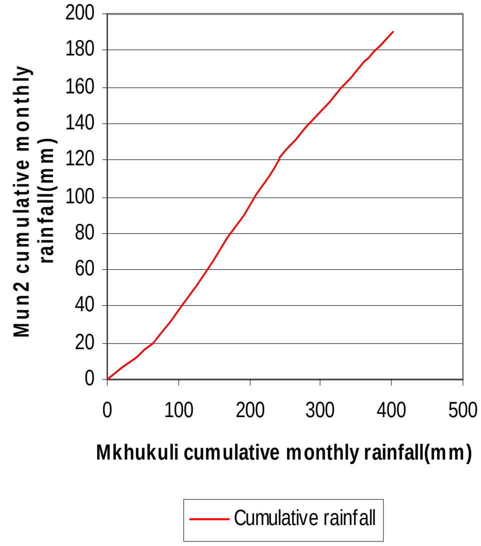

Ncube cumulative monthly rainfall(mm)
Nkomo cumulative monthly rainfall(mm)
Cumulative rainfall

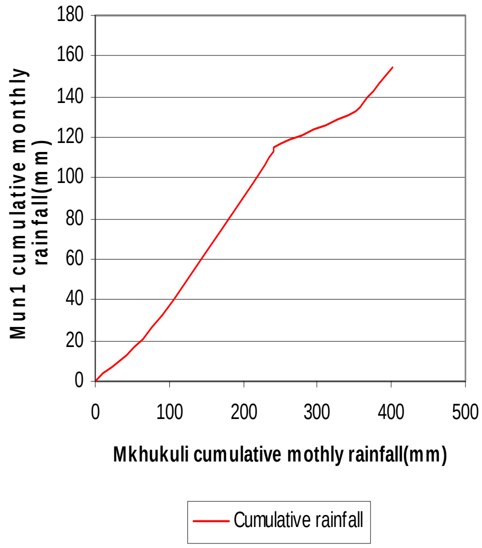

Tshazi.Pr.Sch.cumulative monthly rainfall(mm)
Tshazi.Sec.Sch.cumulative monthly rainfall(mm)
Cumulative rainfall

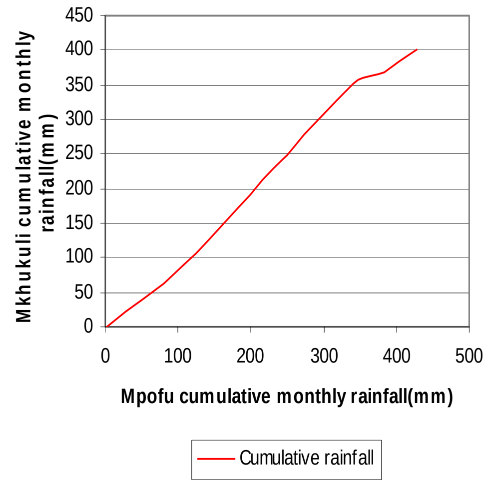

Zulube clinic cumulative monthly rainfall(mm)
Mahole cumulative monthly rainfall(mm)
Cumulative monthly rainfall


Mun1 cumulative monthly rainfall(mm)
Mkhukuli cumulative monthly rainfall(mm)
Cumulative rainfall


Nsingo cumulative monthly rainfall(mm)
Mlalazi.H.cumulative monthly rainfall(mm)
Cumulative rainfall


Mun2 cumulative monthly rainfall(mm)
Mkhukuli cumulative monthly rainfall(mm)
Cumulative rainfall


Mun1 cumulative monthly rainfall(mm)
Mkhukuli cumulative mothly rainfall(mm)
Cumulative rainfall


Mkhukuli cumulative monthly rainfall(mm)
Mpofu cumulative monthly rainfall(mm)
Cumulative rainfall

APPENDIX E: Results of physical and chemical parameters of soil

Variable	Clinic	Nkomo	Moyo	N'cube	Khumalo	Mlalazi	Mafu
Textural class	Sand	Sand	Loamy sand	Sandy loam	Sandy loam	Loamy sand	Sandy loam
pH ($CaCl_2$)	7.4	5.3	5.5	6.0	6.1	4.5	6.1
N (ppm)	11	12	9	6	10	15	23
P (ppm)	6	6	4	4	1	4	1
K (me %)	0.39	0.45	0.40	0.41	0.34	0.41	0.43
Na (me %)	0.18	0.16	0.20	0.23	0.27	0.15	0.27
Mg (me %)	0.65	0.71	0.69	4.53	5.16	0.7	4.7
Ca (me %)	3.73	1.26	2.25	5.62	5.48	0.69	5.83
Clay (me %)	4	4	8	10	8	8	12
Silt (%)	2	2	6	8	12	4	8
Sand (%)	94	94	86	82	80	88	80
WHC	6.89	4.85	8.94	12.59	14.66	7.58	11.38
O.C (%)	0.22	0.32	0.11	0.32	0.55	0.22	0.45

APPENDIX F: Tables of results of household survey

Table indicating proportions of the sexes

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	female	20	33.3	33.3	33.3
	male	40	66.7	66.7	100.0
	Total	60	100.0	100.0	

Cross tabulation village name* asset owned

	Total % owned within village	
Asset	0	1
Cattle	59.3	40.7
Donkeys	56.7	43.3
Goats	38.3	61.7
Sheep	85	15
Chickens	20	80
Plough	43.3	56.7
Hoes	6.7	93.3
Wheelbarrow	76.6	23.3
Harrow	90	10
Bicycle	73.3	26.7
Television	90	10
Radio	50	50
Sewing machine	93.3	6.7
Solar battery	73.3	26.7

Cross tabulation of village name * training in agriculture

	Total % within village name		
Training	0	Yes	No
Formal	3.3	33.3	63.3
Informal	21.7	58.3	20

Chi-Square Tests for formal training in agriculture

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	21.568	10	.017
Likelihood Ratio	19.336	10	.036
Linear-by-Linear Association	.898	1	.343
N of Valid Cases	60		

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Chi-Square Tests for informal training

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	28.448	10	.002
Likelihood Ratio	31.388	10	.001
Linear-by-Linear Association	.273	1	.601
N of Valid Cases	60		

Table of crops grown in Zhulube meso-catchment

	Total % within village name	
Crop grown	**0**	**1**
Maize	0	100
Sorghum	65	35
Cowpea	96.7	3.3
Pumpkin	83.3	16.7
Groundnuts	88.3	11.7
Roundnuts	90	10
Beans	70	30
Millet	91.7	8.3
Watermelon	91.7	8.3

Village name * number of livestock Cross tabulation

Village name		number of livestock NOT INDICATOR	INDICATOR	Total
Siyaphambili	Count	3	7	10
	% within village name	30.0%	70.0%	100.0%
	% within number of livestock	25.0%	14.6%	16.7%
	% of Total	5.0%	11.7%	16.7%
Asibambanani	Count	4	6	10
	% within village name	40.0%	60.0%	100.0%
	% within number of livestock	33.3%	12.5%	16.7%
	% of Total	6.7%	10.0%	16.7%
Mpumelelo	Count		10	10
	% within village name		100.0%	100.0%
	% within number of livestock		20.8%	16.7%
	% of Total		16.7%	16.7%
Thuthuka	Count		10	10
	% within village name		100.0%	100.0%
	% within number of livestock		20.8%	16.7%
	% of Total		16.7%	16.7%
Thandanani	Count	4	6	10
	% within village name	40.0%	60.0%	100.0%
	% within number of livestock	33.3%	12.5%	16.7%
	% of Total	6.7%	10.0%	16.7%
Masiyepambili	Count	1	9	10
	% within village name	10.0%	90.0%	100.0%
	% within number of livestock	8.3%	18.8%	16.7%
	% of Total	1.7%	15.0%	16.7%

ANOVA Table for yield

			Sum of Squares	df	Mean Square	F	Sig.
maize yield per hectare * village name	Between Groups	(Combined)	4774912.048	5	954982.410	1.412	.239
	Within Groups		29089014.929	43	676488.719		
	Total		33863926.977	48			
sorghum yield per hectare * village name	Between Groups	(Combined)	563950.130	5	112790.026	.979	.439
	Within Groups		6221745.851	54	115217.516		
	Total		6785695.981	59			
beans yield per hectare * village name	Between Groups	(Combined)	883.391	5	176.678	1.601	.176
	Within Groups		5960.069	54	110.372		
	Total		6843.461	59			
watermelon yield per hectare * village name	Between Groups	(Combined)	.058	5	.012	.978	.440
	Within Groups		.625	53	.012		
	Total		.683	58			
groundnut yield per hectare * village name	Between Groups	(Combined)	2732.422	5	546.484	1.365	.252
	Within Groups		21613.281	54	400.246		
	Total		24345.703	59			
roundnut yield per hectare * village name	Between Groups	(Combined)	202.007	5	40.401	.945	.460
	Within Groups		2265.625	53	42.748		
	Total		2467.632	58			
millet yield per hectare * village name	Between Groups	(Combined)	13621.311	5	2724.262	.926	.472
	Within Groups		158899.740	54	2942.588		
	Total		172521.050	59			