PERCEPTIONS VERSUS REALITIES ON CLIMATE CHANGE IN THE SUGARCANE GROWING AREAS OF CHEMELIL AND MUHORONI

BY

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Abstract

Perception on climate change is a prerequisite for adaptation. A number of studies have been conducted to investigate perceptions on climate change. However, they rarely incorporate analysis of climatic data to corroborate the findings. This study is a two- pronged attempt to determine perceptions on climate change and to establish if they match the reality. Face to face interviews have been conducted on individuals at household levels in 15 villages in Chemelil and Muhoroni Sugarcane growing area of Kisumu County involving 405 adult residents to elicit perceptions. Climatic data consisting mainly of daily rainfall data for 23 years from Muhoroni Sugar Company's central weather station has been analyzed to provide evidence on reality on the same. Using InStat, a statistical package specially designed for analysis of climatic data and another, GenStat; descriptive statistics, inferential analysis of climatic events for trends and Markov chain modelling of rainfall data have been utilized. Chi-square tests for independence, t-test for equality of two means and regression analysis have been employed. The feelings of the respondents tended to be influenced more by their perceived demands for rainfall. The overall perception among gender irrespective of level of education was that there is climate change. However, exploration and analysis of long term daily rainfall data do not reveal statistical evidence of the same. Involving statistical analysis of climatic data would validate and reinforce evidence based on perception and guide in more informed policy formulation and decision making on climate change related issues.

CHAPTER 1: INTRODUCTION

1.1: Background information

Climate exerts a profound influence on the lives of poor populations who: depend on rain fed subsistence agriculture for their livelihood and sustenance; are unprotected against climate-related diseases; lack secure access to clean water and food; and are vulnerable to hydro-meteorological hazards.

The impact of climate variability on development is two-fold: Climatic extremes, such as drought and flooding, take a direct toll on lives, health, livelihoods, assets and infrastructure, while their unpredictability is an impediment to development even in years when climate conditions are favorable. Climate directly impacts food and fiber production, and the epidemiology of infectious diseases. Severe or repeated climate shocks can push vulnerable households into a persistent poverty trap when their individual coping responses involve divestment of productive assets, such as livestock or land. Without advanced warning, societal safety nets are costly, and difficult to mobilize and target effectively.

Although less visible than extreme events, the indirect impact of climatic uncertainty is an equally serious impediment to development. The inability to anticipate when climatic extremes will occur is a disincentive to investment, adoption of innovation and the success of other development interventions. For the risk averse decision maker, climatic uncertainty necessitates short planning horizons and conservative risk management strategies that buffer against climatic extremes, but often at the expense of inefficient resource use, reduced average productivity and profitability, and accelerated resource degradation due, for example, to under-investment in soil fertility inputs or conservation measures.

While climate change is the statistics of weather over time or space, climate variability refers to time scales ranging from months to decades, falling between the extremes of daily weather and the long-term trends associated with climate change. According to the IPCC (2007) report climate change is "the impact of an ever warmer planet brought by increased levels of greenhouse gases that are trapped in the atmosphere''. The same report defines climate change as "a change in the state of the climate that can be identified (e.g. using statistical tests)...by changes that persist for an extended period, usually decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity." More, it refers to global changes in the climate brought about by the rising concentration of greenhouse gases which arise from various human activities performed with increasing intensity since the start of the industrial revolution. This therefore provides evidence that the world's changing climate is caused by natural phenomena and human activity alike.

Houghton, Ding, & Griggs (2001) have alluded to the availability of evidence that warming experienced in the last 50 years is mainly attributable to human activities. In the same time span, global warming has been estimated to be in the range of 0.4-0.6^{0}C as suggested by Folland, Rayner, & Brown (2001). In the words of IPCC (2007), such revelations inform and enrich our thinking that there is climate change.

Increasing evidence shows that climate change is likely to adversely affect the African continent and will be one of the most challenging issues for future development, particularly in the drier regions. In fact, climate change is likely to have an impact on ecosystem services, agricultural production and livelihoods (Sivakumar, Das, & Brunini, 2005).

In particular, climate change is expected to have serious environmental, economic and social impact on our own country. The extent to which these impacts are felt depends on our ability to detect any change and the extent of adaptation, both of which may largely be influenced by perceptions.

While there are scientific agreements that climate change is ongoing and will continue to be experienced, measures aimed at directing strategies for adaptation are complicated by climatic models that point to increased temperatures but show a combination of complexity encompassing both increasing and decreasing rainfall patterns.

Consequently, farming under semi-arid tropics, where season to season variability in rainfall dictates productivity and profitability is rendered vulnerable and exposed as a risky endeavour especially for small and marginal farmers with limited land and financial resources.

Therefore, farmers are hard placed to make decisions such as which crop or variety to grow on how much land, what inputs to use, and what soil, water and crop management strategies to adopt, the outcome of which is directly linked to the amount and distribution of rainfall during the season.

Due to the high variability and uncertainty associated with seasonal rainfall, farmers make these decisions based on their knowledge and experience gained from several years of keen observation, experimentation and practice in the field. Some of these decisions are based on perceptions and can therefore be speculative and even driven by cultural stereotypes.

This study intends to identify perceptions people hold with regard to the emerging and contemporary phenomenon of climate change and to determine if they match statistical evidence on the reality. The question that may be asked at the onset is, 'why should perception be of interest in any study at this point in time'? The answer is simply that the literature on adaptations is clear that perception is a prerequisite for adaptation (Maddison, 2006).

Among other challenges, the Kenyan highlands which were hitherto malaria free zones are now confronted with the disturbing reality of highly drug-resistant strains of this tropical ailment. This in effect reinforces the perception as to the actual existence of climate change.

While perceptions may be subjective and speculative, we expect that reality must be objective, factual and backed by empirical evidence observed over a considerable period of time.

As suggested by Rebetez(1996), human perceptions of climate are strongly influenced by expectations which may have little relationship to the nature of climate as provided by instrument records.

Meze-Husken (2004) has put up a case on human perceptions of the climate, its variability and potential change as being important challenges in understanding climate-society interactions by stating that 'peoples' subjective observations may be confirmed by statistical data with extreme events being interpreted as a confirmation of human-induced climate'. However, perceptions are likely to be affected by overlooking the contribution of social and environmental factors such as deforestation, population increase, soil erosion and agricultural practices in place.'

An early perception was that climate change was going to occur in a gradual fashion in the medium to long term (in the next 50 to 100 years). In 2006, Sergine et.al raised concern that assessment reports produced by the Intergovernmental panel on climate change (IPCC) provide evidence that climate change is actually happening much faster than initially assessed.

Many developing nations despite being insignificant contributors to emission of greenhouse gases now demand immediate action to reverse the adverse effects of climate change.

To understand realities of climate change, there is need to analyse data based on elements of weather, namely: rainfall, sunshine, temperature (minimum and maximum) and wind speed. Analysis to determine statistical evidence may involve daily, monthly, seasonal and even annual data. Climate being the average weather over time, it therefore compels us to study the historical data from the same site over long time periods.

1.2: Basic concepts

A climatic event is a characteristic of interest for which there is only a single observed value each year. A few examples may be sited to make this clear: considering the total rainfall in April will always be a single value each year and is thus an event, a look at 10-day rainfall totals yields 36 events because a year can be divided into 36 blocks of 10 days each. We can then determine rainfall totals for each partition which will give 36 such distinct values (and thus events). The longest dry spell in April is also an event. However, the length of dry spells in a month is not an event. Other events include length of season, rainfall amount at the start of a season, total rainfall in a growing season and extreme values.

Ancient data analysis relied on monthly data and other summaries for the understanding of rainfall patterns (Stern & Coe, 1982). However present day analysis can be conducted on climatic events based on daily data using appropriate software. Our choice of events to study has been informed by our clients who in this case are the respondents in our survey most of whom are involved in some kind of farming. Their concerns revolve knowledge of the start, end and length of rainy season, how rainfall amounts are distributed through the year and any risk of dry spells.

1.2.1: Start of rains

The start of rains is an event. The best definition for it is one that meets a client's objective in any statistical analysis. In this study with interest in climate change, focus is on identification of any change in rainfall patterns or trends as evidence. Thus events explored include the start of rains bearing in mind the question if there any evidence of change in the start of the rainy season which may have affected successful planting date.

The following definitions have been chosen to suit planting and germination of maize as the main seasonal crop in the area have been used in this study.

a) The first occasion with more than 20mm in 1 or 2 days after 1st of March and no dry spells of 7 days or more within the following 30 days.
b) The first occasion with more than 20mm in 1 or 2 days after 1st April and no dry spells of 7 days or more within the following 30 days.

1.2.2: Rainfall amounts and length of the season

The amount of rainfall at the start of the season is important as it gives an indication of the time the farmers can do their planting. From the definition of the start of rains, this is expected to be at least 20mm for each year. It is necessary to investigate how it has varied for each year for the entire period.

A planting/growing season is the period of time from the planting up to when the plants mature and are ready for harvesting. It includes all time when all field operations are undertaken until the crops mature. The start of the rains determines the start of the season. The end of the season is defined in terms of soil water balance as the first occasion after 1st July when the soil water balance drops to zero.

The length of the season is calculated as the number of days from the start of rains and the first occasion after 1st July when the soil water balance drops to zero (i.e. the end of the season). Changes in the length of the season may be a pointer to change in the climate.

1.3: Modelling of rainfall data

The occurrence of rainfall on any day depends on the condition of previous days and rainfall can therefore be considered as a random variable which follows the Markov chain. We can then fit curves to probabilities of rain for days falling in classes of zero, 1st and 2nd order Markov chain modelling. These are therefore conditional probabilities given the state of rain or otherwise on preceding dates.

1.3.1: The probability of rain

Given a record of n years and that a particular event occurred in m of these years, the probability of that event occurring in any given year is given by $\frac{m}{n}$. A curve is fitted to the probabilities using the computer package InStat, which enables curves to be fitted to proportions which, by definition, are not normally distributed as seen in short term rainfall data. As it was described in (Stern, Dennett, & Garbutt, 1981), to ensure that the fitted curve is one of the probabilities (p) should be transformed as: $f = \log(\frac{p}{1-p})$ (1.1)

This allows f to vary from $-\infty$ (p=0) to $+\infty$ (p=1).

A function f (t) (where t is the day of the year) is fitted to the values of f and the fitted probabilities are given by

A function given by $p(t) = \frac{\exp(f(t))}{1+\exp(f(t))}$ (1.2)

For the function F (t) of Fourier series of n harmonics:

$F(t) = a_0 + c_1 \sin x + b_1 \cos x + c_2 \sin 2x + b_2 \cos 2x + \ldots\ldots\ldots + a_n \sin nx + b_n \cos nx$ (1.3)

where $x = \frac{\pi t}{366}$

This gives a function, which joins at the beginning and end of the year. This rather complex curve with (2n+1) coefficients is required to describe the rainfall pattern through the year.

- **Zero order:** Probability of rain - *p*_r.
- **First order:** Probability of rain given that: Yesterday was dry - *p*_rd; Yesterday was rainy - *p*_rr.
- **Second order:** Probability of rain given that: Yesterday dry, previous day dry, *p*_rdd; Yesterday dry, previous day rainy, *p*_rdr; Yesterday rainy, previous day dry, *p*_rrd; Yesterday rainy, previous day rainy, *p*_rrr.

1.3.2: Amounts of rain

Gamma distributions were fitted to amounts of rain on rainy days (zeros excluded).

The gamma distribution is given by: $f(x) =: f(x / \mu, k) = \frac{\left(\frac{-k}{\mu}\right)^{k} x^{k-1} e^{\left(\frac{kx}{\mu}\right)}}{\Gamma(k)}$ (1.4)

Where $\acute{\Gamma}$ is the gamma function and the two parameters of the distribution are: the mean rain per rainy day (μ) and the shape parameter, k.

1.4: Statement of the problem

Perceptions we hold on climate change may not match the reality. Surveys on perception often guide policy formulation and decision making. However, results of surveys are rarely validated by reality from analysis of climatic data. This study determines perceptions on climate change and finds out if the same is confirmed by analysis of long term daily rainfall data from the same site.

1.5: Objectives of the study

A survey on perceptions on climate change will be validated using analysis of historical climatic data from the same site.

Specific objectives are:

- Determine perceptions on climate change using a survey.
- Determine evidence of climate change by analysing historical rainfall data.
- Analyse if results on the perceptions and evidence on realities match or not.

1.6: Significance of the study

This study would:

- Lead to future surveys on perception on climate change being validated by evidence based on analysis of climate data from the same site.
- Initiate all inclusive statistical analysis in measures aimed at mitigating the challenges of climate change.

1.7: Outline of the thesis

Chapter one is the introduction, chapter two is review of related literature, chapter three is on Materials and Methods employed, chapter four is on analysis of perceptions on from survey data, chapter five is about statistical analysis of climatic data and finally chapter six is about summary, conclusions and recommendations followed by references and appendices.

CHAPTER 2: LITERATURE REVIEW

2.1: Perceptions on climate change

2.1.1: Perceptions regarding changes in weather patterns

Climate change is happening and will continue into the future (Christensen, 2007). A number of climatic factors of interest identified by farmers in earlier studies include the amount and distribution of rainfall, the onset of rains and changes in temperature (Rao et al, 2011); (Macharia et al, 2010); (Maddison, 2006); (Ovuka et al, 2000). The perception has been that there is: decline in amount of rainfall, increased variability of rainfall and unpredictable rainfall patterns, delayed as well as shifting of the onset of rains, increase in temperature in all the months and decrease in temperature during the cool dry periods. Yields are said to have been reduced and inability to grow some crops hitherto cultivated has since set in.

A study by Mertz et al (2009) showed that rural households in Sahel, Tunisia were aware of climate variability and identifying wind and occasional excess rainfall as most destructive climatic factors.

Seven in ten of the farmers in the four districts of lower Eastern province in Kenya were found in a study by Rao, Ndegwa W, KizitoK, & A, (2011) to be aware of significant changes in weather patterns over the previous 5 years. However, those accustomed to dry conditions were less conscious of change in climate than those in wetter areas.

Evidence from a number of African countries suggest that many farmers already perceive climate to have become hotter and rains less predictable and shorter in duration (Cooper et al, 2009); (Maddison, 2006). Farmer's perception is that the risk associated with variable rainfall is greater than is currently thought.

Research has highlighted the critical role played by access to information in shaping farmers' perceptions of climate variability (Deressa, 2009) and (Maddison, 2006). These studies assert that farmers with access to weather information and those with many years of farming experience are more likely to be aware of and concerned with changes in climate.

However, some researchers now more than before pay attention to local perception on climate changes in an attempt to understand human adaptation to climate change. Meze-Husken,

(2004) asserted that understanding of the trends in a phenomenon such as rainfall is not clear cut and seriously doubted farmers' ability to accurately discern climate trends by casual observations. She expressed the fear that, more often than not, perceptions are easily influenced by levels of crop yields for any season and other factors such as level of education and the size of the field.

2.1.2: How perceptions tally with climatic data

Perception being a prerequisite for adaptation, there is a strong link between perception and behaviour. Perception of climate risk will always affect adaptation management (Thomas et.al, 2007). Perception of climate risk and perception in general is highly influenced by peoples' opinions and values, which are in turn influenced by the economic, cultural and social environment (Thomas et.al, 2007).

Attempts have been made to investigate farmer perceptions and how they tally with climate data from the same site. As noted by West,(2008) ; Meze-Husken, (2004) and Ovuka & Lindqrist, (2000), a limited number of studies on farmer perception have made attempts to assess the accuracy of the same with observed data on rainfall and temperature. A study by Kurukulasuriya & Mendelsohn, (2008), in 11 African countries revealed that significant numbers of farmers believed temperatures have increased but precipitation declined. The same views of respondents in most of the cases have been corroborated by what their neighbours felt had happened. However, evidence on whether farmers' perceptions tallied with records from weather stations was equivocal. The records available covered shorter periods of time than the farmers could remember. More glaring was that marginal and poor groups were unaware of climate change.

Peoples' perceptions of rainfall decrease in northern Ethiopia were studied by Meze-Husken, (2004). The 1980s were remembered by most of the respondents as the worst because of the large-scale famine conditions. However, climatic data used in the study found that this decade was on average the wettest in comparison with previous 4 decades, whereas the 1970s showed the lowest summer rains. Absence of a shift in seasons was also shown.

An examination of how farmers' perceptions corresponded to temperature and rainfall data in Nepal was carried out by Yubraj in 2009. Nine in ten of the respondents perceived temperature to have increased, while a similar ratio revealed having experienced unpredictable rainfall patterns in the preceding 10 years. The linear trend analysis of averaged mean temperature for 1978-2007 showed that temperature had risen by 0.9^0 C but rainfall was characterized by large inter annual variability with substantial decrease in the amounts over the years 2002-2006. Seen from the IPCC definition which says climate change in the real sense involves changes that persist for extended periods spanning decades and even more, these changes lasting five years may not be attributed to climate change.

To determine whether expectations lag behind reality on climate change, three approaches to the analysis have been advanced testing particularly:

- if perceptions are dependent on the years spent by respondents in farming;
- if perceptions are spatially auto correlated (individual respondents' perception can be validated by the neighbours' responses);
- if perceptions correspond to evidence provided by nearby monitoring stations.

The results showed no significant difference in views expressed by both experienced and inexperienced farmers, farmers of different age groups and even educational attainments (Yubraj, 2009).

In Katumani, Kenya, farmers attributed declining maize yields to climate change and reduced rainfall; however, long term rainfall records do not support this perception Cooper et.al (2009). In Machakos farmers had rated nearly 47% of the seasons as poor, while historical data indicated that in only 27% of the seasons would maize crop failure have occurred (Cooper, Rao, Singh, & Dimes, 2009).

Rao et.al(2011), went a step further to contrast farmer perception from five districts of Eastern Kenya with analyzed climatic data from the same sites. In a survey that covered the age, educational attainment and gender of respondents, the perception was that rainfall during long rainy season was more variable than during short rainy season. However, the climatic records do not conform to the views.

In Uganda, perceptions of decline in rainfall in recent decades have been verified through comparison with daily climatic records. The records show that while the total monthly and seasonal rainfall amount have been stable, the dry spells in months critical to crop development have increased (Ovuka & Lindqrist, 2000), thus leading to partial agreement between perception and reality from data being realised. The limited time span of the data under study does not permit to consider this as confirmation of climate change.

Perceptions on climate change among immigrant communities in semi-arid regions of Nyeri North and Laikipia East districts of Central Kenya were studied by Macharia et.al in 2010. All the respondents were aware of climate change which they felt had influenced their farming. The 64 members of Nmrutia, Naro Moro and Matanya communities interviewed identified environmental degradation as the major visible effect of climate change and variability in the area. Main indicators were erratic and low rainfalls, frequent droughts and dust storms, low crop yields and high day and low night temperatures. In their view, climate change had resulted into increased levels of poverty, food insecurity and changes in biodiversity and security of resources like water and indigenous trees. Climatic data from Kenya Meteorological department showed that in the Central region, trends of minimum temperature from 1960 had been increasing with a magnitude of 0.8^0-2.0^0C, while maximum temperature has been increasing with a magnitude of 0.1-0.7^0C in the subsequent ten years. There had been a general decline with time of rainfall during the main rainfall season (March to May) as well as during the short season. Also, the short rains which normally would start in October had shifted to hot and dry months of January and February (Macharia, Lugadiru, Wakori, & Ng'ang'a, 2010).

The actual climate change in a specific year is described by Ethiopian farmers as a deviation from the 'ideal' level of rainfall (which enables them to have a good harvest). However, to them there is no climate change when the rainfall is exceptionally good. This strongly indicates that the perception of climate change is linked to the utilitarian aspect of rainfall (Meze-Husken, 2004).

In most of the studies on climate change, temperature is agreed to have increased. However, no clear cut conclusions have been advanced with regard to rainfall in terms of time of start, number of rainy days, distribution and mean rain per rainy day. In all studies referred to above, changes in weather conditions have tended to be associated with crop productivity. In Kenya and Uganda, farmers classify seasons in terms of the onset and cessation of rainy season as well as the distribution of rainfall in relation to critical stages of plant growth. There is a strong belief that the climate has changed for the worse but evidence for this is lacking in the corresponding climatic data, Rao et.al, (2011). Apparently, there were no differences in perceptions between the two genders, among members of various age-groups and levels of education. In Katumani and Machakos, farmers ascribed changes in farm productivity to changing rainfall patterns. The assessment of seasons was influenced by the performance of their main crops. Although there was a decline in maize yields, did was not conform to changes in the amount and distribution of rainfall as identified by records, Rao et.al, (2011).

There have been minimal attempts to simultaneously investigate patterns in rainfall and temperature events alongside studies on perceptions. Where data on precipitation were available, annual and seasonal rainfall totals were used while data on temperature available were annual maximum and minimum means. The methods have been directed towards determination of mean values of annual mean monthly maximum and minimum temperature.

In this study information on the start of rains and their distribution as revealed in a survey are analysed; investigation of any shifts in the start, rainfall counts, and amount of rain per rainy day of interest are carried out and how the yields were over three years preceding the time of the survey. The perception by gender, level of education, age-group among farmers and even those not involved in farming are explored. Trends in rainfall, seasonality, extremes and risk of dry spells are also investigated through an analysis of the data from one central meteorological station which is within the survey location (Muhoroni Sugar Company).

2.2: Realities on climate change

Surveys on perceptions on climate related scenario often seem to attach more emphasis to negative events or impacts, leading to biased estimation of the frequency of occurrence of the negative events. Evidence based on climatic data from the same site as that of the survey would provide more credible information.

2.2.1: Daily rainfall data

The monthly rainfall time series do not reveal changes in rainfall -either in total amounts or in seasonal distribution. The shortcoming of using monthly or annual data is that from them we may not be able to detect potential changes of characteristics, such as the occurrence of dry spells that is possible from the daily rainfall data.

Studies on the developments in rainfall events by Stern & Coe (1982) showed that while daily data may not be independent over periods of a few days, they are virtually independent over longer periods. In their analysis, the approach included definition of the start and end of rains by setting the condition that allowed sowing and successful emergence of a crop. However, they were not specific to the requirements of any particular crop.

2.2.2: Start of rains

The start of rains is a climatic event. It is therefore possible to estimate the frequency distribution of the date of start of the rains and assess the probability of rains starting on different dates in each year (Stern, 1980). The estimation of the chance of rains starting on different dates was done by Benoit in 1977. His criterion for the start of the rains was defined to deal with the 'false starts' which occur when rainfall that meets the chosen criterion is followed by a long dry spell.

As highlighted by Stern et.al(1981), it is necessary to define climatic events like the start and end of the rains very clearly in such a way that successful planting is possible. The criterion they suggested was one which incorporates no dry spells of at least 7 days in the month after sowing.

Analysis of the start of rains alone may not be sufficient as a guide to the sowing of crops. Good rainfall may be followed by dry spells that would prevent crop establishment Stern et.al (1981). It is therefore necessary to calculate the probability of a dry spell of a specified length occurring within a specified period following a rainy day. This enables the choice of a planting strategy.

This study considers the main season to start in the months of March or April and end around mid to end of July. The main seasonal crop cultivated during this time is maize. The definition of the start of rains incorporates enough rainfall for germination of crops and a dry spell that does not exceed 7 days after sowing. This would be good enough for establishment for a maize crop.

2.2.3: Modelling daily rainfall data

The chance of rain on any day may depend on whether the previous day had rain or not. The occurrence of rain is thus treated as a random process analogous to a Markov chain in which the occurrence of an event only depends on the previous immediate outcome and not history. A study of the daily rainfall data for Samaru, Nigeria was undertaken by Stern in 1980. Using a two part model, he identified the dependence of the probability of rainfall on both whether the previous day had rain or not as well as seasonality. Stern et al (1981) extended the same on the start of rains in West Africa in 1981 Stern et.al(1981) and finally Stern and Coe in 1982, fitted models to daily rainfall data Stern et.al(1982)

The underlying assumption is that daily rainfall amounts depend on seasonality and follow a gamma model, with parameters that may depend on the seasonality. The rainy seasons may be studied in sections for areas where the rainfall distribution is bimodal Stern et.al (1981).

The modelling approach in the investigation of evidence of climate change can be used as a confirmatory test alongside the descriptive statistics since it identifies even the smallest changes in rainfall pattern Kurji et.al (2005).

This study extends the study by Stern (1980) and incorporates the proposal by Kurji et.al(2005). However, we go further to model rainfall data for chance of occurrence, risk of dry spell following planting, mean amount of rain per rainy day and weekly rainfall totals. Also included is investigation of even small changes in the pattern of rainfall for the 23 years of data sub-divided into two and then four blocks of years.

2.2.4: Statistical analysis of data

Statistical analysis becomes useful in climatology since it has the primary objective of identifying systematic behaviour in a data set and has the capacity to reveal periodicity, trend and persistence of extreme events in any climatic element being analysed (Buchdahl, 1999).

A study by Price et.al(1999) analysed long term temperature data from stations on the island of Cyprus and identified increasing trends in the annual mean temperature at both stations. However, the mean daily temperatures resulting in a decrease in the long term diurnal range was detected. This was consistent with observations from other parts of the globe, an indication that the climate of the region was part of a larger climate change occurring over the last century.

The need for flexibility in the choice of software used in data exploration and analysis was stressed by Kurji et.al (2005). Since these are merely tools, they suggest the principle should be to use the best that may be available at any given time.

To implement all the analysis done by Stern and others, a statistical package, InStat, was developed and is available and has been used in this study. The latest is the 2006 version (Stern &Rijks(2006). The package can be used to model among other things, rainfall amounts and in particular, the mean rain per rainy day because rainfall amounts also depend on seasonality.

From the literature review, not much seems to have been done to incorporate the use of analysis of climatic data particularly daily rainfall data to validate the results of many analyses of survey data on perceptions on climate change. Equally, use of modelling of long term rainfall data is a concept that would be utilised in analysis to complement other methods of analysis. To a large extent, investigations of trends of events, such as starting dates, monthly rainfall totals and counts using similar data are have hardly been undertaken.

CHAPTER 3: MATERIALS AND METHODOLOGY

3.1: Introduction

This study employs primary and secondary data on perceptions and evidence on climate change respectively. Information on opinions has been collected through a survey constitutes primary data while long term daily rainfall data from Muhoroni Sugar Company's central meteorological station for 1986-2008 is the secondary data.

This study was carried out using data from the Chemelil and Muhoroni sugarcane growing regions in Kisumu County of Kenya. Chemelil and Muhoroni areas were chosen due to availability of long term daily rainfall data from Muhoroni Sugar Company's central meteorological station. Farmers and all those who are dependent on agriculture from the same site were to provide primary data.

The area is largely a settlement scheme. The inhabitants are mainly small to medium scale sugarcane farmers who also grow predominantly maize for subsistence. However, there are some who don't engage directly in farming and earn are public sector employees while quite a number traders within the area. Agriculture is predominantly rain-fed and there is one main cropping season from March or April to mid to end of July. This is the season this study is focused on.

The soils in the area are of clay type commonly referred to as black cotton soil. They easily get water-logged when it rains and are equally very sensitive to prolonged dry spells as they become quite dry to support plant life. The farmers always wish for dry spells in December and January to enable them to adequately prepare their fields for the main cropping season. Any rains in December interfere with land preparation and would therefore adversely affect the season's output.

Fieldwork initially involved discussions with managements of Chemelil and Muhoroni sugar companies, and especially the officers in the agronomy sections. They undertook to avail climatic data in their possession for the intended research and had no problem in some of their staff taking part in a survey if called upon. The study reported was a survey together with the use of long term rainfall data. The survey started in the month of January when piloting of the survey was conducted by the author using a sample of 60 respondents in the villages surrounding Chemelil and Muhoroni sugar companies. The full survey was carried out in the months of May, June and part of July. It involved 405 respondents who were all adults and was conducted by the author who recorded the responses during face to face interviews administered at the household level. The survey questionnaire included simple questions aimed at eliciting farmers' understanding and knowledge of farming in the area as well as about the season to season variability of weather and in especially rainfall. The questions focused on perception of climate trends and events for the few years prior to the survey.

3.2: Primary data

To elicit the perceptions of the residents on climate change it was necessary to interview individual on their views. In particular the respondents were asked to give information about their opinion on the start, end and length of rainy season and length of dry spells.

3.2.1: Population of the study and sampling procedure

Information from the out growers' manager at Muhoroni Sugar Company shows that the study area has 15,000 to 20,000 farmers.

Sample size was determined as recommended by Mugenda & Mugenda (2003).The population expected to accept to participate in the survey, p is assigned the proportion 0.5 and that we expect to decline, q = 1-p is assigned the proportion 0.5.

Taking 95% confidence interval, 0.05 level of confidence, the sample size, n is given as;-

The sample size, $n = \frac{z^2}{d^2} pq$

Z- Score = 1.96 (for 95% confidence interval), p = q= 0.5 d = 0.05, (d being the level of significance), where $n = \frac{1.96^2 (0.5)(0.5)}{(0.05)^2} = 384.16$

For convenience, 15 villages or areas have been identified as administrative units for conducting the interviews. Due to time and financial constraints which could not allow involvement of other enumerators in the survey, non- probability sampling which involved drawing a sample from part of the population which is close to hand, (Mbeche I.M, 2004), convenience sampling has been used. The other consideration was accessibility of homesteads from all weather roads or major feeder roads that traverse the entire area since this time was a relatively rainy season or inaccessible during period soon after the rains. Interviews were conducted in a different village every morning. From all the homesteads accessed, each household was visited and adults found there were interviewed subject to the condition that they had been residents in the area for at least two years.

The researcher personally conducted face to face oral interviews to individual respondents and recorded their responses. The time line available for administration informed the choice of the respondents. On average, 12 – 15 interviews were conducted on each day of the week from Monday to Friday between 17th May and 25th July. By the end of the survey, 405 respondents had been interviewed.

3.2.2: Instruments used in the survey

A questionnaire was used to get perceptions on climate change. It was structured with questions to determine personal identification of respondents (including: gender, age, level of education and occupation), personal experience in farming in the area, knowledge about the seasons and personal opinion on the weather conditions relating to having heard about climate change (if they thought climate change does exist and if it had influenced their farming methods as well as any mitigating measures they intend to undertake due to climate change (Appendix 2).

3.2.3: Survey data analysis

The survey data was entered in Microsoft Excel, cleaned and coded then exported to the statistical package, InStat. For the analysis of the survey data, cross tabulation mainly using two-way tables were to show frequency of responses and the relationship among the variables under investigation.

3.3: Secondary data

The entire study began with a visit made by the researcher making inquiries to various research institutions and sugar millers including the Kenya Meteorological department in search of climatic data. Eventually, Muhoroni and Chemelil sugar companies availed data which were used.

The data consisted of Muhoroni daily rainfall data for 1986-2008 from the Muhoroni Sugar Company's central meteorological station which was provided in Excel spreadsheet. The data for the entire 2001 as well as 1993 May to December are missing. For Chemelil only data for 2000-2009 were available; however, data for most of the year 2001 were missing.[2]

The records at the Muhoroni central meteorological office consisted of files from where the data had been entered from into excel. These were used to check for the accuracy of the entries which were confirmed to have been correctly done. It was first rearranged to have them in columns for each year and rows for each day number, cleaned, organized and imported into InStat after giving appropriate coding for missing, trace and non-existent values.

3.3.1: Climatic data analysis

The analysis of rainfall data began with exploration involving stacking then exporting it to GenStat to produce monthly and yearly summaries for trellis plots. The rainfall data was stacked into amounts by day and monthly totals and counts calculated for investigation.

A statistical package, InStat, specially designed for the analysis of climatic data has been used alongside GenStat. InStat has features that enable it to make special consideration for 29th February (day 61) during the non-leap years.

Descriptive statistics and graphs have been used to investigate the rainfall data in order to establish patterns and trends for evidence of climate change. Analyses include: the start of the long rains, length of the rainy season, end of the season, rainfall extremes[3], amount of rainfall at the start of the rains and total amount of rainfall during the planting/growing season. Markov chain models are fitted to the occurrence of rainfall, risk of a dry spell of 5 or 7 days after planting, amount of rainfall per rainy day and weekly rainfall totals.

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[2] The rainfall data analysis for Chemelil area has not been carried out due inadequate data.

[3] Occurrence of extreme climatic phenomena like flooding, drought and even heavy rainfall characterized by storms may signal climate change.

Start of rains and dry spells

Start of rains is an important event for analysis of rainfall data. We give its definition at this stage. This is done for the months of March and April separately.

a) i) the first occasion with more than 20mm of rain in a 2day period after 1st March.

ii) The first occasion with more than 20mm of rain in a 2day period after 1st March and no dry spell of 7 days or more within the following 30 days.

b i) the first occasion with more than 20mm of rain in a 2day period after 1st April.

ii) The first occasion with more than 20mm of rain in a 2day period after 1st April and no dry spell of 7 days or more within the following 30 days.

Long dry spells after the onset of rains may cause crop failure. Of interest is if there's evidence of change in length, frequency or spread of the dry spells, or if there any noticeable trend in the same. Dry spells in the months of March and April are investigated since these are the months that residents grow maize, their staple food. Then the risk of a long dry spell in the 30 days after sowing is investigated.

Total rainfall during the planting or growing season

To analyze the total rainfall during the planting/growing season, we employ the dialogue **Climatic > Summary** and get totals from StMar (start of rains in March) to end of season for March, and from StApr (start of rains in April) to end of season for April.

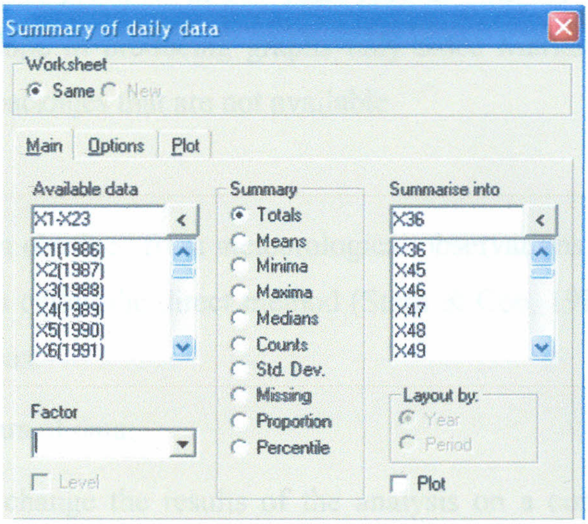

Figure 1: InStat dialogue for total rains during growing season

3.3.2: Descriptive statistics

Planting date is an indicator of when the farmers hope to realise a good crop in each season. We use InStat to investigate the distribution of the planting dates as a means identifying any shift in time of occurrence. This is done using both box plots and probability plots. Percentiles (quartiles, median and 20th and 80th percentage points) for the occurrence the same events as well as their means are determined as well as the risk of crop failure and their return periods. The standard deviation (as a measure of variability) and range (as a measure of spread of the events) are also determined. All the results are expressed in terms of day numbers, which gives specific dates of their occurrence.

Time series plots and regression analysis are employed to investigate any trend over the years under consideration.

3.3.3: Markov chain modelling

Markov chain modelling is employed as a more comprehensive way of determining evidence of climate change. The descriptive statistics may not be good enough to answer all our questions. It is therefore necessary to incorporate modelling as a confirmatory analysis. While the descriptive statistics demand the use of long term records (at least 30 years) to achieve high precision. It was shown by Sooriyarachchi in 1989 that the modelling approach with records of 20 years should give the same precision as 100 years records with the use of the simple method. This study confines its scope in producing graphs only since Markov chain analysis requires more advanced statistical packages that are not available.

If daily rainfall data obtained from meteorological observations is directly used for doing the data analysis, then it is called the direct method (Stern & Coe, 1982). This kind of analysis has some limitations, such as:

- It needs many years of data;
- It is difficult to change the results of the analysis on a conditional basis (when the definition of the characteristics of interest is changed), in which case the analysis has to be done from the very beginning with the raw data.

For 30 years daily rainfall data, the direct method suggested by Stern &Dennett (1982b) has given reasonably good results in describing the characteristics of interest. But, if the same analysis is planned for shorter data record, the method makes insufficient use of the data.

To incorporate shorter years' records of rainfall as in this study with 23 years of rainfall data and avoid running into problem of shortage of data, an alternative method called the indirect method (Stern & Coe, 1982) is applied. This approach of using statistical models summarizes a large volume of data as concisely as possible, by modelling daily rainfall using Markov chains.

Various studies have used the Markov processes for modelling rainfall and have got very useful results. The indirect method enables fitting of Markov Chain models of different order (zero, one and two) into the probability of occurrence of rain and mean rain per rain days.

Markov chain modelling within InStat

Markov chain models are fitted to the 23 years of daily rainfall data and then used to fit curves to different subsets of the data (see Chapter 5). We apply the Markov chain modelling to the daily rainfall data over the period 1986-2008, to model: (i) chance of rain; (ii) rainfall amounts (mean rain per rainy day); and (iii) weekly rainfall totals. The aim is to compare the corresponding subsets to determine if any evidence of climate changes results.

Markov chain modelling is a three-stage analysis which begins with a summary of the data preceding model fitting. It uses **Climatic > Markov Modelling** dialogue.

Stage 1: Preparation

In this stage we identify the data to be used. After opening the Muhoroni daily rainfall spreadsheet (1986-2008), and then selecting **Counts and Totals** dialogue box and choosing the order of the counts (zero, first or second); we then identify the columns in which the counts are recorded. This stage involves summary of the data: Appendices 9 and 10 show, for each day of the year, the number of years when that day was rainy or dry (order zero and order one respectively). Rain is defined as a day with more than 0.85 mm. Next is the **Markov modelling > Prepare** dialogue. It sets up the columns to fit the model and also produces a graph of the chance of rain.

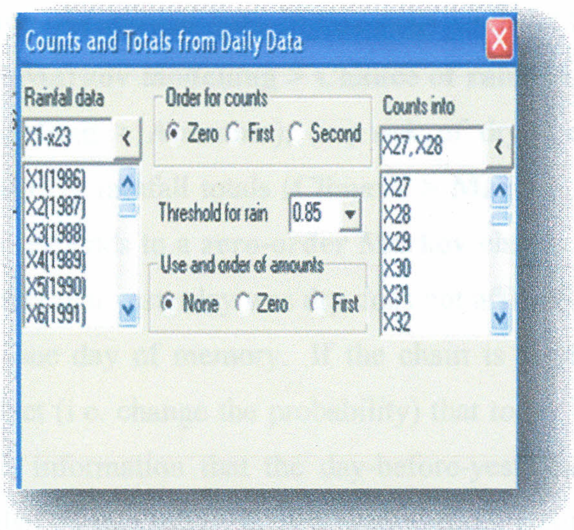

Figure 2: InStat dialogue for counts and total rainfall

Stage 2: Fitting the model

This produces the fitted probabilities which are indicated in Figure 3 as 'f.r'. It uses the model probabilities dialogue, **Markov Modelling > Model probabilities**. We choose the order of probabilities 0 and 1. The model has two components. The first component is the set of equations that fit the chances of rain through the year. Here both the chance of rain given the previous day was dry and given it was rainy are considered. Thus there will be two curves to fit.

X35	X36	X37	X38	X39	X40	X41	X42
dc3	ds4	dc4	ds5	dc5	l_r	f_r	estr
-0.9986741	861474E-02	0.9976432	-0.0857305	-0.9963183	-0.6286086	0.2360753	-0.485643
-0.9946999	0.1369061	0.990584	-0.1708297	-0.9853005	-1.280934	0.2343317	-0.1124109
-0.9880879	0.2045521	0.9788557	-0.2546712	-0.9670277	701137E-02	0.2326881	0.357744
-0.9788557	0.2712339	0.9625134	-0.3366373	-0.9416344	-1.280934	0.2311456	-0.3601139
-0.9670277	0.3366373	0.9416344	-0.4161247	-0.9093075	-1.280934	0.2297051	-0.3207411

Figure 3: Fitted probabilities, harmonics and total rainfall

Stage 3: Using the fitted model

During this stage we produce the graphs. The objective is a model that encapsulates all the relevant information from the rainfall data. In this stage we have four options: we model (i) chance of rain (**Climatic > Markov modelling > Chance of rain**); (ii) mean rain per rainy day (**Climatic > Markov modelling > Amounts**); (iii) risk of dry spells (**Climatic > Markov modelling > Spells**); (iv)weekly rainfall totals (**Climatic > Markov modelling > Totals**). The fitting of a single curve corresponds to a **zero-order Markov chain**. A zero-order chain is one that has no memory. The fact that yesterday was dry does not affect the chance of rain today. A first-order chain has only one day of memory. If the chain is **first-order**, then the fact that yesterday was dry may affect (i.e. change the probability) that today is rainy. However, with a first-order chain, the extra information that the day-before-yesterday was also dry does not further change the probability of rain today. With a second-order chain the memory extends two days, but no more. And so on. In the current version of InStat's the Markov command is limited to second-order chains. The chance(s) of rain change depend on the day of the year. This is allowed for, by using InStat's regression facilities to fit curves to the probabilities.

In a climate change scenario, the chance of rain, rainfall totals, mean per rainy days and dry spells are expected to change. To investigate any variation, we look at data for the whole period (1986-2008). However, it is also useful to break the data into two and four blocks.

CHAPTER 4: PERCEPTIONS ON CLIMATE CHANGE

4.1: Introduction

The survey covered adult individuals of different age, education, gender and occupation. Such factors are generally expected to influence an individual's perception about short and long-term variability in climate. To investigate the perceptions, a number of questions were put to the residents in a survey through face to face interviews at the household level.

4.1.1: The composition of the respondents

We show the composition of participants in the survey in terms of age, gender, level of education. 405 respondents composed of 49% male and 51% female participated in the survey (Table 1), it in terms of levels of education those with: No formal schooling (29% males and 71% females), Primary school education (41% males and 59% females), Secondary school education (52% males and 48% females) and College education (61% males and 39% females).

Table 1: Level of education by gender

	Level of education (%)				
Gender	No school	Primary	Secondary	College	Total
Male	29	41	52	61	49
Female	71	59	48	39	51
Total	100	100	100	100	100

Looking at the age groups (Table 2), we had those below 30 years (10%), (30-45) years (18%), (45-60) years (41%) and over 60 years (31%).

Table 2: Level of education by age group

Age group	Level of education (%)				
	No education	Primary	Secondary	College	Total
Below 30	2	13	11	8	10
30-45	2	17	21	23	18
45-60	10	36	53	46	41
Over 60	86	34	15	23	31
Total	100	100	100	100	100

4.1.2: The respondents' knowledge on farming in the area

Before asking for respondents' perceptions on climate change, their participation and knowledge in farming were investigated. The number of those who grow sugarcane by gender, their knowledge on the start of long rains the previous season among the gender, age groups and level of education was investigated.

This being a sugarcane growing zone, the question of who among the respondents grow the crop was of interest. 87% of the males and 83% of the females and in overall 85% of the respondents answered in the affirmative. 13% of all farmers said they were not sugarcane farmers. Table 3 has the details.

Table 3: Sugarcane farmers by gender

Do you grow Sugarcane?	Gender (%)		
	Male	Female	Total
Yes	87	83	85
No	13	17	15
Total	100	100	100

The farmers' knowledge about the start of long rains in the previous season was sought. (41% males and 59% females) said the rains had begun in February, (45% male and 55% female) gave March and (54% male and 46% female) said the start had been April.

There is the desire to determine the opinion on the start of rains in March – May season by gender. We separate into female and male and make observation among the age-groups as shown in table 4.

Table 4: Start of long rains by gender

	Start of long rains (%)			
Gender	Feb	March	April	Total
Male	41	45	54	49
Female	59	55	46	51
Total	100	100	100	100

There were considerable variations in opinion on the start of the rains among male and female respondents.

Table 5: Start of long rains by age group

	Start of rains (%)			
Age group	Feb	March	April	Total
Below 30	19	7	8	10
30-45	20	14	16	18
45-60	40	30	28	41
Over 60	21	49	48	31
Total	100	100	100	100

Table 5 shows the proportions of those who felt rains start in the months of February, March and April among the various age groups.

4.1.3: Time of planting

We were interested in knowing what those who grow maize as the staple food had to say about the amount of rainfall in the previous year had been like. Over 95% of the respondents grow maize in the March –May season. Opinion on the time of planting by amount of rain per rainy day is displayed in table 7. 94 % the farmers had realized lower amounts of rain per rain day in the previous year plant when rains start.

Table 6: Planting time by amount of rain

When do you plant In each season?	Amount of rain per rainy day (%) Lower	Normal	Higher	Unaware
When rains start	94	87	75	83
Later after start	6	13	25	17
Total	100	100	100	100

4.1.4: Opinion on climate change by gender

One question of interest was to know if the respondents had knowledge of climate change. 9 in 10 of all the 405 respondents acknowledged having heard about climate change. It was thought that for various reasons like identifying if equality and access to information and interest among members of both genders, their opinion on whether climate change had actually occurred was sought. Table 7 gives the results.

Table 7: Opinion on climate change by gender

Gender	In your opinion is there climate change? (%) Yes	No	Unaware	Total
Male	84	4	12	100
Female	85	3	12	100
Total	85	3	12	100

85% of all the respondents who had heard about climate change were of the opinion that there was climate change. Nearly equal proportions (84% and 85%) of both males and females felt there was climate change (table 7).

Chi-square test for association between Gender and Opinion on climate change

Pearson chi-square value is 9.21 with 2 d. f.

Probability level (under null hypothesis: Opinion on climate change depends on gender).

P-value = 0.238. This is not significant. Opinion on climate change is associated with gender.

4.1.5: Elements of weather affected by climate change

An open-ended question on which elements of weather would be associated with climate change was also asked to the respondents. Respondents were allowed to mention more than one of the elements.

Table 8: Elements of weather influenced by climate change

Response	Counts	(%)
Rainfall	364	90
Temperature	113	28
Sunshine	24	6
Disease	12	3
Wind	4	1
Humidity	4	1

The results in table 8 informed the choice to focus mainly on long term daily rainfall data in this study. However, it was surprising that relatively few respondents mentioned temperature.

4.1.6: Opinion on climate change by education

It is expected that educational attainment should influence awareness on an issue like climate change. We therefore asked for the opinion on climate change among the various levels of education. As shown in Table 9, 77% of the respondents with some education (college, secondary and primary) felt that there is climate change; on the other hand, a lower proportion (59%) of those who had no formal education were of the opinion that there is climate change.

Table 9: Opinion on climate change by level of education

In your opinion is there climate change? (%)	College	Secondary	Primary	Did not go to school	(%)
Yes	80	79	79	59	77
No	3	2	6	6	4

Unaware	17	19	15	35	19
Total	100	100	100	100	100

Access to schooling or lack of it is a reality experienced in all areas within Africa. It is therefore of interest to determine the opinion of both those who had some education or not on climate change.

We test the hypothesis that the opinion on climate change and level of education are independent.

Chi-square test for association between Level of education and Opinion on climate change.

H_0: Opinion on climate change depends on of level of education

H_1: Opinion on climate change does not depend on of level of education

Likelihood chi-square value is 2.77 with 4 d. f. P- Value = 0.597. This is not significant. Opinion on climate change is independent of level of education.

4.1.7: Opinion on climate change by level of education among those who felt climate change affects rainfall

From table 8, 90% of respondents did say climate change influences rainfall. It was interesting to know how educational attainment and opinion on climate change compare within this category of respondents.

Table 10: Opinion on climate change by level of education among those who felt there is climate change

In your opinion is there climate Change?	Level of Education (%)				
	College	Secondary	Primary	Did not go to school	Total
Yes	86	94	88	84	89
No	4	0	6	4	3
Unaware	10	6	6	12	8
Total	100	100	100	100	100

86% of College, 94% of secondary, 88% Primary school graduates and 84% of those who did not go to school among those who felt climate change affects rainfall confirm that climate change had actually occurred (table 10).

It may be inferred that irrespective of the respondents' educational level, perception of climate change is biased when it is related to rainfall. This bias might be due to the farmers, tendency to link bad yields to inadequate or exceedingly high rainfall (as in 2.1.2).

Chi-square test for association between level of education and Opinion on climate change among those who felt there is climate change.

H_0: Opinion on climate change among those who felt there is climate change depends on the level of education.

Pearson chi-square value is 8.00 with 4 d.f and P-value = 0.092. Opinion on climate change and level of education are independent.

4.1.8: Opinion on climate change by amount of rain per rainy day

Rainfall amounts and opinion climate change are closely related from respondents' opinion as seen from table 8. Of interest is how observation on amount of rainfall per rainy day and opinion on climate change relate. The results were: The amounts had been lower, higher and normal while others were unaware how the situation had been.

Table 11: Opinion on climate change by amount of rain per rainy day

	In your opinion is there climate change?			
Amount of rainfall per rainy day	(%) Yes	No	Unaware	Total
Lower	69	81	86	79
Higher	10	11	3	11
Normal	17	8	11	8
Unaware	4	0	0	2
Total	100	100	100	100

79% (319 out 405) of the respondents had experienced lower rainfall per rainy day in the year preceding the survey (table 11). 69% of farmers who said there is climate change had experienced lower rainfall the previous year.

Hypothesis that the amount of rain per rainy day is independent of the opinion on climate change were then tested.

Chi-square test for association between Amount of rain per rainy day and Opinion on climate change.

H_0: Opinion on climate change depends on the amount of rain per rainy day in the previous two years.

Pearson chi-square value is 18.00 with 4 d. f. P- Value = 0.001and is very significant. Therefore, opinion on climate change depends on the amount of rain per rainy day in the previous two years.

4.1.9: Opinion on climate change and yields in 3 years preceding the survey

72% of all the respondents had experienced lower yields in 3 years preceding the survey. 73% felt there of the opinion that there were climate changes had lower yields. Most of the farmers had lower yields. 85% of those who felt there was no climate change also had lower yields (table 12).

Table 12: Opinion on climate change and yields in 3 preceding survey

How have your yields been in the last 3 years?	In your opinion is there climate change? (%)			
	Yes	No	Unaware	Total
Lower	73	85	66	72
Normal	13	0	9	13
Higher	11	8	22	12
Unaware	3	7	3	3
Total	100	100	100	100

Chi-square test for association between Opinion on climate change and Yield for the 3 years preceding the survey.

Likelihood chi-square value is 6.06 with 2 d.f, (under null hypothesis) p-value = 0.048. This is not significant. Opinion on climate change and yield for the 3 years preceding the survey are independent.

4.2: Measures taken to respond to climate change

Realisation of existence of climate change can be manifested by any effort or measure aimed at responding to live with the same. We therefore have interest in knowing how climate change had influenced their farming methods and what they would do about it. Tables 20 and 21have the results.

Around 76% (307 out of 405) of farmers said that climate change has influenced their farming methods (table 13). 79% of the farmers who said they had diversified their farming in response.

Table 13: How climate change had influenced farming methods

How has climate change Influenced your farming method?	(%)
Diversified farming	79
Lower acreage under crops	14
Unaware	7
Total	100

91% of those whose farming methods had been influenced by climate change were prepared to take adaptation measures (planting trees, irrigation of their land and change in crops cultivated) in the next 3 years (table 14).

Table 14: What they were prepared to do due to climate change

What are you prepared to do?	(%)
Plant trees	78
Irrigate the land	12
Change crop type	1
Unaware	9
Total	100

78% of the farmers whose farming methods had been influenced by climate change were prepared to plant trees in the next three years as a response measure. 12% would irrigate their land and only 1% would change their crop type (table 14).

CHAPTER 5: STATISTICAL INVESTIGATION OF CLIMATE CHANGE

5.1: Introduction

Statistical analysis of daily rainfall data from the same site as the survey data has been done in this chapter to investigate evidence of climate change. The data was initially explored using descriptive statistics, investigation of trends have been done by use of regression analysis, analysis of climatic events including the start of rains, Markov chain modelling as well as t-test for equality of means and analysis of variance (Anova) have been used as a confirmatory tests.

5.2: Descriptive statistics

5.2.1: Trellis plots on monthly rainfalls

This section began with the investigation of variation of rainfall over seasons (months). This was done by studying patterns during months. Daily rainfall totals and number of rainy days (counts) for each month are explored using trellis plots.

The daily rainfall data was stacked using InStat to produce two columns of data for rainfall amounts and dates respectively. The stacked data is then exported to GenStat which was then used to calculate monthly and yearly totals and counts. These were used to do time series analysis by producing Trellis plots for years with months as groups. Trellis plots that included fitted value were incorporated to display any trends. The monthly total were then tested for trends using general linear regression while generalised linear model were used in exploring trends in the rainfall counts.

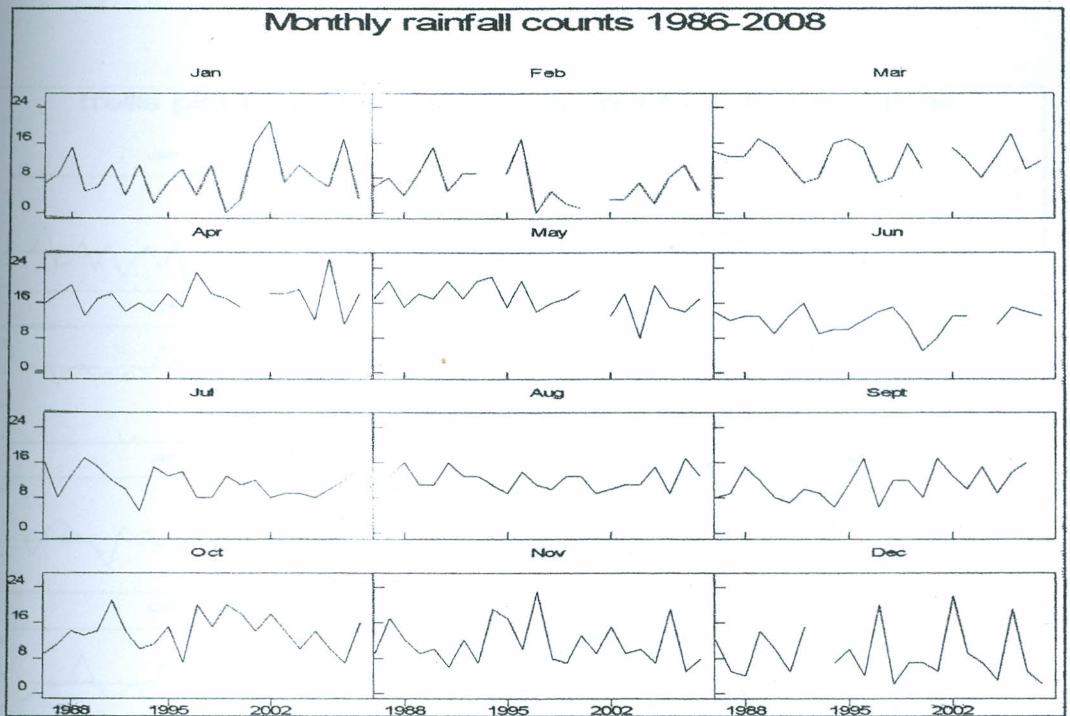

Figure 4: Monthly rainfall counts 1986-2008

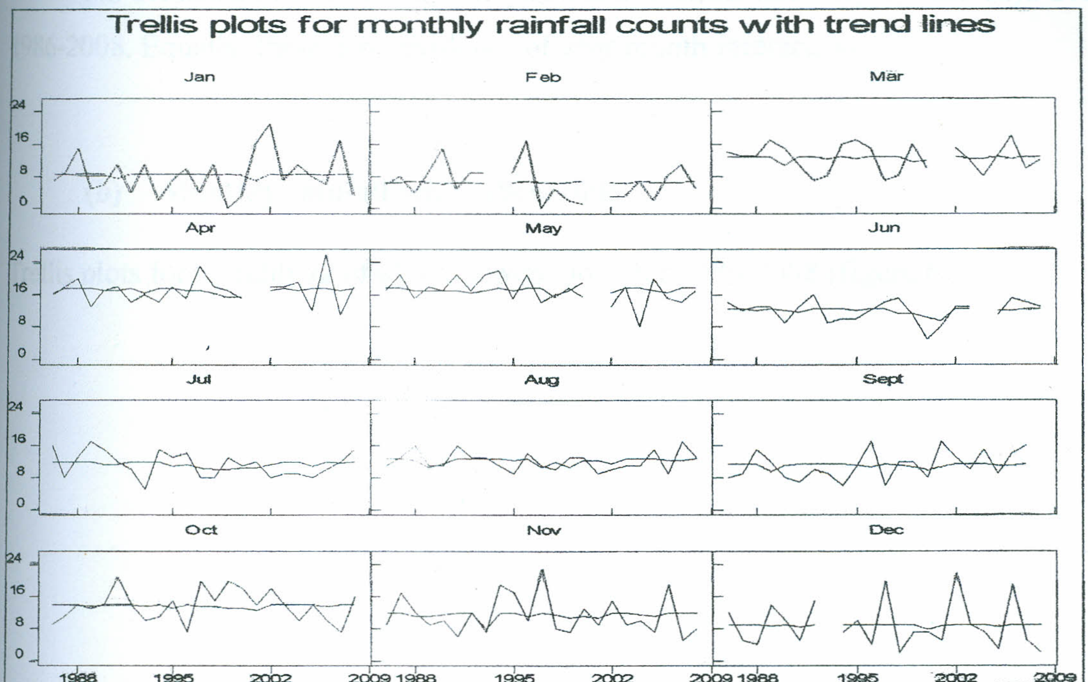

Figure 5: Monthly rainfall counts with trend lines

(a) Monthly Rainfall counts

Time series analysis of monthly rainfall counts was undertaken by plotting them against year to investigate any trends. Figure 4 shows trellis plots for the counts. There was variability in the rainfall counts. Using generalized linear models and treating the counts as binomial distribution (rain or no rain) and including trend lines (figure 5) no trends were observed.

(i) Generalized linear models total rainy day counts

Regression analysis of trend was then conducted using generalized linear trends for trends.

Accumulated analysis of deviance

Change	d.f.	deviance	Mean deviance	deviance ratio	approx F pr.
Year	1	1.525	1.525	0.61	0.437
Month	11	327.824	29.802	11.83	<.001
Year .Month	11	19.036	1.731	0.69	0.750

Residual	244	614.427	2.518
Total	267	962.811	3.606

No evidence of trends since the years and months had varying rain days over the period 1986-2008. Equally, there is no evidence of year-month interaction.

(b) Monthly rainfall totals 1986-2008

Trellis plots for monthly rainfall totals were done for 1986-2008 (figure 6).

(a) Monthly rainfall totals 1986-2008

Trellis plots for monthly rainfall totals were done for 1986-2008 (figure 6).

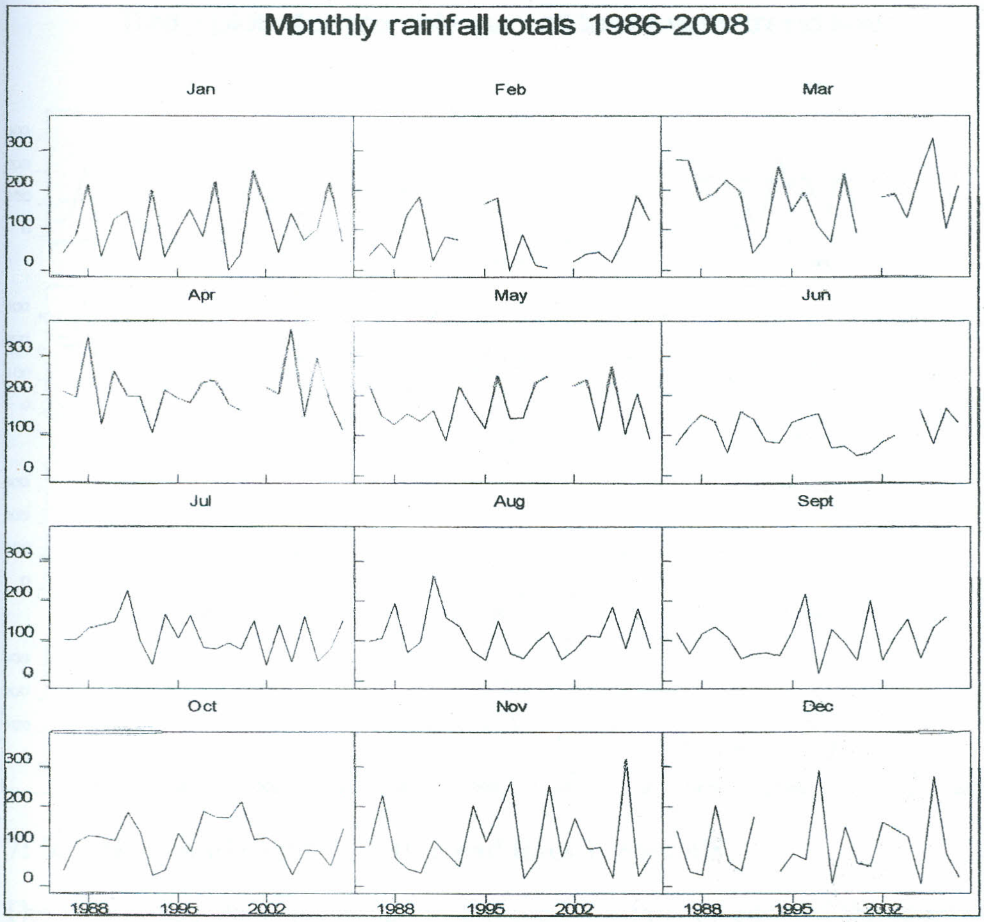

Figure 6: Monthly rainfall totals 1986-2008

(i) The plots display variability over the period.

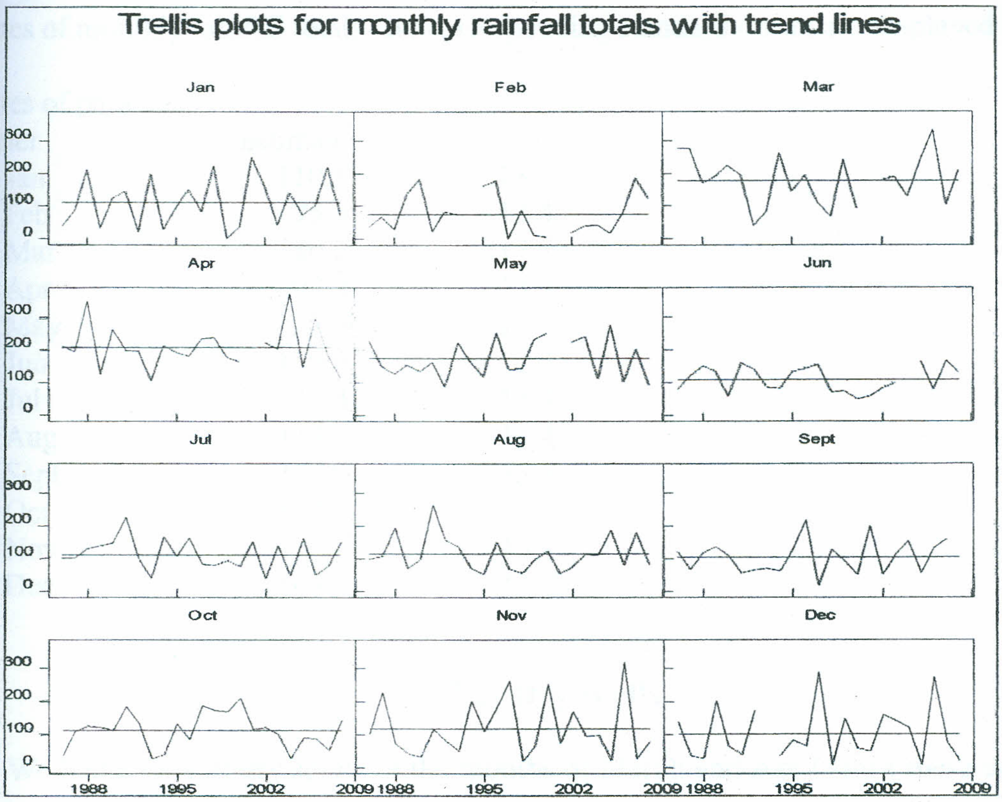

Figure 7: Monthly rainfall totals with trend lines 1986-2008

The trend lines show no trends in the total rainfall for each of the months during 1986-2008(figure 7).

(i) Trend analysis on monthly rainfall totals 1986-2008

Regression analysis of trend on the monthly rainfall totals was conducted.

Analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
Year	1	1	1	0.00	0.988
Month	11	362302	32937	7.66	<.001
Year Month	11	8926	811	0.19	0.998
Residual	244	1048715	4298		
Total	267	1419943	5318		

Year effect are not significant (p-value = 0.988). There is also no interaction between months and years. This shows there is no trend in the monthly rainfall totals during 1986-2008.

Estimates of monthly rainfall totals and corresponding standard errors are displayed below.

Estimates of parameters

Parameter	estimate	s .e.
Month Jan	110.5	13.4
Month Feb	75.5	13.4
Month Mar	180.2	13.7
Month Apr	207.8	13.7
Month May	173.7	13.7
Month Jun	109.4	13.7
Month Jul	112.4	13.4
Month Aug	114.6	13.4
Month Sept	105.0	13.7
Month Oct	113.0	13.4
Month Nov	117.9	13.4
Month Dec	101.5	13.7

5.2.2: Dry spells

We had a look at dry spells in the months of March and April since these are the months that residents of this are grow maize, their staple food. This led to estimating the risk of a long dry spell in the 30 days after sowing if day 0 was the sowing date that had rain (figure 6).

Number of dry spells March-April 1986-2008

The month of March had dry spells of more than 7 days in 11 years, and April in 9 years (see Appendix 5). This clearly shows that any choice of a potential successful date must put the possibility of a dry spell after plant into consideration.

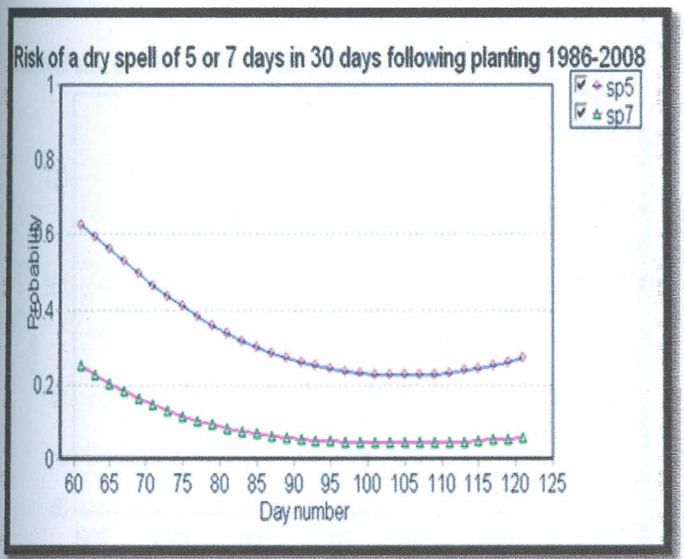

Figure 8: The risk of spells of 5 or 7 days in March 1986-2008

We considered a dry spell of 5 or 7 days as the longest that could be allowed for maize after sowing. Our choice of maize was informed by the fact that it is the main seasonal crop grown during the March –April season (figure 8).

To determine successfully planting time it is necessary to take into account the chance of having dry spells of 5 or 7 days on the planting days. The chance of a dry spell decreased from the 1st of March towards April, and is lowest during April; however, it seems to increase towards the end of April for the 5 dry spell while that for 7 day dry spell seems constant.

5.2.3: Rainy season: Start, length and end

The results for the start of rains as given in 3.3.1 are shown in figure 7. The two graphs below show the start of the rains in the months of March and April between 1986 and 2008. Figures 9 and 10 show the start of rains when dry spells of not more than 7 days are considered (as defined in 3.3.1).

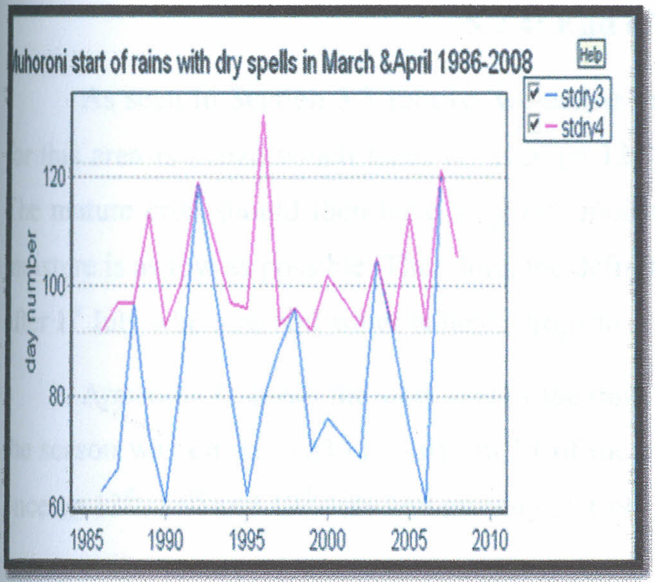

Figure 9: Start of rains in March and April 1986-2008

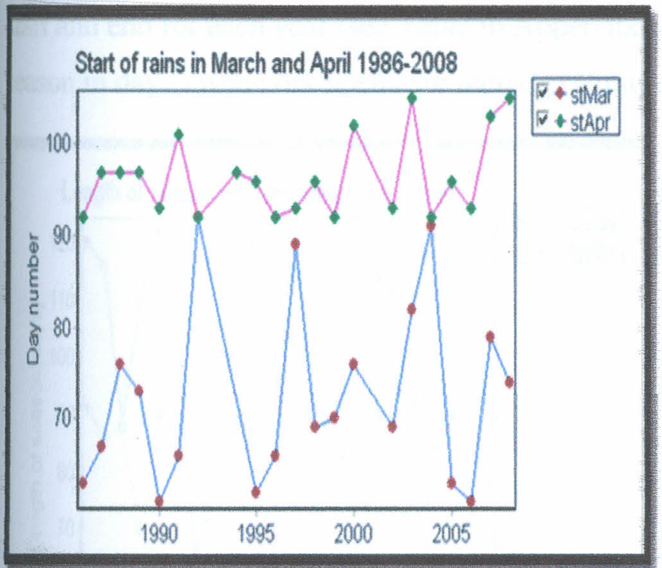

Figure 10: Start of rains by year 1986-2008

From both graphs, we observe that the start of rains show a lot of variability through the years but we cannot identify a trend that may suggest evidence of climate change.

5.2.4: End of season

As seen in Section 3.3.1above, we define the end of the season. The main seasonal crop for this area is maize which takes on average 120 days to mature and be ready for harvesting. The mature crop should then have very low moisture content. This is facilitated when the soil moisture is as low as possible. Therefore, the definition adopted in this study is: the first occasion after 1st July when the soil water balance drops to zero.

Appendix 6 shows the start end of the rainy season for the period 1986-2008. The end of the season was on day 183 (1st July) in 14 of the years, on day 185 (3rd July) in 3 of the years once on 13th, 15th and 19th July and missing in 1993, 1994 and in 2001.

5.2.5: Length of the season

We wish to calculate the length of the season. The definition of the start of the rains and end of the season given in part 3.3.1is used. The length of the season then is the time between the start and end for each year (see Table in Appendix 6). The figure below displays the length of the season in days, when dry spells are included (Figure 9).

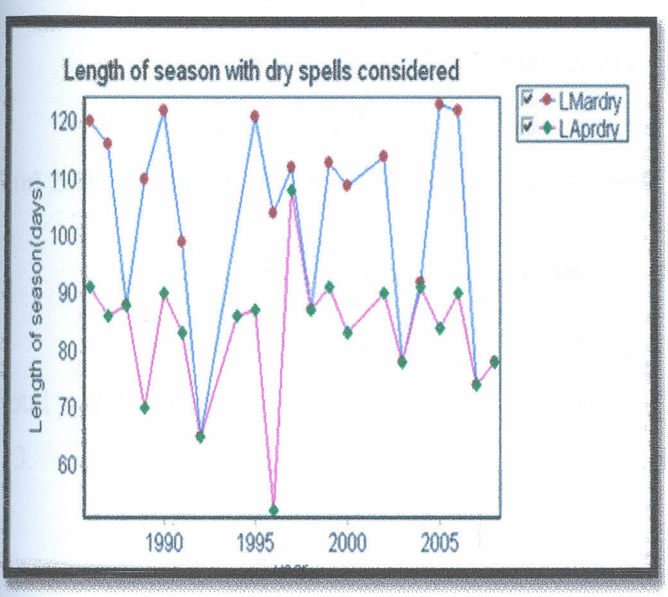

Figure 11: Length of season 1986-2008

The length of the season in the Figure shows a lot of variability and no trend.

5.2.6: Rainfall Extremes

We often need to know the risk of extreme events like heavy rainfall as they characterize climate change. To find the maximum values each year, we use InStat dialogue, **Climatic > Events > Extremes**. Figure 12 gives the maximum amount of rainfall each year and the number of the day in the year when it occurred as well.

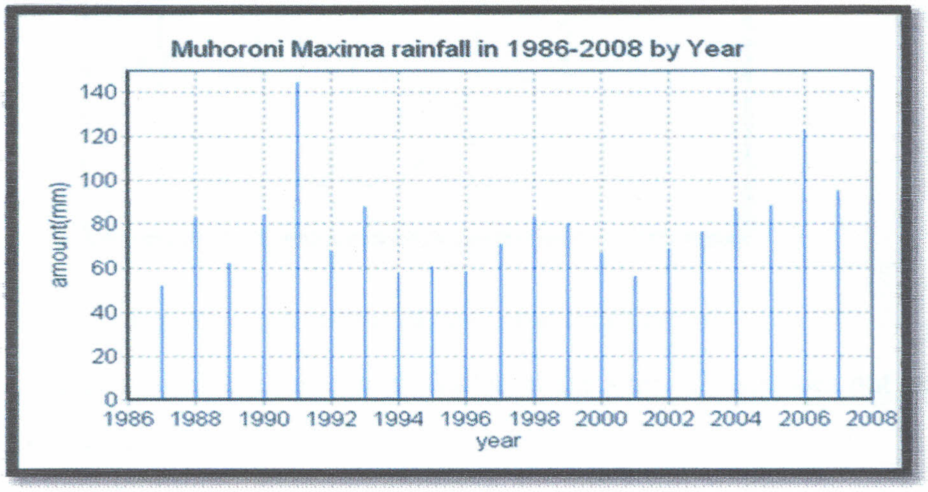

Figure 12: Maximum rainfall 1986-2008

We observe the maximum rainfall of more than 100mm in only two of the years (1991 and 2006). No trend is observed to suggest evidence of climate change.

5.2.7: Amount of rainfall at the start of the rains

The start of the season is defined as in section 3.3.1. In this case, both the date and actual total that triggered the start are of interest. The results are displayed in Appendix 4 and in figure 13.

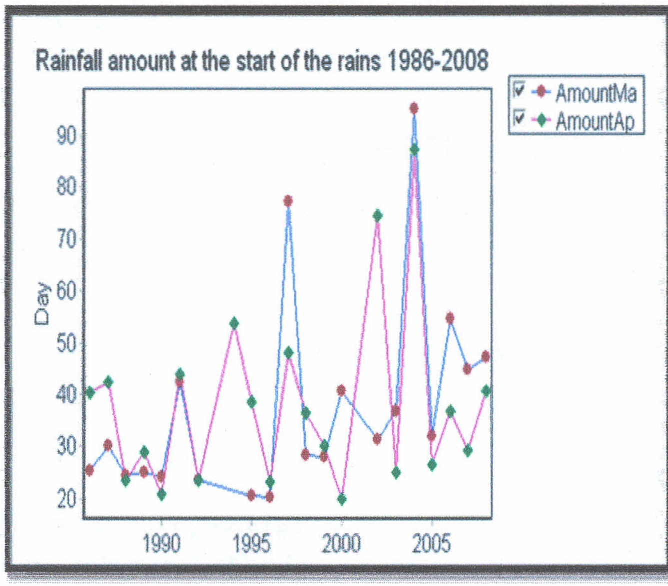

Figure 13: Amount of rain at start of rains

In both March and April, the amount of rainfall at the start of rains does not display any pattern of either a decrease or increase.

5.2.8:Statistical test on mean of the amount of rainfall

One sample t-test of the data is done for mean being equal to zero, two sample test for equality of variance of the data during 1986-1997 and 1998-2008 and equality of mean for 1986-1997 and 1998-2008.

(a) One-sample t-test

Variate: Amount of rainfall in 1986-2008

Summary

Sample	Size	Standard Mean	Variance	Standard deviation	s. e of mean
Amount of rainfall	7918	3.167	10077	100.4	1.128

95% confidence interval for mean: (3.167 – 1.96*1.128, 3.167 + 1.96*1.128) = (0.9561, 5.3779) (b **Test of null hypothesis that mean of rainfall during 1986-2008 is equal to 0**

Test statistic t = 2.81 on 7917 d.f.

P-value = 0.005

This is very significant. The null hypothesis is rejected. The conclusion is that the mean of rainfall during 1986-2008 is not equal to zero.

5.1.9: Two-sample t-test

Variate: Rainfall 1986-1997, Rainfall 1998-2008.

(i) Test for equality of sample variances

Test statistic F = 241.74 on 3694 and 4222 d.f.

(ii) P-Value (under null hypothesis of equal variances) < 0.001

This is very significant. The null hypothesis is therefore rejected and conclusion of the sample variances not being equal made. This suggests high variability of the data in the two samples.

Summary

Sample	Size	Mean	Variance	Standard deviation	s. e of mean
Rainfall1986-1997	4223	4.339	89	9.43	0.145
Rainfall1998-2008	3695	1.827	21491	146.60	2.412

Difference of means: 2.512

Standard error of difference: 2.416

95% confidence interval for difference in means:
(2.512- 2.416*1.96, 2.512 +2.416*1.96) = (-2.223, 7.247)

(ii) Test of null hypothesis: Mean of Rainfall in 1986-1997 = Mean of Rainfall in 1998-2008

Test statistic t = 1.04 on approximately 3720.75 d.f. P- Value = 0.299

This shows there is no evidence to reject the null hypothesis. It can then be concluded that the mean rainfall during 1986-1997 was not significantly different from that during 1998-2008.

5.2.10: Statistical test for the mean rainfall during the months of March and April in 1986-1997 and 1998-2008

Variate: Mean rainfall in March 1986-1997, Mean rainfall in March 1998-2008.

(i) Test of null hypothesis that Mean of rainfall in March 1986-1997 =Mean of rainfall in March 1998-2008

Test statistic t = 1.00 on approximately 11.00 d.f.

P-value = 0.339. There is no significant difference in the mean of rainfall during 1986-1997 and 1998-2008.

(ii) Two-sample t-test

Variate: Mean rainfall in April 1986-1997, Mean rainfall in April 1998-2008,

Test for equality of sample variances

Test statistic F = 1.55 on 9 and 11 d.f.

P-value = 0.49. This shows that there was no significant difference in the variance of mean rainfall during April 1986-1997 and April 1998-2008.

95% confidence interval for difference in means: (-2.431, 1.688)

(iii) Test of null hypothesis: The mean of rainfall in April 1986-1997 = mean of rainfall in April 1998-2008

Test statistic t = -0.38 on 20 d.f.

P-value = 0.711. There was no significant difference in the mean rainfall during April 1986-1997 and April 1998-2008.

5.3: The distribution of the start of rains

Attention was then turned to the analysis of distribution of the start of the rains over the period 1986-2008, in order to investigate if there has been a shift in the start of the rains and therefore the planting time over the years, as this could signal climate change. The initial comparison started with the box plots.

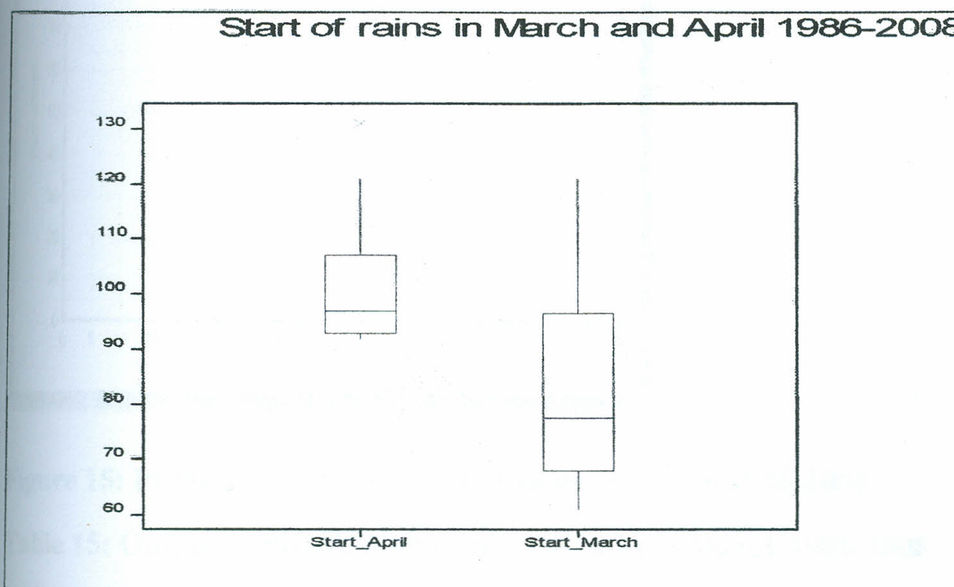

Figure 14: Box plot for start of rains in March and April

Figure 14 shows that the start of rains is more variable and is distributed over a higher number of days in March than in April. The data is also looks skewed in both months.

Next is the distribution of the start of rains for each month using probability plots over the period 1986- 2008.

5.3.1: Distribution of start of rains

(i) 1986-2008.

Figure 12 shows the probability plot for the start of the rains in March, over the period 1986-2008. Table 15 shows the output displaying mean, standard deviation, 25th, 50th and 75th percentiles.

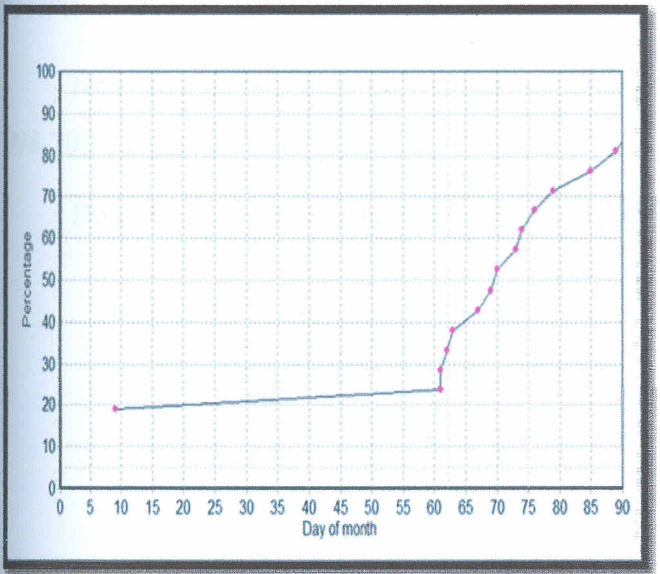

Figure 15: Probability plot for start of rains in March 1986-2008

Table 15: Output of distribution of start of rains in March 1986-2008

1986-2008	March
No. of observations	23
No. not missing	20
Minimum	9
Maximum	121
Range	112
Mean	78.8
Std. deviation	24.929
25th percentile	64
50th percentile	75
75th percentile	95.5

On average (median), sowing would occur by day 75 (15th March) in the period 1986-2008. One year in four, they would sow by day 64 (4th March), three years in four they would sow by day 95 (4thApril). The mean sowing date for this month during the period was by day78 (18th March) with a standard deviation of 24 days (table 15).

(ii) 1986-1997 and 1998-2008

Next are the box plots of the start of rains during the month of March in 1986-1997 and 1998-2008(figure 15).

Box plot of start of rains 1986-1997 and 1998-2008

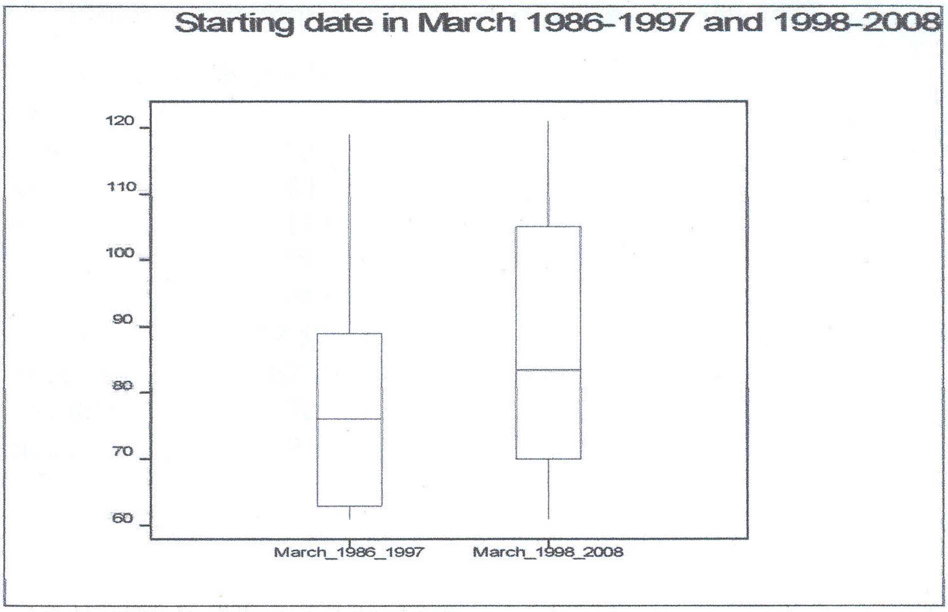

Figure 16: Start of rains in March 1986-1997 and 1998-2008

Starting date during 1998-2008 was more variable and skewed than during 1986-1997.

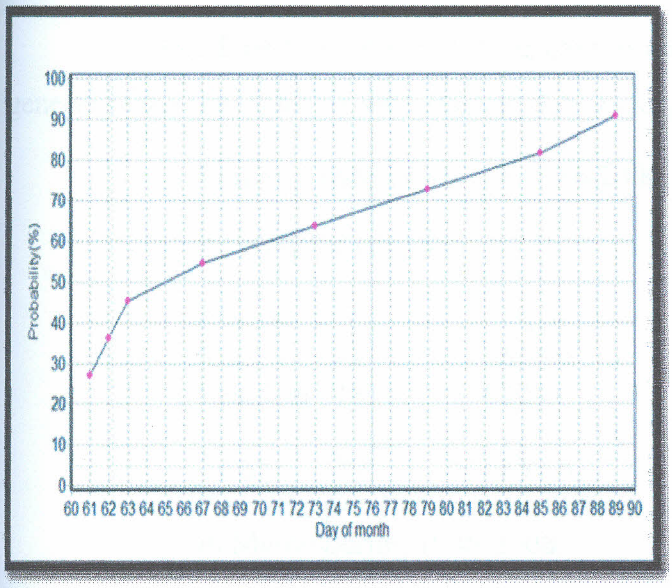

Figure 17: Probability of start of rains during March 1986-1997

Table 16: Output of distribution of start of rain March 1986-1997

stmar1(1986-1997)	
No. of observations	12
No. not missing	10
Minimum	61
Maximum	119
Range	58
Mean	79.5
Std. deviation	18.579
25th percentile	62.75
50th percentile	76
75th percentile	91

On average (median), the farmers sow around day 76 (16th March).One year in 4 they would sow by day 62 (2nd March) and 3 in four years sow by day 91 (31st March) (table 17).

(iii) Analysis of starting dates of rain in March 1986-2008 for trend

The trend analysis of the starting date of rains for the months of March were done using general regression analysis with starting date as response variate and year as explanatory variate.

Starting date in March 1986-2008

Analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
Year	1	622.9	622.9	1.80	0.196
Residual	18	6229.6	346.1		
Total	19	6852.6	360.7		

From the p-value = 0.196, there is no evidence of trend in the starting date of rains in March during 1986-2008.

(iv) Distribution of starting date of rains during March 1986-1997 were analyzed by t-test

(a) One-sample t-test

Variate: starting date of rains March in 1986-1997

Summary

Sample	Size	Standard Mean	Variance	Standard deviation	s .e of mean
Start March	10	79.50	345.2	18.58	5.875

95% confidence interval for mean: (66.21, 92.79) = (79.5 – 2.262*5.875, 79.5 + 2.262*5.875)

(b) Two-sample t-test (paired)

Calculated using one-sample t-test with the null hypothesis that the mean starting date of rainfall in March 1986-1997 = mean starting date of rainfall in March 1998-2008.

The distribution of start of rains for March 1998-2008

Table 17: Output for distribution of start of rains in March 1998-2008

No. of observations	11
No. not missing	10
Minimum	9
Maximum	121
Range	112
Mean	78
Std. deviation	31
25th percentile	67
50th percentile	75
75th percentile	105

On average (median), those who said rains start in March during 1998-2008 would plant around day 75 (15th March),one year in every four they would plant by day 67 (7th March),3years in every 4 by day 105(14th April) (table18).

(a) One-sample t-test

Variate: starting date of rains in March 1998-2008.

Summary

Sample	Size	Standard Mean	Variance	Standard deviation	s .e of mean
Starting date	10	86.80	386.6	19.66	6.218

95% confidence interval for mean: (72.73, 100.9) = (86.8 – 2.262*6.218, 86.8 +2.262*6.218)

(b) Test of null hypothesis that mean of starting date of rains in March during 1998-2008 = 0

Test statistic t = 13.96 on 9 d. f. $t_{9,0.05} = 2.262$

P-value<0.001.This shows the mean starting date is significantly different from zero.

(c) one-sample t-test

Variate
Summary

Sample	Size	Standard Mean	Variance	Standard deviation	s. e of mean
Mar1986-97-Mar1998-08	8	-12.50	813.4	28.52	10.08

95% confidence interval for mean: (-36.34, 11.34) = (-12.50 – 10.08*2.365, -12.5 + 10.08*2.365)

Test of null hypothesis that mean of Starting date of rainfall in March during 1986-1997 = mean of Starting date of rainfall in 1998-2008.

Test statistic t = -1.24 on 7 d.f.

P-value = 0.255. There is no evidence for rejecting the null hypothesis. The conclusion is that the mean starting date of rainfall during the periods 1986-1997 and 1998-2008 do not differ significantly.

5.3.2: Distribution of starting date of rains during April

(i) 1986-2008

Figure 18 shows the probability plot for the start of rains for April, over the period 1986-2008. Table 18 shows the output also from InStat.

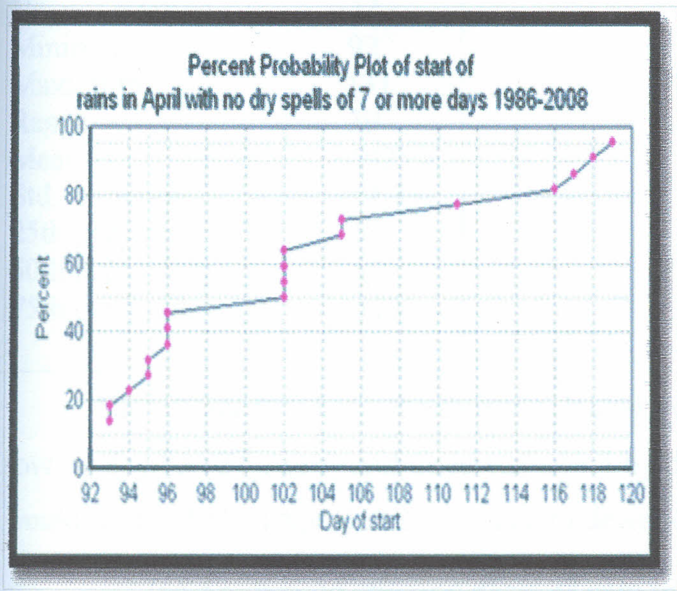

Figure 18: Probability of start of rains in April 1986-2008

Table 18: Output of distribution of start of rain in April 1986-2008

No. of observations	23
No. not missing	21
Minimum	92
Maximum	131
Range	39
Mean	101.95
Std. deviation	11.232
25th percentile	93
50th percentile	97
75th percentile	109

For those who would sow in April during 1986-2008, on average, (median), they would sow by day 101 (10th April). One year in 4they would sow by day 93 (2nd April), 3 in every 4years they would sow by day 109 (18th April). The mean sowing date was day 101(10th) April with a standard deviation of 11 days.

Table 19: Output of distribution of start of rains in April 1986-1997

No. of observations	12
No. not missing	11
Minimum	92
Maximum	131
Range	39
Mean	102.64
Std. deviation	12.73
25th percentile	93
50th percentile	97
75th percentile	113

On average (median), the farmers planted by day 97 (6th April).One year in 4 they would sow by day 93 (2nd April) and three years in 4 by day 113 (22nd April). The mean planting date would be day 102(11April) and the standard deviation 12 days.

(ii) Analysis of starting dates of rain in April during 1986-2008 for trend

Analysis of trend in the starting date of rains for the months of April are done using general regression analysis with starting date as response variate and year as explanatory variate.

Analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
Year	1	43.3	43.3	0.33	0.571
Residual	19	2479.7	130.5		
Total	20	2523.0	126.1		

With the p-value = 0.571, there is no evidence of trend in the starting date of rains during the April 1986-2008.

(iii) 1986-1997 were analyzed by t-test

(a) One-sample t-test

Variate: starting date of rains in April 1986-1997

Summary

Sample	Size	Standard Mean	Variance	Standard deviation	s .e of mean
Start in April	11	102.6	162.1	12.73	3.838

95% confidence interval for mean: (94.05, 111.15) = (102.6 – 2.228*3.838, 102.6+ 2.228*3.838)

(b) Test of null hypothesis that mean date of start of rains in April during 1986-1997 = 0

Test statistic t = 26.74 on 10 d. f. $t_{10,\,0.05}$ = 2.228. P- Value < 0.001. This is significant. The mean starting date of rains in April is significantly different from zero.

(iii) **Distribution start of rains in April 1998-2008**

Table 20: Output of distribution of start of rains in April 1998-2008

No. of observations	11
No. not missing	10
Minimum	92
Maximum	121
Range	29
Mean	101
Std. deviation	10
25th percentile	93
50th percentile	99
75th percentile	107

From table 20, in April during 1998-2008, on average (median), planting would be around day 99 (8^{th} April), one year in four, they would plant by day 93 (2^{nd} April), 3 years in 4 they would plant by day 107 (16^{th} April).

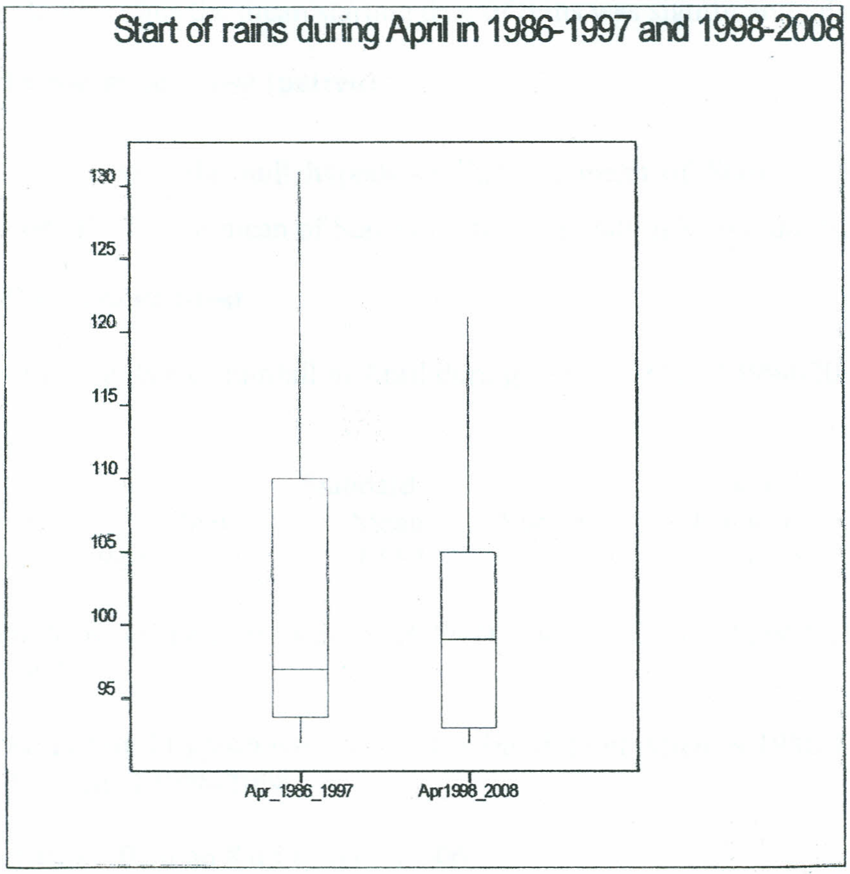

Figure 19: Start of rains in April 1986-1997 and 1998-2008

The start of rains during 1986-1997 was more variable and skewed than during 1998-2008.

(a) One-sample t-test

Variate: starting date of rain April (1998-2008)

Summary

Sample	Size	Standard Mean	Variance	Standard deviation	s. e of mean
Starting date in April	10	101.2	99.07	9.953	3.147

95% confidence interval for mean: (94.08, 108.3) = (101.2 – 2.262*3.147, 101.2 + 2.262*3.147)

(b) Test of null hypothesis that mean starting date of rains in April during1998-2008 = 0

Test statistic t = 32.15 on 9 d. f. $t_{9, 0.05} = 2.262$

P-value <0.001. Thus the mean starting date of rains was significantly different from zero.

(c) Two-sample T-test (paired)

With the null hypothesis that the mean of Starting date of rainfall in March during 1986-1997 = the mean of Starting date of rainfall in March during 1998 – 2008.

(d) One-sample t-test

Variate: Starting date of rainfall in April during 1986-1997 and 1998-2008.

Summary

Sample	Size	Standard Mean	Variance	Standard deviation	s. e of mean
Apr86-97-Apr 98-08	9	2.667	258.0	16.06	5.354

95% confidence interval for mean: (-9.680, 16.946) = (2.667 – 2.306*5.354, 2.667 + 5.354*2.667).

(e) Test of null hypothesis: Mean starting date of April in 1986-1997= Mean starting date April 1998-2008

Test statistic t = 0.50 on 8 d.f. $t_{8, 0.05} = 2.306$

P-value = 0.632. This is not significant. Therefore, the mean starting date of rainfall during the periods 1986-1997 and 1998-2008 do not differ significantly.

The risk of crop failure if planting was done in March 1986-2008

It is necessary to determine the risk of crop failure (therefore repeat planting). It is assumed that sowing failed if farmers planted without considering dry spells. Appendix 6 shows the planting dates in each month, when dry spells are not considered and when they are. In the case when sowing is done in March, the start date that considers dry spells (see column called "st dry Mar" in Appendix 6) gives the successful sowing date. Hence, the sowing failed each time the start date without considering the dry spells (called "st Mar") is different from the one that takes into account dry spells (table 21).

Table 21: Risk of crop failure in March 1986-2008

Values	Counts	%	Cumulative %
< 0	0	0	0
= 0	11	55	55
> 0	9	45	100
Total	20	100	

The risk of crop failure during March is (9/20) or 45%. This means that the farmers would have to plant again once every 1/0.45 = 2.2 years. This is the return period, i.e. the time interval between two crop failures.

Table 22: Risk of crop failure for planting was in April 1986-2008

Values	Count	%	Cumulative%
< 0	0	0	0
= 0	16	76	76
> 0	5	24	100
Total	21	100	

The risk of crop failure for those who planted in April was (5/21 = 24%), (table 29). This means that farmers would have to repeat planting once every 1/0.24 = 4.2 years. In conclusion, planting in March is at risk of experiencing crop failure 4.2/2.2 = 2 times more than in April.

We now look at the risk of crop failure during March and April, separately for the periods 1986-1997 and 1998-2008, in order to investigate whether there have been variations in the pattern of the start of rainfall during the two periods.

The analysis of the risk of crop failure if planting was done in each of the months was considered. The starting and ending dates of rains during the period 1986-1997 are displayed in appendix 6. The two corresponding dates of start of rain in the month of March were compared. Each occasion the two were different, there was a risk of crop failure. This is the risk that was measured. Table-23 has the results. This process was repeated for each period under consideration.

Table 23: Risk of crop failure in March 1986-1997

Values	Count	%	Cumulative frequency (%)
< 0	0	0	0
= 0	6	60	60
> 0	4	40	100
Total	10	100	

The risk of crop failure for those who said the rains start in March during the period 1986-1997 was 4/10 or 40%. They would have to replant once every (1/0.4 = 2.5): 2.5 years.

The risk of crop failure if planting were done in April 1986-1997

Table 24: Risk of crop failure if planting were in April 1986-1997

Values	Count	%	Cumulative%
< 0	1	9.1	9.1
= 0	7	63.6	72.7
> 0	3	27.3	100
Total	11	100	

The risk of crop failure for those who said the rains start in April during the period 1986-1997 was (3/11) or 27%. They would have to plant again once every (1/0.273) or 3.66 years.

Our analysis for the period 1986-1997 shows that those who planted in April were less likely to experience crop failure than those who planted in March.

We now turn to the analysis of the risk of crop failure if planting was done in each of the months, looking at the period 1998-2008.

The risk of crop failure if planting were done in March 1998-2008

Table 25: Risk of crop failure if planting were in March 1998-2008

Values	Counts	%	Cumulative%
< 0	0	0	0
= 0	5	50	50
> 0	5	50	100
Total	10	100	

The risk of crop failure for those who would plant in March during 1998-2008 was (5/10):50% (table 25), they would have to plant again once every (1/0.5): 2 years.

The risk of crop failure if planting were done in April 1998-2008

Table 26: Risk of crop failure if planting were in April 1998-2008

Values	Count	%	Cumulative%
< 0	0	0	0
= 0	8	80	80
> 0	2	20	100
Total	10	100	

The risk of crop failure for those who plant in April during 1998-2008 was (2/10): 20% (table 26).They would have to replant once every (1/0.2):5 years.

The analysis of the return periods shows that those who planted in April had double chances of success than those who planted in March during the same period.

Comparison of the risks of crop failure for (1986-1997), (1998-2008) and (1986-2008)

Table 27: Comparison of risks of crop failure and return periods 1986-1997, 1998-2008 and 1986-2008

	Risk of crop failure (%) in		Return period (years)	
Period	March	April	March	April
1986-1997	40	27	2.5	3.7
1998-2008	50	20	2.0	5
1986-2008	45	24	2.2	4.2

Table 27 shows that the risk (chance) of crop failure in March during 1986-1997 and 1998-2008 differ by only 10% while that for 1986-2008 is the average of the two. That for April 1986-2008 was 24%. The chance for1986-1997 and 1998-2008 differ by only 7%. March shows slightly higher recurrence of crop failures than April. Risk for April is lower than that of March in all the periods. During 1986-1997 crop failure would recur after 3.7 years while it would recur after 5 years during 1998-2008. Therefore, it seems that the chances of getting better crops increased during the second period. In general, the month of April was a better month to plant than March due to high return periods.

From small differences in the risk of crop failure and the return periods in months of March and April during 1986-1997 and 1998-2008, only variability in risk of crop failure is identified. Comparison of distribution of planting dates for those who planted in March for the periods;1986-2008, 1986-1997 and 1998-2008 is done next. This is carried using mean , median, standard deviation, interquartile range and range for the periods under study.

Table 28: Comparison of distribution of planting dates for March 1986-1997, 1998-2008 and 1986-2008

Period	Mean	Median	Lower quartile	Upper quartile	Standard deviation	Range
1986-2008	18th March	15th March	4th March	4th April	24days	112days
1986-1997	19th March	16th March	1st March	30th April	18days	58days
1998-2008	18th March	15th March	7th March	14thApril	31days	112days

Period	Inter-quartile range
1986-2008	31 days
1986-1997	29days
1998-2008	38days

In table 28, on average (media), in the periods 1986-2008, 1986-1997 and 1998-2008, the farmers would plant by 15th ,16th and 15th March respectively. This gives a variability of between one. The Planting dates were spread over (standard deviation) between 18, 24 and 31 days.

The mean, median, s.d (standard deviation) and range for the planting dates do not differ much in the two periods under analysis.

We then determine coefficient of variation, V of the starting dates for March during the same periods; 1986-2008, V= 24.929/78.8x100% = 32%, 1986-1997, V = 18.579/79.5x 100%= 23%, 1998-2008, V =31/78x100% = 40%. It is seen that coefficient of variation (CV) is not consistent, being evidence of higher variability. For April, V for 1986-2008, 1986-1997, 1998-2008 are; 11%, 12% and 10% respectively which are quite consistent.

Comparison of distribution of planting dates for those who planted in April for the periods; 1986-2008, 1986-1997 and 1998-2008.

Table 29: Comparison of distribution planting dates for April 1986-2008, 1986-1997 and 1998-2008

Period	Mean	Median	Lower quartile	Upper quartile	S.d.	Range
1986-2008	10th April	6th April	2ndApril	18th April	11days	39days
1986-1997	11thApril	6thApril	2nd April	22nd April	12days	39days
1998-2008	10thApril	8thApril	2nd April	16th April	10days	29days

Period	Inter quartile range
1986-2008	16
1986-1997	20
1998-2008	14

In table 29 on average (median), the planting date was by 8th and 11th April, giving a variation of between two and five days. Once in every four years they would plant by 2nd April. The planting dates were spread over 10 to 12 days (standard deviation). The duration between the earliest and latest planting dates (range) were: 29 to 39 days.

In conclusion, from tables and comparing mean, median, standard deviation as well as the range for the planting dates in March and April, we do not observe any shift in the planting dates.

5.4: Markov chain modelling

As described in section 3.4.5, we now apply the Markov chain modelling to the daily rainfall data over the period 1986-2008, to model: (i) chance of rain on any day and (ii) rainfall amounts (mean rain per rainy day). Markov chain analysis in this study is mainly by graphical representation and display of the models.

We first look at the entire period 1986-2008, and then break it into two periods (1986-1997 and 1998-2008) in order to compare the patterns of rainfalls for evidence of climate change. If there are significant changes in patterns observed, then this would be evidence of climate change. We use modelling of orders zero, one and two.

5.4.1: Chance of rain

(i) Chance of rain order zero

Order zero simply considers what happens on any day irrespective of the state of rainfall in the preceding day. The data for rainy and dry days are displayed in table in Appendix 9. The Appendix shows that during 1986-2008, 8 of the years had rain on day 1 while 15 of the years were dry; 5 of the years had rain on day 2, while 18 of the years were dry among others.

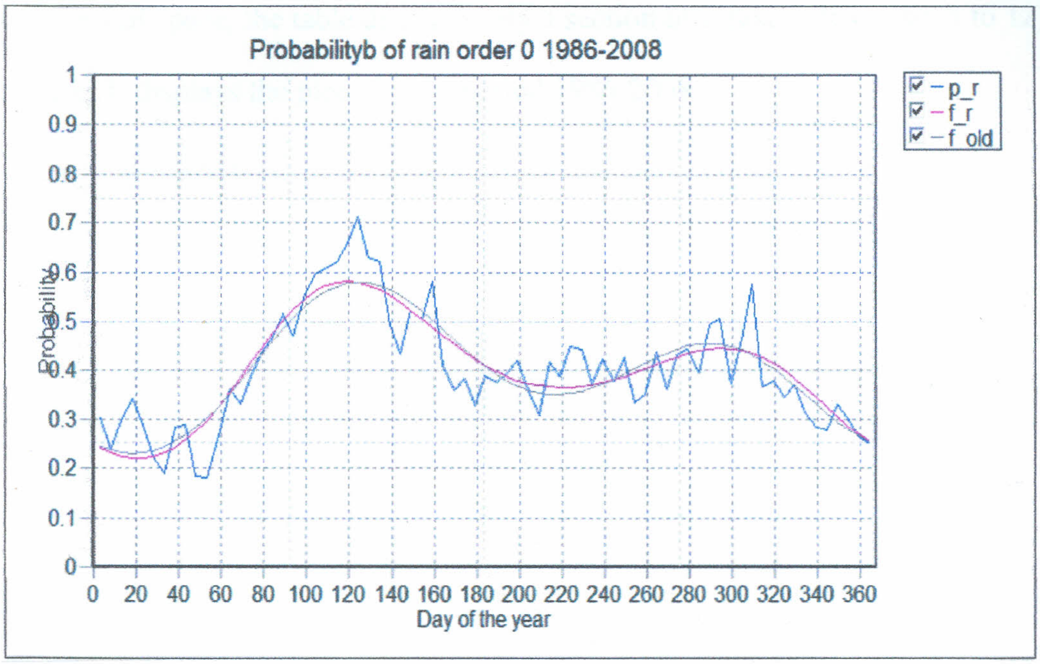

Figure 20: Probability of rain order 0 1986-2008

ANOVA for regression of log r on sine, cosine, sine^2 and cosine^2.

Source	d.f	SS	MS	F-Value	Prob.>F
Regression	4	13.75	3.44	47.05	0.000
Residual	68	4.97	0.73		
Total	72	18.71			

Model for chance of rain:

$\log_e l = -0.11\text{sine} + 0.38\ \text{cosine} - 0.36\text{sine}^2 - 0.31\text{cosine}^2 + 0.42$

Chance of rain order one

In the previous section, we discussed the zero- order Markov chain

(two categories of dry and rain only).

Markov chain of order one has one day memory. There are two possible outcomes rain given the previous day was rainy (r r) and rain given that the previous day was dry (r d). A time series plot for chance of rain during 1986-2008 is displayed. The table in appendix 10 shows in how many years each second day was dry or rainy given the conditions of the previous day; for obvious reasons of space, the table displays only a section of January (from day 1 to 12)[5].

Figure21 displays the plots for the period 1986-2008.

[5] Hence, the table shows that in 13 of the years the 2nd of January was dry, given that the 1st January was dry (see column called "d d"), in 5 of the years the 2nd of January was dry given that the 1st January had rain ("rd"), and so forth.

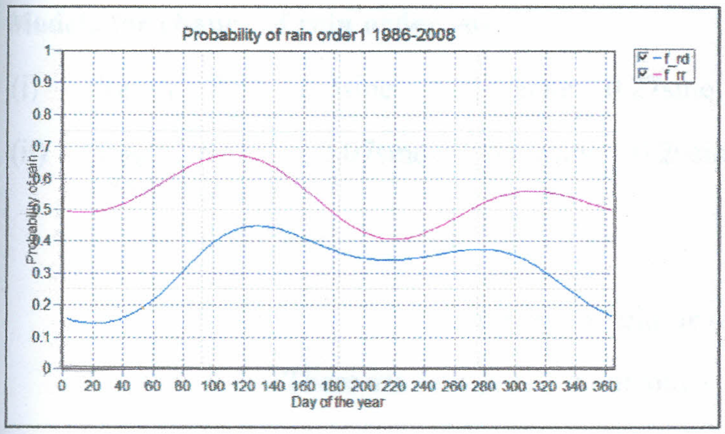

Figure 21; Probability of order one 1986-2008

Anova for regression of $\log_e$ r r on sine, cosine sine^2 and cosine^2

Source	d.f	SS	MS	F-Value	Prob.>F
Regression	4	356.96	89.24	19.51	0.000
Residual	68	311.1	4.58		
Total	72	668.06			

The current model for the probability of rain given rain has 4 terms (plus constant)

ANOVA for regression of log rd on sine, cosine, sine^2 and cosine^2.

Weights: rd

Source	d.f	SS	MS	F-Value	Prob.>F
Regression	4	1137.1	284.28	53.06	0.000
Residual	68	364.3	5.36		
Total	72	1501.41			

Models for chance of rain order one:

(i) $\log_e rr = 0.14 - 0.3sine - 0.04\ cosine - 0.27sine^2 - 0.2cosine^2$; (rain given rain).

(ii) $\log_e rd = -0.82 + 0.07sine + 0.54cosine - 0.29sine^2 - 0.28cosine^2 + 0.04sine^3$; (rain given dry).

Chances of rain order two:

There are four possible outcomes rrr, rdd, rdr and rrd.

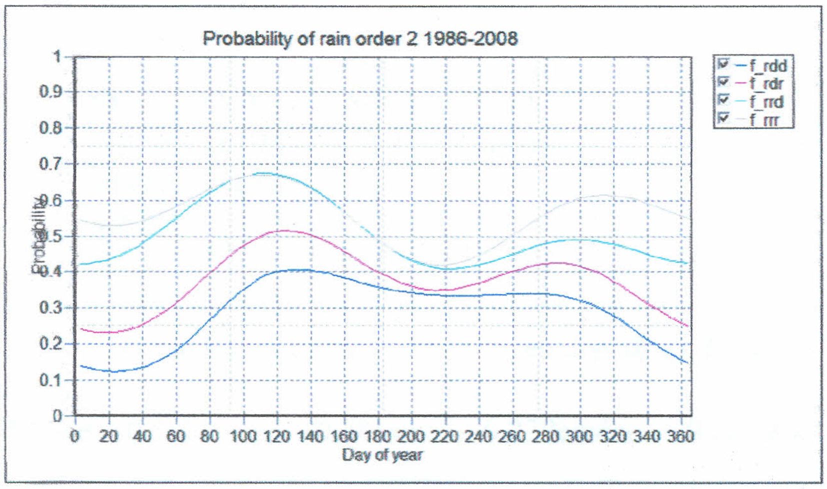

Figure 22: Probability of rain order 2 1986-2008

Models for chance of rain order 2

(i) Chance of rain given rain -rain

$$Log_e\, rrr = -0.216\, sine - 0.138 cosine - 0.279 sine^2 - 0.279 cosine^2 - 0.182 cosine^2 + 0.238$$

ANOVA for regression of log rrr on sine, cosine, $sine^2$ and $cosine^2$

Weights: _rr

Source	d.f	SS	MS	F-Value	Prob.>F
Regression	4	151.02	37.75	8.31	0.000
Residual	68	309.08	4.55		
Total	72	460.09			

(ii) Model for chance of rain given dry- dry(r d d)

$$Log_e\, rdd = 0.112 sine + 0.592 cosine - 0.281 sine^2 - 0.239 cosine^2 + 0.063 sine^3 - 0.953$$

(iii) Model for chance of rain given dry- rain (rdr)

$$Log_e\, rdr = -0.05 sine + 0.341\, cosine - 0.28 sine^2 - 0.256 cosine^2 - 0.524$$

(iv) Model for chance of rain given rain-dry

$$Log_e\, rrd = -0.366 sine + 0.112 cosine - 0.214 sine^2 - 0.226\, cosine^2 + 0.035$$

Analysis of the models for evidence of climate change requires more advanced tools which is beyond the scope of both InStat and GenStat employed in this study. Therefore, Markov chain models case could not be carried beyond the graphics.

5.4.2: Mean rain per rainy day

Rainfall amounts depend on seasonality. Rainfall amounts are modelled because changes in patterns or trends would signal climate change. We model rainfall amounts as the amount of rainfall days: the daily totals are summed over 5 day periods to provide reasonably higher values than for one day (in fact, some days have rainfalls below the threshold level of 0.85mm, and would therefore be considered as dry days).

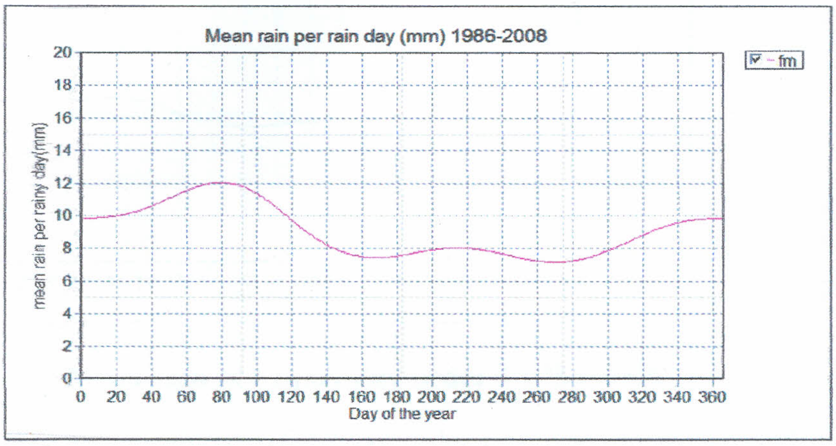

Figure 23: Mean rain per rainy day order 0 1986-2008

ANOVA for regression of $\log_e m$ on sine, cosine, $sine^2$ and $cosine^2$

Weights: rain

Source	d.f	SS	MS	F-Value	Prob.>F
Regression	4	73.94	18.48	11.2	0.000
Residual	361	595.91	1.65		
Total	365	669.85			

Addition of four terms to the original to fit the model is significant

Model for mean rain per rain day order zero:

$\log_e m = -0.171 sine - 0.13\, cosine + 0.037 sine^2 - 0.032\, cosine^2 + 2.188$

Mean rain per rainy day order one 1986-2008

Mean rain per rainy day order one 1986-2008

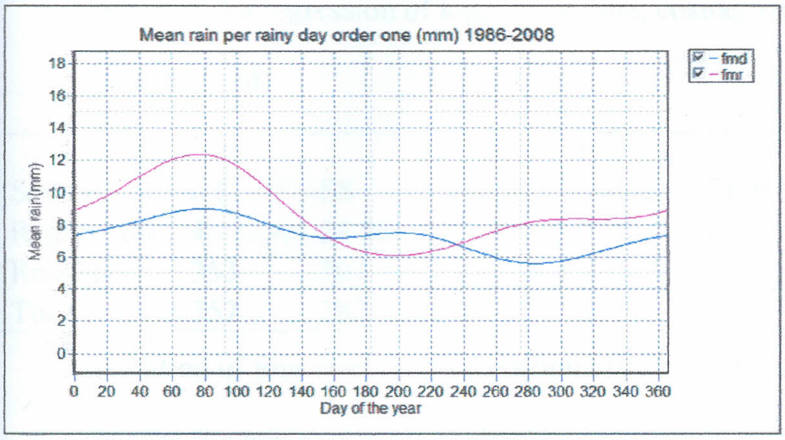

Figure 24: Mean rain per rainy day order 1 1986-2008

The mean rain per rainy day order one was highest around day 80 (20th March) during 1986-2008. The mean given rain was higher than that of mean given dry but the maximums occurred around the same time. The mean given rain depicted bimodal pattern than the mean given dry.

The model for mean rain per rainy day order one (mean rain given rain)

ANOVA for regression of $\log_e$ mr on sine, cosine, sine^2 and cosine^2

Weights: rr

Source	d.f	SS	MS	F-Value	Prob.>F
Regression	4	71.04	17.76	9.31	0.000
Residual	352	671.46	1.91		
Total	356	742.51			

Mean of rain given dry previously

ANOVA for regression of $\log_e$ md on sine, cosine, sine^2 and cosine^2.

Weights: rd

Source	d.f	SS	MS	F-Value	Prob.>F
Regression	4	24.56	6.14	3.08	0.02
Residual	353	703.5	2		
Total	357	287			

Addition of four terms to fit the original plot is not significant.

Model for mean rain given dry

$$\text{Log}_e\ \text{md} = -0.178\text{sine} + 0.001\text{cosine} + 0.60\text{sine}^2 + 0.021\text{cosine}^2 + 0.05\text{sine}^2 + 1.980$$

Like for chance of rain, analysis of the models for mean rain per rainy day is beyond the scope of the study underway due need to employ more advanced tools than InStat and GenStat. This part therefore could not be carried on beyond graphical representation.

CHAPTER 6: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS.

6.1: Introduction

This chapter brings together the results from the analysis of both perceptions and statistical analysis of realities on climate change carried out in chapters 4 and 5 and investigates if these match or not. The farmers in Chemelil and Muhoroni area have strong opinions regarding climate in the area and are quite explicit about perceived changes especially in rainfall patterns and events. The respondents were emphatic that there is climate change. In their understanding, climate change occurs in any season that their yields are poor as a result of inadequate or exceedingly high rainfall.

6.2:Summary

The survey covered adults (49% male and 51% female) of age groups: below 30 years (10%), 30-45 years (18%), 45-60 years (41%) and over 60 years (31%), (table 1).

6.2.1: Perception on climate change

(a) Opinion on climate change among gender

9 in 10 of all respondents acknowledged having heard of climate change. 85 % of both gender (84% males and 85% of females) were of the opinion that there was climate change (table 7). Chi-square test on association of gender and opinion on climate change showed the two are independent.

(b)Opinion on climate change and the various levels of education

77% of respondents irrespective of their level of education were of the opinion that there was climate change (table 9). 80% of college graduates, 79% of secondary school graduates and 59% of those with no formal education were of the opinion that there was climate change. Opinion on climate change and level education were shown to be independent by Chi-square test.

(c) Opinion on climate change among respondents who felt climate change had influence on rainfall.

9 in 10 of the respondents said climate change had influence on rainfall (table 8). 79% of respondents had received lower amounts of rainfall in the year preceding the survey. 69% of those who felt there was climate change had received lower amounts of rainfall in the same period (table 10). Opinion on climate change was shown to be dependent on the amount of rainfall received by Chi-square test (after table 11).

(d) Opinion on climate change and yields received in 3 years preceding the survey.

72% of respondents had experienced lower yields in 3 years preceding the survey. Out of these, 73% were of the opinion that there was climate change (table 12). Opinion on climate change and yields were found to be independent.

(e) Measures aimed at mitigating prevalence of climate change

79% of respondents had diversified their farming methods due to influence of climate change (table 13). To mitigate effects of climate change 91% of the farmers whose farming practices had been influenced by the same were prepared undertake measures which included planting of trees(78%) and farming under irrigation (12%), (table 14).

6.2.2: Statistical investigation of climate change

(a) Descriptive statistics

Time series plots of climatic events namely: start of rains in the months of March and April (figures 7 and 8), length of the season (figure 9), rainfall extremes (maximum rainfall; figure 10) and amount of rainfall at the start of rains (figure 11) all show variability during the period 1986-2008 but no trend.

(b) Analysis for trend

Trellis plots for monthly rainfall counts and totals for 1986-2008 showed variability (figures 4 and 5). The trend lines for the two do not display any trends (figures 6 and 7). Regression analysis of trend for both monthly counts and totals show the year effect was not significant. This shows there is no evidence of trend in monthly rainfall counts as well as totals during the years 1986-2008.

(c) Mean rainfall during 1986-1997 and 1998-2008

The mean rainfall during 1986-1997 and 1998-2008 were not significantly different (5.2.8).

(d) Mean rainfall for the months of March and April during 1986-1997 and 1998-2008

Equality of mean rainfall during 1986-1997 and 1998-2008 during the months of March and April were analyzed by t-tests.

The mean rainfall in March 1986-1997 and 1998-2008 were not significantly different (5.2.9).

The mean rainfall in April 1986-1997 and 1998-2008 were not significantly different (5.2.10).

(e) Analysis of the starting date of rains in the months of March and April

Analysis of starting date of rains in the months of March during 1986-2008 showed no evidence of trend, (5.3.1(iii)).

The mean starting date of rainfall date of rains in the months of March 1986-1997 and 1998-2008 do not differ significantly, (5.3.1 (v), (c)).

Analysis of starting date of rains in the months of April during 1986-2008 showed no evidence of trend, (5.3.2 (ii)).

Mean starting date of rains in April during 1986-1997 and 1998-2008 did not differ significantly, (5.3.2 (iii), (e)).

6.2.3: Distribution of the start of rains

Starting dates of rains were highly variable and skewed during both the months of March and April in the period 1986-2008(figure 14). The dates were even more variable when the data is broken into 1986-1997 and 1998-2008 (figure 16).

The mean starting date of rainfall in the month of March during the periods 1986-2008,1986-1997, 1998-2008 respectively were: Mean were; 18^{th} ,19^{th} and 18^{th}. Median were; 15^{th}, 16th and 15^{th}. The standard deviations were; 24, 18 and 24 days (table 28).

The mean starting date of rainfall in the month of April during the periods 1986-2008, 1986-1997 and 1998-2008 respectively were: Mean were; 10^{th}, 11^{th} and 10^{th}. Medians were; 6^{th}, 6^{th} and 8^{th}. The standard deviations were; 24, 18 and 24 days (table 29). Evidence from rainfall data shows variability but not any noticeable shift in the starting date of rains.

6.2.4: Markov Chain modelling

(i) Chance of rain

The chance of rain of orders zero, one and two were modeled and displayed in figures 0, 1 and 2. The corresponding models for each are shows alongside each graph.

Addition of four terms to the original of each is quite significant. However, the analysis of the models for evidence of climate change needs more advanced packages and therefore included as recommendation for further studies.

(ii)Mean rain per rainy day

Mean rain per rain day of orders 0 and 1 were modeled and displayed in figures 23 and 24. Corresponding models are displayed after each graph. The analysis could not be carried out beyond graphics due to more advanced tools required which are beyond the scope of both InStat and GenStat. These are therefore included as recommendations for further studies.

6.3: Conclusions

From analysis of survey data, the perception between the two gender; among the various levels of education; those who had received lower rains in the year preceding the survey; those who had realized lower yields in three years preceding the survey, was that there was climate change. Opinion on climate change was found to depend on the amount of rainfall received.

Climate change had even influenced their farming methods to the extent that they had considered planting trees and practicing irrigated farming to mitigate effects of climate change.

However, analysis of monthly rainfall counts and monthly rainfall totals over 1986-2008 did not reveal any trends. Analysis of the starting date of rains in the months of March and April during the period 1986-2008 did not reveal evidence of trend. The mean rainfall during the periods 1986-1997 and 1998-2008 were found not to be significantly different. The mean rainfall for the months of March and April during the periods 1986-1997 and 1998-2008 were found not to be significantly different.

Absence of evidence of trends in statistical analysis of monthly rainfall counts, totals and starting dates; significantly no difference in mean rainfall in the months of March and April during as well as significantly no difference in mean rainfall during the periods 1986-1997 and 1998-2008 are enough reasons to conclude that there is no statistical evidence of climate change in the data in this study.

It is evident from analysis of the survey and daily rainfall data that perceptions and evidence of reality on climate change in this study did not march.

6.4: Recommendations

It may be more useful to extend the analyses using climatic data from more than one station. Any further rainfall based studies should consider investigating the effect of Elnino and possibly Lanina years. Future studies of rainfall data should incorporate analysis of longer term data than was available for this study. Modelling and analysis of rainfall data by Markov chains as confirmatory test should be carried out in further study of evidence of climate change using more advanced statistical packages.

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