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**MIDLANDS STATE UNIVERSITY**

**APPROVAL FORM**

The undersigned people certify that, they read and recommend Midlands State University to accept a dissertation entitled, **“*An Exploratory Analysis of the Effects of Climate Change on Vegetation.*,” *The Case of Mutoko District in Mashonaland East Province, Zimbabwe*** by Mudowaya Pfungwa Malvern in partial fulfillment of Bachelor of Science Honours Degree in Geography and Environmental Studies.

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# Dedication

*To people whom l dearly adore the most, my late parents Pfungwa (Sir) and Mauline Mudowaya,*

*For their tireless support financially, psychologically, spiritually and encouragement in my life,*

*Unfortunately you were not able to witness the great vision you started, developed and empowered,*

*But l assure you that l will continue with the vision,*

*This is not the end but is just an inauguration,*

*I will forever miss, love and cherish you,*

*The zenith is awaiting for me……., as I am complete in Christ.*

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I profoundly acknowledge Jesus Christ for the creation of earth, environments and human beings. I give glory to him for carrying me this distant, for I believe it is through His grace that I accomplished this project, as “WE ARE COMPLETE IN HIM” (Colossians 2 vs. 10).

My deep appreciation goes to the Department of Geography and Environmental Studies for imparting me with infinite knowledge of the universe, from meteorology, climatology, hydrology, human and physical geography, g.i.s and remote sensing, relationships of humans to different environments that has made me a complete environmentalist.

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I express my appreciation to Forestry Commission Mashonaland East Province especially my Supervisor Mr. Magora (FEO for Mutoko District) for nurturing me during work related learning with vast knowledge in different aspects of forestry and environment which I utilized in this research. I also extend my gratitude to Mutoko Rural District Councilors, EMA and AGRITEX for their cooperation during the undertaking of this project.

My heartfelt gratitude also goes to my siblings particularly Roselyn, Constance, J.B, Owen and Tinashe for their support throughout my academic epoch and not forgetting my classmates and friends “Tekas’ Clan and Yard 11.”

# Abstract

A plethora of researches have been done worldwide to determine and illustrate the effects of climate change on ecosystems, biodiversity especially on vegetation, using the most imperative climatic variables, rainfall and temperature which are of vital importance to plant species growth henceforth, determine biomes, ecosystem and woodlands plant species composition, structure and distribution. This study focused on effects of the climate change on vegetation in Mutoko District in Mashonaland East, Zimbabwe. The forestry inventory managed to assemble data for baseline reference to determine the demography of the district. The district is dominated by the miombo woodland interspersed with other woodlands species of combretum/terminalia, and acacia genera. During the last 3 decades rainfall and temperature have been changing in Mutoko District. In this research, trends in rainfall, maximum and minimum temperature at annual time-scale for the period 1978 – 2010 were analysed using a non-parametric test, Mann-Kendall and linear regression. The results indicated that rainfall and maximum temperature are positively increasing (S-statistic, r = 90; Tmax =39) but have statistically insignificant trends and minimum temperature is strongly negatively decreasing (S-statistic, Tmin = -160) hence a statistically significant trend. The information gathered from key informant interviews, revealed that majority of the respondents have a perception that the phenology of some indigenous fruit trees have shifted from their normal timing sequence. Thus, an overall analysis of the findings acquired in this study indicated that changes in climate have impacted on vegetation in Mutoko District as there are changes in yields, textural attributes (taste, colour, firmness shape, etc), fruit sizes and an upsurge of incidences of mortalities and disappearances of tree species. The researcher recommends that as changes in climate are in transition, it is difficult to ascertain future climate and vegetation scenarios, and further studies should be conducted based on individual species as they respond and adapt to climate change differently, in order to have the complete image of changes in vegetation, for sustainable utilization of forestry resources to improve rural livelihoods and food security, for instance there are cases of disappearance and mortality of plant species such as *Sygyzium Guineense*, *Bauhinia Petersiana* and *Peltophorum Africanum*.This might be the predicted transition phase and plant species are anticipated to be lost.

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# List of Acronyms

**DAO** - District Agricultural Officer

**DBH** - Diameter at Breast Height

**EMAO** - Environmental Management Agency Officer

**FAO** - Food and Agriculture Organization

**FEO** - Forestry Extension Officer

**GCMs** - Global Circulation Models

**GHGs** - Greenhouse Gases

**IPCC** - International Panel on Climate Change

**MK** - Mann-Kendall

**MSD** - Meteorological Services Department

**NGOs** - Non-Governmental Organization

**SSA** - Sub-Saharan Africa

**SCBD** - Secretariat of the Convention on Biological Diversity

**SP** - Species

**UNFCCC** - United Nations Framework Convention on Climate

Change

**WWF** - World Wide Fund for Nature

**ZSNCUNFCCC** - Zimbabwe Second National Communication to the United

Nations Framework Convention on Climate Change

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# CHAPTER ONE: INTRODUCTION

## 1.1 Background of the study

International Panel on Climate Change (IPCC 2007) defined “climate change as a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/ other variability of its properties, and that persist for an extended period, typically decades or longer.” Implication of climate change on vegetation dates back to many thousands of years. Irregardless of studies showing that vegetation has adapted to temperature escalations of 2-3 ⁰c in the past, the alterations occurred over thousands of years (Shugart et al 2003), but recent climate forecasts suggest that global temperature increment could be 1.4 – 5.8 ⁰c cover the period 1990 to 2100 is very likely to be without precedent during at least the last 10, 000 years (IPCC 2007).Such a hasty change in a relatively short epoch of time could affect vegetation significantly.

Researches conducted over past decades by intellectuals such as Winnet 1998, Parmesan and Yohe 2003, Lovett et al 2005, Skyes 2009, in different areas both in high and low latitude and altitude ecosystems suggests that climatic changes could either cause massive redistribution and restructuring of vegetation on the planet. Plant species are expected to be lost during the transition phase (Smith and Tirpak 1989 cited in Winnet 1998) or could have a multiplier effect to other species due to enhanced productivity and possibilities to expand or colonize off their range. Substantial alterations in the composition, distribution of ecosystems and ecology are probably to be ongoing over the coming years (Penuelas and Boada 2003 cited in Schut et al 2014). Historically, change in climate has resulted in dramatic shifts in the geographical distribution of species and ecosystems (WWF 2006). According to the Secretariat of the Convention on Biological Diversity (2003), the contemporary global plant diversity was affected by fluctuating Pleistocene (last 1.8 million years) temperature, precipitation and atmospheric carbon dioxide. The Pleistocene era was characterized by usually 100 000 years glacial phase with fluctuating climates interrupted by 10 000 to 20 000 years interglacial period. During Pleistocene glacial, biomes such as deserts, steppe, grasslands tundra and open savannahs, expanded while closed temperate and moist tropical forest retreated towards the equator and became patchy (Kohfeld and Harrison 2000 cited in Secretariat of the Convention on Biological Diversity 2003).

Climate change is already having an impact on the dynamics of African biomes and its rich biodiversity (Lovett et al 2005, Eramus et al 2002 cited in WWF 2006), although species response to climate change is expected to be individualistic, therefore plant species will change their behavior or timing cycle for instance on flowering, leafing, fruiting, according to their physiological capacity disrupting the interactions and processes among species, altering existing communities, which could lead to numerous localized extinction. In Sub Saharan Africa, several ecosystems particularly grass and shrub savannahs are shown to be highly sensitive to short availability of water due to climate variability (Vanacker et al 2005 cited in WWF 2006), hence plant species of the savannah grassland of Africa may shift in structure and composition (Bezahib et al 2010).

Schitter and Higgens (2009) noted that decrease in precipitation would reduce the overall vegetation and Africa experienced a temperature increment of 0.5 ⁰c over the course of the twentieth century, with some areas warming faster (Eriksen et al 2008). It is estimated that between one quarter and one half of a total of 5.197 of African plant species will be severely affected by change in climate (McClean et al 2005 cited in WWF 2006). Also research conducted in Tanzania in the 1990s predicted that there would be a general shift in vegetation in terms of changing forests types, species and distribution (Mwandoya 2006 cited in Bezahib et al 2010), while in the savannahs of Zambia, research shows that climate change markedly affects growth of certain tree species (WWF 2006). Chidumayo (2005), concluded that miombo species such as *Brachystegia* and *Julbernadia* species are showing prospects of alteration in terms of germinating and growth, which is suggested to be slow.

Changes in climate nurtures dilemma for many developing countries, Zimbabwe has not been spared by climate change, in fact current dry spells heart-rending the country are been ascribed to climate change. According to Unganai 1996; Hulme and Sneard 1999; Hulme et al 2001 cited in Feresu (2010), Zimbabwe will warm more hastily than the global average because of its continental interior to the extent that annual warming will reach about 0.15 – 0.55⁰c per decade by 2080. The increase in temperature and fluctuating precipitation make the environment vulnerable to any change. Climate changes over time and such change may affect plant communities, even over short periods as decades or few centuries (Davies 1986 cited in Winnet 1998). Mutoko District has also not been spared by climate change. Freeman (1994) concluded that temperatures in the last decade have risen in winter months around Mutoko District by 1⁰c and precipitation have been fluctuating. A research conducted by Shumba et al (2012) in Mutoko district suggested that local people perceptions on climate change are of the view that there is now an uneven distribution of rainfall.

In addition, Leeman and Eickhout (2004) cited in WWF (2006) noted that with 1–2 ⁰c of warming the adaptive capacity of most species and ecosystems is limited and plant species will be affected first because they lack the propensity to migrate or stay within the climate zone they are adapted to. Therefore change in climate variables such as temperature and precipitation in Mutoko District could have an effect on vegetation especially on phenology, distribution, composition, abundance etc. Therefore it is against this background that the researcher seeks to investigate the effects of climate change on vegetation in Mutoko District.

## 1.2 Statement of the Problem

Changes in climate are factual and they are now concurrently occurring, the effects of climate change such as rising temperature and fluctuating precipitation are undeniably clear with impacts already affecting ecosystems and biodiversity (WWF 2006). Due to variations in species phenotypic plasticity (Kramer 1995 cited in Winnet 1998), plants rely on certain ranges of temperature and precipitation for proper function in their various life stages (Bassow et al 1994 cited in Winnet 1998), any exceedingly deviations outside a tolerable range can damage individual species, and not all species will be able to adjust and make use of the extension of the vegetative period. However, with temperature increase and fluctuating precipitation (Freeman 1994), and higher probability of experiencing shorter precipitation season of less than 110 days in Mutoko District (Shumba et al 2012), there are possibilities that there is a shift on vegetation behavior in terms of the timing cycle for instance on flowering, fruiting, leafing and ripening which could causal-effects on yields, textural attributes among others. Therefore, it is the purpose of this research to find out how vegetation in Mutoko District has been affected or responded to the climate change that has been observed to be happening in Mutoko District.

## 1.3 Objectives

### 1.3.1 General Objective

* To assess the impacts of climate change on the nature and extent of vegetation changes in Mutoko District.

### 1.3.2 Specific Objectives

* To establish the structure and composition of vegetation in Mutoko District.
* To determine the trends in temperature and precipitation from 1978 – 2010.
* To analyze people’s perceptions on phenology of indigenous tree species.

## 1.4 Hypothesis Testing.

H0. Assumes that there is no statistical significance in increase in annual precipitation from 1978-2010.

H1. Assumes that there is a statistical significance in increase in annual precipitation from 1978-2010.

H0. Assumes that there is no statistical significance in decrease in annual minimum temperature from 1978-2010.

H1. Assumes that there is a statistical significance in decrease in annual minimum temperature from 1978-2010

H0. Assumes that there is no statistical significance in increase in annual maximum temperature from 1978-2010.

H1. Assumes that there is a statistical significance in increase in annual maximum temperature from 1978-2010

## 1.5 Justification

Many previous researches in Zimbabwe and Africa mostly focused on structure, distribution, composition and abundance of plant species and implication of human activities on vegetation without considering the effects of climate change, therefore the study is of paramount importance not only to Mutoko District but to the entire nation as, it provide a platform for climate induced change vegetation data which is lagging behind in Africa (Hely et al 2006). Also with a projected further global temperature increment of about 1.1-6.4 ⁰c at the end of the 21st century with about 0.2⁰c per decade warming for the next two decades (IPCC 2007) and variable rainfall (Young Woo 2009; Idinoba et al 2010), the study therefore provides current evidence on effects of climate change on vegetation and future vegetation scenarios could be predicted from the outcomes of the research.

The research is important to Mutoko as it helps to assess the implications of climate change on vegetation in the district. Given the effort put by the government, non-governmental organizations, and international organizations on awareness of climate change effects in Zimbabwe hence the need to continuously gather data, information relating to the consequences of climate change on multi-spatial and temporal scale to quantify the effects of climate change, and come to conclusion if climate change is really affecting Africa as there is little information on climate change implications either ecologically, economically, socially etc.

The research adds on data already existing on effects of climate change, it is a stepping stone in investigating the actual extent and nature of effects of climate change on vegetation in Mutoko District which can be adapted by policy makers, government departments such as Environmental Management Agency, Forestry Commission and Meteorology Section and Non-Governmental Organizations’ (NGO) and Communities to conjoin and operate in a cohesive trajectory, for current and future development in rural areas, as the main source of raw materials, inputs and incomes for the rural folk are from forests resources (Mabugu and Chitiga 2002; Katerere 2009; Dewees et al 2010), hence the significance of the research in assisting alleviating rural poverty as the woodlands such as miombo, and combretum/terminalia, cover almost one half of Zimbabwe and other SSA countries. In other words, the findings of this research are expected to determine the nature and extent of effects of climate change to enhance sustainable utilization of forests resources and reduce vulnerability of rural communities, as adaptive measures can be implemented precisely with current and relevant data.

## 1.6 Description of the Study Area

This study focuses on Mutoko district, which is one of the ten administrative districts in Mashonaland East Province of Zimbabwe. Mutoko district is located in the North-eastern corner of the province about 143 kilometers away from Harare (Mvumi et al 1998). It is bounded by Murehwa in the west, Uzumba Maramba Pfungwe in the northwest, Mudzi in the north east, Nyanga communal areas and Mayo resettlement scheme in the east and south respectively. It consist of 29 wards (428 916 hectares) and the administrative centre is situated at Mutoko Centre (Mubonderi 2012), consists of infrastructure such as post office, hospitals, banking facilities as Standard Chartered, Post Office Savings Bank, MetBank and Grain Marketing Board depot, various shops as Thomas Meikles, Spar, Farm and City, Profeeds and service stations among others.

### 1.6.1 Physical Characteristics of Study Area

In terms of the agro-ecological regions of Zimbabwe, Mutoko District lies in Region III (Tigere et al 2006) but the department of lands categorise Mutoko district into three natural regions which are IIb, III and IV with proportion of 15.6%, 40.1% and 44.3% respectively (Mvumi et al 1998), as shown in Table 1. They are semi-intensive farming regions with an annual rainfall range of 650- 850mm (Tigere et al 2006) and a temperature range of 19 to 27 Degree Celsius.

**Table 1.1. Farming Sectors and Natural Regions in Hectares for Mutoko District.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Farming Sector** | **Total Hectares** | **NR IIb** | **NR III** | **NRIV** |
| **Communal** | 208 800 | - | 39 067 ha | 169 733 ha |
| **Resettlement** | 166 224 | 71 000 ha | 79 161 ha | 16 063 ha |
| **SSCFA** | 53 892 | - | 34 767 ha | 19 125 ha |
| **Total** | 428 916 | 71 000 ha | 152 995 ha | 204 921 ha |

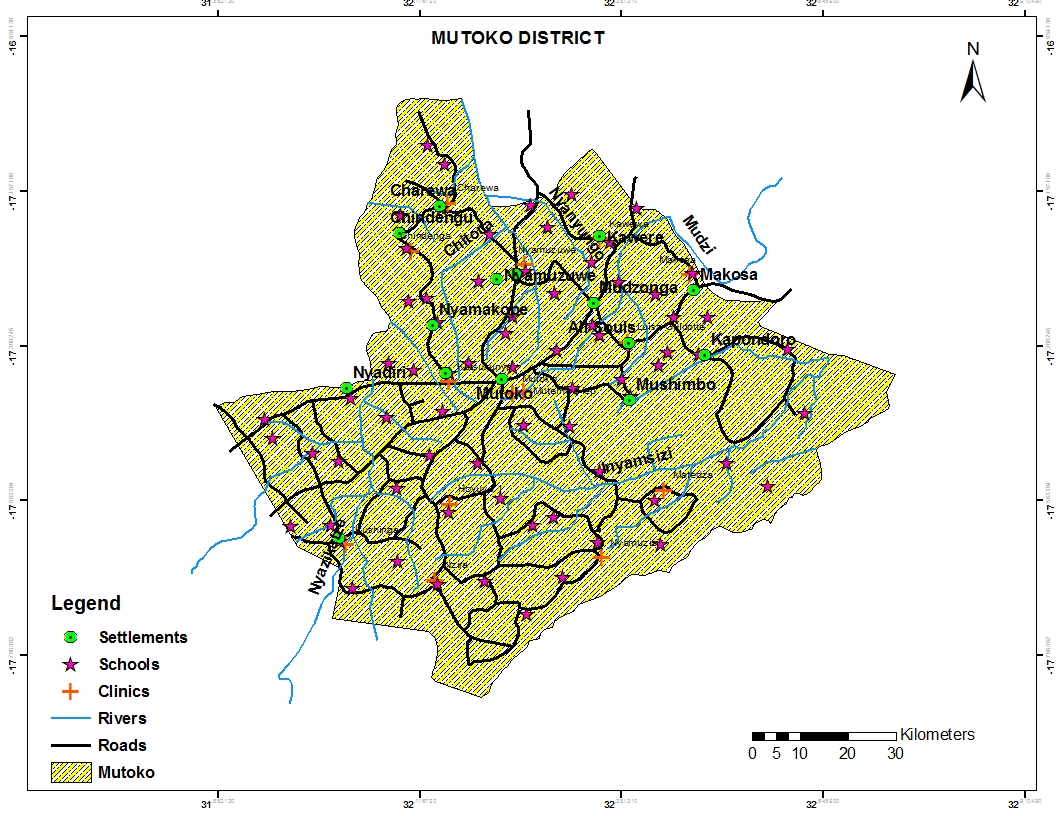
Mutoko district is generally a granitic mountainous area with an altitude range of 650 to 1400m (Freeman 1994). According to the 1980 provisional soil map of Zimbabwe, and Tigere et al (2006), Mutoko district has three soils which belong to the Kaolintic order, which can be grouped moderately to heavily leached sand, clay loams of low inherent fertility. Major perennial rivers that drain the district include Nyagadzi River in the south, Nyamuzizi River in the west and Nyadire River.

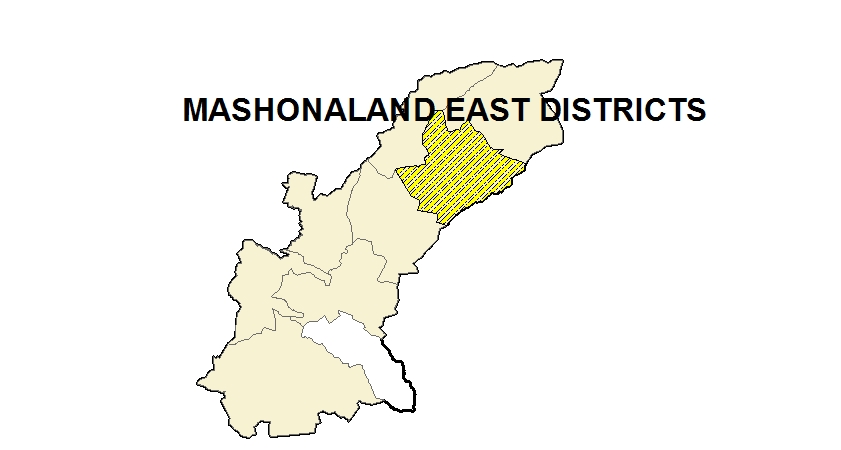
### 1.6.2 Floristic Composition and Structure of Vegetation in Mutoko District

Mutoko District has a forest cover of approximately 47%, mostly dominated by miombo woodland (Shumba et al 2012). The district is characterized by the overwhelming dominance of trees in the genera *Brachystegia* (musasa), *Julbernadia* (munhondo) (Tigere et al 2006). Other significant tree species found in the district include *Pseudolachnostylis* *Maprouneifolia (*mutsvonzvowa*)*, *Burkea* *Africana (*mukarati*)* among others. In mature miombo these species comprise an upper canopy layer made of 10-20m high trees and a scattered layer of sub canopy trees. The ground layer is dominated by a sparse but incessant herbaceous layer of grasses, forbs and sedges composed of *Hyparrhenia*, *Andropogon*, *Digitaria* and *Eragrostis* (Campbell 1996). Other areas hardly degraded are dominated by scattered acacias, terminalia/combretum species with interspersed grassland and hills provides habitat for animals such as bush pigs, baboons, monkeys, birds and spring hares among others. The indigenous trees are inter-mixed with exotic fruits such as mangoes, citrus species and gum woodlots at individual homesteads and at schools.

### 1.6.3 Socio-economic Characteristics

Zimstat (2012) indicate that the population in Mutoko District was a total of 145.676 inhabitants, of which 48.4% (70 567) are males while 51.6% (75 1090) are females. The inhabitants of Mutoko District specialize in crop production, such as sweet potato (*Ipomoea batatus*); maize, finger millet (*Eleusine coracana*); sorghum (*Sorghum bicolor*); cowpea (*Vigna unguiculata*); groundnut (*Arachis hypogea*); Bambara groundnut (*Voandezea subterrenea*) and rice (*Oryza sativa*) (Tigere et al 2006) and horticulture crops grown include tomatoes, onions, butternuts, cucumbers, okra etc. By virtue of being the staple food, maize is the predominant crop followed by groundnuts, however farmers are shifting towards cash crops such as tobacco and cotton. Most of their products are either sold at Mutoko Centre or in Harare at Mbare Musika. The livestock types within the farming systems are cattle, goats and poultry (Mubonderi 2012).



**Fig 1.1 Map of Mutoko District.**

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 State of Zimbabwe’s Vegetation

Zimbabwe is a land locked country with a total land area of just under 391,000 km2 (39.1 million ha). The country’s woodland or forestry resources cover approximately 66% (25.8 million ha) of the total area and fall into three broad categories specifically rainforest, indigenous woodlands and plantations (Mabugu and Chitiga 2002, Marufu 2012) while the Zimbabwe Fourth National Biodiversity Report (2010) and Jiri et al (2013) asserted that forestry resources cover 53% (20.7 million ha) and 43% (16.80 million ha) of the total land mass respectively. Campbell et al (1997) cited in Mabugu and Chitiga (2002) provides a more eloquent detail of what can be considered to be forests outside of exotic plantations, which therefore include miombo, teak, acacia, mopane and terminalia/combretum woodlands. Jiri et al (2013) further included other two types of woodlands which include savannah and montane. According to the Forestry Commission Zimbabwe Vegetation Baseline Map, miombo woodlands constitute 24.3%, which is about 9.5 million ha of the total land mass, terminalia/combretum constitute 12.2% (4.8 million ha), acacia constitute 7.9% (3.1 million ha), mopane constitute 18.8% (7.3 million ha), teak constitute 5% (2 million ha) and grassland also constitute 3.7% (1.4 million ha) (Jiri et al 2013). However most of the woodlands especially the miombo have been converted to agricultural lands and is the most extensive and utilized woodland in Zimbabwe and the most likely to be impacted by change in climate.

## 2.2 Utility of Woodlands in Sub-Saharan Africa.

Most of the Zimbabwe’s population is located in the Zambezian phyto-chorographical region which therefore emphasize that miombo, acacia, mopane and terminalia/combretum, products and services are of paramount significance for their survival. These woodlands provide diverse uses ranging from provision of soil fertility, grazing and browsing, firewood, watershed protection, edible fruits, caterpillars and timber among others. The interlinkage and interdependency of the woodlands and livelihoods of communities can be illustrated in Figure.2.1.

|  |
| --- |
|  |

**Figure.2.1 Products and services provided by vegetation for sustainable living (Source: Campbell 1996)**

Miombo woodland cover 10% of the African land mass, it covers substantial part of central and southern Africa, for instance Angola, Zimbabwe, Zambia, Malawi, Mozambique, Tanzania and most of southern Democratic Republic of Congo (Malmer 2007; Campbell et al 2008). Given their vast extent, miombo woodlands inhabits over 50 million Africans, of which about 80% are rural folks (Shackleton and Clarke 2007) and an additional 25 million urban dwellers also rely on miombo for products such as wood and charcoal for energy (Campbell et al 2008). It is clear that the extensive geographic distribution of miombo woodland has been molded in large part from past climate (Van Wilgen and Scholes cited in Campbell 1996). Therefore biodiversity in miombo woodlands is likely to be impacted by climate change. Henceforth any change in climate in Africa will affect about seven countries of Sub-Saharan Africa, causing cascading effects on the livelihoods, health and well-being of people.

## 2.3 Concepts of Climate Change

### 2.3.1 Definition of Climate Change

Houghton et al (1990) cited in Unganai (1996) defined climate change as a shift of climatic conditions in a directional incremental mode, with values of climatic elements changing significantly, while Cavaliere (2009) referred climate change as any significant change in measures of climate such as rainfall, wind and temperature among others, over an extended period of time, decades or longer. IPCC (2007) clearly stated climate change “as a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/ other variability of its properties, and that persist for an extended period, typically decades or longer.” The UNFCC defines climate change as a change in climate that is attributable directly or indirectly to human activity that alters atmospheric composition. To summarize climate change is a shift of climatic variables for an extended epoch, usually decades, expedited either by natural or anthropogenic induced scenarios.

## 2.4 Conceptual and Theoretical Framework

In order to understand the implications of climate change on vegetation, there is need to grasp the complexity of the inter-linkages and interdependency of vegetation to climate. Past studies have been conducted and there is significant correlation between climate and vegetation, hence any change in climate especially precipitation and temperature will affect vegetation in any biome, ecosystem and woodland. Figure.2.2 illustrate the relationship between climate variables and vegetation.

|  |
| --- |
| Rise in GHGs GGHGs  Rise  In temp  Changes in: viability of population; species numbers & distribution; structure, composition & functioning of ecosystem |

**Figure.2.2 Conceptual Framework of Climate Change Implications on Vegetation**

**Adapted from Kappelle et al (1999).**

## 2.5. Past Climate Changes and Changes in Vegetation

Climate change can influence structure, distribution and composition of the vegetation. Changes in climate have continuously been occurring and will continue to occur and plant species have and will always respond to such changes individually. Climate change induce environmental change which alters range, abundance, composition and dominance of species as plant communities’ change through time as the environment changes. The past global changes in climate resulted in distinct restructurings of biological communities, landscape and biomes, and major shifts in species geographical ranges (Secretariat of the Convention on Biological Diversity 2003, SCBD).

The effects of the Pleistocene era on vegetation were evidenced, as some plant species communities expanded, migration of plant species latitudinally, local and regional extinctions in different biomes. Biomes such as open boreal forest-parkland, savannahs, deserts, steppe, grasslands and tundra expanded during the Pleistocene glacial while moist tropical forest and closed temperate retreated towards the equator. In addition, moist tropical forests in Southeast Asia and the Amazon basin persevered intact through the glacial-interglacial transition, even though dry, seasonal savannahs were significantly enlarged. Irregardless of the alternating glacial-interglacial phase’s global woody vegetation and closed forest expanded, and during interglacial peaks moist forest types reached their maximum abundance. The enlargement and reduction of the northern ice sheets and modification of cooler and arid glacial climates with warmer, wetter interglacial forced major changes in species geographic distribution, especially at northern latitudes. Nevertheless, most of the globe, particularly in the desert areas, tropics, subtropics, mountains and southern latitudes, habitat reduction was the most common response hence many tree and shrub species migrated to more favourable ecotones. (SCBD 2003).

## 2.6. Plant Species Response to Climate Change

The degree of changes in climate are unlikely to be uniform over the globe and the aftermaths for both plant species and populations respond variably to these changes, therefore plant establishment, reproduction, growth and survival through its life cycle are directly linked to the environmental conditions sensed by the plant species, for instance the General Circulation Models (GCMs) predict warmer winter temperatures for northern latitudes but less precipitation and amplified droughts for southern latitudes. Shifting temperature and precipitation, particularly when they occur promptly and extremely, directly impacting species, often differently.

### 2.6.1. Direct Effects of Climate Change on Vegetation

Plants respond to climate change in a two sequence mode; increasing growth and population size or decreasing growth with probable local extinctions usually by dispersal to new, more favorable locations. Two processes, phenology and range shifting, are important in a plant's response to climate change and are often used to determine plants response to climate change:

### 2.6.2. Vegetation Phenology

Phenology is the timing of events over the annual cycle of plants and animals and is often a response to changing temperature, moisture and light levels that occur throughout the year (Skyes 2009). In plant species the phenological sequence encompasses events such as leaf fall and flush, flowering, fruiting, and ripening etc. Growth and reproduction of most plant species is regulated by the time of season. The time of flowering of plants is one such cyclic event that is significant for sexual production, and the time required for flowers to develop to maturity, for instance, growth processes are strongly reliant on temperature. According to Chidumayo and Frost cited in Campbell (1996) precipitation, temperature and seasonal variations in soil moisture influence the phenology of miombo plants but reviews on phenology not solely in Zimbabwe but in Africa as a whole are lagging behind, in summary, the phenological sequence of many, but not all species, has responded to climate change. Numerous recent reports suggest that the time of first flowering has been affected by the warming trend of the half century. For instance, there have been a number of researches on influence of climate change on phenology. A research conducted by Menzel et al (2006) cited in Skyes (2009) concluded that by 1971-2000, earlier leafing, flowering and fruiting had increased by 2.5 days per decade with a delay in leaf fall by 0.2 days per decade. In United Kingdom the first flowering was reported to have advanced by 4.5 days per decade in the 1990s (Fitter and Fitter 2002 cited in Skyes 2009), while in Spain, Penuelas (2002) cited in Skyes (2009) reported earlier leafing, flowering, fruiting and delayed leaf fall in range of 1.2 – 3.3 days per decade over the last half of the century. However, changes are not consistent across species. In addition, Doi and Katano (2007) cited in Skyes (2009), observed four tree species in Japan, in four different locations and established that over the past 50 years, location with utmost warming, budburst had advanced by up to 5.6 days per decade. Temperature had been regarded, by most studies as the most significant aspect triggering these phenological changes. However, Keatley et al (2002) cited in Skyes (2009). using the phenological observation of flowering from the 1920s to 1980s in Australia on four Eucalypt species concluded that there were significant relationships between temperature and precipitation and commencement of flowering for all species hence both climatic factors are of paramount importance on the phenology of plants

### 2.6.3. Range Shifting

The in progress rapid induced climate change, is likely to create suitable climate space for species that require warmer conditions. There is evidence which suggest that species are already responding to changes in climate by range shifting (Parmesan and Yohe, 2003). The main limitation of the range shifting concept is that of plant species movement is difficult to observe due differential responses among species, as mature individual species can survive for hundreds of years outside their climate envelope until some disturbances such as wind, fire among others, eliminates them, with no germination taking place (Skyes 2009) and it depends on the ability of each species to disperse or migrate to new areas. Climate change is likely to change spatially the range that species can inhabit, therefore plant species may disperse or migrate to areas, most suitable to their photoperiod, hydro-period and phenotypic plasticity to survive.

### 2.6.4. Indirect Effects of Climatic Changes on Vegetation

Climate change can have detrimental effects on vegetation, many incidents of forest diebacks have been positively correlated with extreme weather events. Winnet (1998) stated that should modification on climate lead to significant periods warming within the winter, or extreme heating, cooling, or drought during the summer; can make plant species susceptible to threats from pests and diseases. Plant species are frequently under attack by a set of insects, pests and diseases, which under normal conditions, they are generally able to either survive the effects of or fend off for example, In British Columbia, a native disease called Dothistroma needle blight, caused by fungus, was causally linked to an increase in frequency of warm and moist conditions that were experimentally found to be favorable for infection (Wood et al 2005 cited Hamann and Wang 2006).

While plant species under unusual temperature or moisture stress are less able to preserve themselves from attack and may suffer more losses (Logan et al 1995 cited in Winnet 1998). In addition, the IPCC 1996a cited in Winnet (1998) postulated that an increment in temperature may amplify the growing season and growth rate for some pests, for instance may propel more generation in a season or year. A combination of inordinate stress and more numerous attacks from pests may lead to unwarranted mortality of plant species.

Changes in climate is likely to affect the soil and ecosystem processes by which the nutrient are stored, released and recycled (Pastor and Post 1988). Decomposition processes and activities of the soil micro-organisms ,which have a substantial role in determining the structure, composition, health and function of plant communities, change with moisture, temperature and litter quality (Lovett 2007), therefore altering the nutrient cycling regime and functioning of an ecosystem. Studies conducted indicate that forests response to climate change depend on local conditions, such as stand age, site soil, moisture characteristics, species composition and the history of disturbances and development. These factors affect how quickly forests respond to rising temperatures and changes in precipitation patterns. Climate change will worsen the situation of plant species surviving under stresses unless it mitigate the situation.

### 2.6.5. Effects of Climate Change on Fruits Taste and Textural Attributes

With the current climate change episodes there are possibilities shift in the phenology of plant species would end up affecting the products produced by the plants. Several studies have demonstrated that temperature stress can impact the secondary metabolites and other compounds that plants produce (Pal and Giorgi 2004 cited in Cavaliere 2009). There are possibilities that the taste and textural attributes of fruit species could be affected by climate change. For instance, tea growers in northeastern India claim that climate change has altered the flavor of their tea brew. L.P Chaliha a professional tea taster was quoted by Hussain (2010), saying “Earlier, we used to get a bright strong cup. Now it’s not so”. A study conducted by Sugiura et al (2013) in Japan came to conclusion that there are changes on the taste and textural attributes of apples in response to current climate warming, which has causal effect on changing phenology. The change in taste and texture are probably caused by earlier blooming and higher temperatures during maturation period.

## 2.7. Climate Change Scenarios for Africa

There is evidence that Africa is warming more rapidly than the global average, causing warming for all seasons of the year, with an overall geographical widespread variation (Boko et al 2007, Conway 2009). The IPCC analyzed 21 Atmospheric-Ocean General Circulation Models and summarized that southern and northern Africa are probably to become much warmer by as much as 4 degrees or more over the next 100 years (Conway 2009), implying that southern and northern Africa will become more drier as precipitation is likely to fall by 15%. Only in East Africa, comprising the Horn of Africa precipitation is likely to increase. Thomas et al (2004) cited in Conway (2009) suggested that, globally, approximately 15- 40% of plant species will be extinct by 2050 as a result of climate change. Conway (2009) concluded that, in future, the occurrence of exceedingly dry winters and springs in South of Africa are possibly to increase together with the occurrence of exceedingly wet summers. Therefore, environments of dry and sub-humid areas are predominantly vulnerable because any change in precipitation and temperature patterns can have deleterious effects on the sustainability of plants.

However, long-term forecasts are for a drier western Africa and expansion of the Sahara southwards into the Congo rainforests. Evidence shows that this has occurred before during the previous global climate change as the present day forests are growing in desert sands and the Namib Desert also reflects influence of tropical forests (Ning and Dupont 1997). In addition, vegetation models suggest that plant species will move southwards into Angola and up into the mountains of the central rift. The wetter parts of central Africa which include coastal regions of Cameroon, Gabon and mountains of eastern coastal Africa are forecasted to preserve more plant species than elsewhere.

Historic and future climate change scenarios for Zimbabwe have been studied, by researchers such as Unganai 1996; Hulme and Sneard 1999; Hulme et al 2001 cited in Feresu (2010), using observed climate data and seven global climate models. The outcomes of the climate change scenarios suggest that annual rainfall will decline by 5 to18 percent of the 1961 to1990 average by the 2080s (Feresu 2010). The decrease is anticipated to happen in all seasons, but is more certain for the early and late rains than for the main rainy season months of December to February, therefore a higher probability of experiencing shorter precipitation season of less than 110 days in Mutoko District (Shumba et al 2012). The Zimbabwe Second National Communication to the United Nations Framework Convention on Climate Change, ZSNCUNFCCC (2012), emphasizes that, “mean monthly temperature projections for both the worst and best case scenarios based on the Commonwealth Scientific and Industrial Organization (CSIROMK3) model indicate a general warming of around 2 degrees by 2080”. In Zimbabwe cooler and hotter days and the length and severity of drier periods are increasing (FAO 2004 cited in Conway 2009). In short precipitation determines the location and distribution of vegetation in Zimbabwe (Zimbabwe Fourth National Biodiversity Report 2010). Scenarios of rising temperature and reduced rainfall for Zimbabwe imply a decline in woodlands and an expansion of the scrub savannah (Feresu 2010).

## 2.8 The Relationship between Precipitation, Temperature and Vegetation in Zimbabwe

Temperature and precipitation, two of the climatic factors changing with increased GHGs concentration and are the primary determinants of plants productivity, health and distribution of vegetation. Several GCMs predict rising temperatures over the next century (Fosaa et al 2004) and the possibilities for greater changes in precipitation patterns over various parts of the globe (Sedjo and Sohngen 1998). Matarira and Mwamuka (1996), using the Goddard Institute of Space Studies Model scenario concluded that in Zimbabwe, there is a climate alteration towards reduced annual precipitation and high ambient temperatures and suggested possible shifts in vegetation from subtropical thorn woodland to tropical very forest and from subtropical dry forest to tropical very dry forest. Climate determines the nature and extent of the major vegetation formations and in warmer world biomes are on the move. Increase in temperature, for example will not necessarily increase growth of trees and may it prohibit it for some species, not all plant species can or will keep up (Lovett 2007).

ZSNCUNFCCC (2012), outcomes from studies conducted show that plant diversity increases as the precipitation of the warmest quarter increases. In addition, when rainfall of the warmest quarter exceeds 450mm, further increment in rainfall seem to have no effect on plant diversity, therefore implying that drier regions of the country, for example western and southern areas, plant diversity is more sensitive to precipitation variability than the Eastern Highlands. Plant species are also sensitive to changes in temperature, the ZSNCUNFCCC (2012), suggest that plant diversity decreases as the maximum temperature of the warmest month increases. Henceforth, these outcomes suggest that the anticipated upsurge in temperature accompanied by diminution in precipitation quantity may have a negative impact on plant species and ecosystems function in Zimbabwe.

## 2.9. The Knowledge Gap: Researcher’s Analysis

Climate, more than any other factor, controls the broad scale distribution of plant species and vegetation in general (Skyes 2009).Understanding how species have responded to past changes in climate can provide some indicators on how species and vegetation may assemble under current and future climate change. However, it is unlikely given the substantial amount of anthropo-modifications of current landscapes and effects of changes in climate on vegetation are complex and understanding of interactions are complicated by local conditions, such as stand age, site soil, moisture characteristics, species composition and the history of disturbances and development hence difficult to provide a flawless picture of future species pattern trajectory, composition and distribution, henceforth;

* The need to conduct research’s exploring the influence of factors such as soil, stand age, history of disturbance and development on vegetation composition and distribution contrary to climate change in Africa not necessarily in Zimbabwe.

Studies conducted in Africa particularly in Zimbabwe focused more on forest incentives on rural livelihoods, impacts of veldt fires and agriculture on vegetation but climate change related data to vegetation is lagging behind, henceforth;

* The need to conduct studies investigating the spatial and temporal effects of climate change on vegetation from a local scale to national and then regional scale.

# CHAPTER THREE: RESEARCH MATERIALS AND METHODS

# 

## 3.1 Research Design

According to Edmonds and Kennedy (2012) a research design refers to actual structure or framework that indicates the time frames in which data will be collected or how and when the data will be analyzed. In this research, both quantitative and qualitative techniques were used in data collection as they are empiric, but collect different types of data using different methods, neither approaches (quantitative and qualitative) are intrinsically superior to the other, but rather a key in developing an accurate and holistic picture of the effects of climate change on vegetation. Quantitative methods collect information which can be analyzed numerically and the results are typically shown using statistics, tables and graphs (ACAPS 2012) while qualitative methods provide added value in identifying and exploring intangible factors such as relationships and perceptions of local inhabitants affected (Patton and Cochran 2002).

A scientific approach was utilized in the research. Edmonds and Kennedy (2012) refers scientific research as a technique in which the investigator decides what to study, asks specific, narrow questions, gather quantifiable data from participants, analyze the numeric data using statistics and conduct the inquiry in an unbiased, objective manner. A Non-experimental design was used in the research, which is referred to as a design that does not involve manipulation of the condition or circumstances (Johnson and Christensen 2008) but the effects of some naturally occurring situations can be studied. A Non-experimental prospective *ex post facto* study was embraced in the research, which is a study of phenomena over time by linking a presumed cause with a presumed effect (Black 1999). It is of paramount significance to the research because it allows association or relations between variables in a predictable pattern without intervention of the researcher and there was a rapid turnaround in data collection as attributes from the whole population were inferred from a small portion of the population.

The main thrust of this research was focused on forestry inventory, defined as a system of collecting and analyzing data for the purpose of assessing the quantity and quality of forestry resources in a given area (Chidumayo 1995 cited in Chenje et al 1998). It encompasses techniques such as field surveys supported by key informant interviews. Thus data triangulation was significant in gathering a shared image on effects of climate change on vegetation as quantitative and qualitative data assist to deduce and understand the intricate reality of a climate change.

## 3.2 Target Population

Korb (2012) defined a unit of analysis as the entity under study henceforth vegetation or plant species are entities under study. Cox (2008); Castillo (2009) referred to target population as the entire set of units for which the investigation data are to be used to make inference. Therefore, the definition denotes that the target population is systematically chosen by the researcher as it provides the generalization to the study. The target population encompasses a 20 hectare state woodland/forest which consist of indigenous plant species for forestry inventory. The main reason being that the state woodland is easy to access and of minimum disturbance from anthropogenic activities. The researcher targeted local key informant interviewees, who includes Forestry Extension Officer, Environmental Management Agency Officer, District Agriculture Officer and Councilor’s and were interviewed for their familiarity and expertise on climate change, environmental issues and are knowledgeable about past trends in phenology and can determine any change in phenology and climate in the district.

## 3.3 Sample Size and It’s Determination

Raj (1972) defined sampling as a procedure where a fraction of the data is taken from a large set of data and the inference drawn from the sample is extended to the whole group. Frey et al 2000 cited in Latham (2007) referred a sample as a subgroup of a population. Therefore, Castillo (2009) defined sample size as the number of sample units that will be measured in the inventory. The state woodland area under study is twenty hectares (49.4 acres) and a comprehensive inventory requires a 20 % sampling intensity for area under three hundred acres (University of Florida 2006), to acquire an accurate estimation, therefore the sample size for the woodland was four hectares (10 acres).

The plot size or sample unit was determined by the formulae adapted from Carbon Fix Standard Methodology Forestry Inventory Guideline. It recommends that a plot size should be large enough so that at least 10 – 15 trees are measured within the boundaries and larger plots leads to smaller sampling errors. Lackmann (2011) articulated that, the first priority is to determine the plot size. Therefore the formulae for plot size determination from the Carbon Fix Standard Methodology Forestry Inventory Guideline is as shown below;

***=*** 10000 \* 10/200

= **500m2**

***Where:***

*Amin = minimum plot size.*

*Nmin = amount of minimum trees required per plot (at least 10).*

*Ne = amount of trees when the forest reaches its equilibrium stand volume (250 an estimated value from woodland).*

***Source:*** *Carbon Fix Standard (2012)*

Henceforth, the plot size for each quadrant was 500m2, which therefore meant that a 20 \* 25m rectangular quadrant was used, because the larger the quadrant size variations among the sample units decreases, hence data collected was significantly valid. Another formulae for determining the maximum number of sample/plot units to be measured within a stratum/hectare was adapted from Lackmann (2011), by dividing the area of the stratum in hectares by the measurement of the plot/sample area as illustrated below, hence each hectare has twenty sample units and the total sample size/area was divided into 80 quadrants.

Maximum number of sample units = area of the stratum in hectares / sample unit area

= 40000m2 / 500m2

= **80 sample units**

The researcher targeted to inventory 80 rectangular sample units/plots measuring 20m \* 25m, ( 9.8 acres /4 hectares), however a total of 63 rectangular sample units/plots were inventoried, (6.4 acres /2.6 hectares), because of lack of time, limited benchmarked woody plant species (which are at least 10 trees in sample plot, should have 6cm dbh-sp and at least 3m in height) and interference of a mountain to the extent that it became too strenuous and impossible to accurately and precisely record the required data.

## 3.4 Research Instruments

The research design focused on primary data collection or generation which was augmented by secondary data. Sallant and Dillman (1994) referred data collection as a systematic way of gathering information which is relevant to the research purpose or questions. Primary data is data obtained directly from the information source and which has not undergone analysis (ACAPS 2012), it was gathered in a two phase sequence consisting field quadrants, remotely sensed imagery and key informant interviews. Secondary data is an analysis of data that have already been gathered for other purposes (ACAPS 2012). It can be historical or contemporary, qualitative and quantitative in nature but needs validation and alterations before utilization.

### 3.4.1 Primary Data Sources

The field survey was conducted in a two phase approach;

1. **Quadrant Measurement Survey**
2. **Key Informant Interviews**

### 3.4.2 Quadrant Measurement Survey

#### 3.4.2.1 Materials Used

* Measuring Tape 50m
* Caliper
* Calibrated 6m pole
* A4 counter exercise book
* Red cloth

#### 3.4.2.2 Procedures Undertaken Conducting Quadrant Measurements

Quadrants were used to determine and evaluate woodland vegetation parameters such as frequency, composition, density, dominance and basal area etc. The main aim of quadrant survey was to collect primary data for establishment of a baseline reference and current demography of vegetation in the area. A twenty hectare state woodland was chosen to be the sampling unit because it is the only area in the district with minimum human interference as local farmers surrounding the woodland own more than fifty hectares of land.

The sample units were systematically sampled, Cox (2008) defined systematic sampling as the random procedure of sampling that applies a constant interval to picking a sample unit from the sampling frame. Systematic sampling was utilized in the research, because it is common, simple and allows the researcher to make statistical unbiased conclusions from the gathered data. Using a sampling interval of 5m, derived from a formulae as shown below,

Sampling Interval = sampling frame/ sample size

= 200000m2/ 40000m2

= **5m**

The main sample unit or reference unit was located at the boundary of the woodland so that other sampling units/quadrants would be selected after every 5m utilizing a tape measure, in any direction from the last sample unit of the sampling frame to avoid recount of quadrants, using a sampling intensity of 20%, four hectares of the woodland were sampled. The selection of sampling units using systematic procedures proved to be superior because the rectangular quadrants were spread evenly over the sampling frame as illustrated in Figure3.1.

**Figure.3.1. 5m Interval Systematic Sampling Procedure.**

Doolittle (2013) articulated that studies have shown that rectangular quadrants are more accurate than square or circular sample quadrants. The rectangular quadrants reduces overlaps on the boundary, cover wider area incorporating a greater diversity of population (Mitchell and Glenn 1995) and are easy to demarcate, hence 80 rectangular quadrants of 20 x 25m were used to determine the total sample.

According to Mitchell and Glenn (1995), data collection in inventorying is more efficient when performed by at least two crew members, hence the researcher was assisted by a local inhabitant of Mutoko District with the expertise of local indigenous tree species. The researcher did most of the work, for instance recording and measuring height whereas the assistant was taught how to measure diameter at breast height and marking the quadrant.

Each quadrants length and width was measured using a tape measure and marked on each corner by a red cloth to demarcate the boundaries. On each of the selected quadrants the following vegetation parameters were recorded in an A4 counter exercise book, each tree was identified in local name and later its botanical name was confirmed using a botanical name list paper, diameter at breast height (DBH) measured by a caliper, and height a calibrated 6m pole was used, height exceeding 6m were estimated. The recorded data from the survey was later transferred to quadrant/plot tally sheet. The researcher adopted the benchmarks asserted by Mitchell and Glenn (1995); Lackmann (2011) and Gandiwa et al (2013) to ascertain a tree, and trees with a diameter of 6cm and height of 3m and over were recognized as trees were as those below are recognized as shrubs and herbaceous plants, grasses and dbh was measured at 1,3m above ground.

### 3.4.3 Key Informant Interviews

According to ACAPS (2012) key informant interviews provide individual perspectives and experiences through direct discussion, it involves a set of questions which explore the effects of climate change on vegetation in the community and a source of primary data. Purposive sampling was also used to determine key informants interviewee, who include FEO, DAO, and EMA officer. Black (1999) referred purposive sampling as selecting all knowledgeable persons on the subject issues. Therefore, key informant interviews were used in this research to complement information analyzed from quadrant measurements and remotely sensed imagery. The researcher conducted a preliminary survey on the 15th of January 2014, to organize and determine the day to conduct the interview in April and familiarize the key informants on issues to be discussed. The researcher took advantage of the Mutoko Rural District Council Strategic Planning Workshop held at Nyamakwere Lodge in Mutoko District on the 07th of April 2014 and randomly interviewed 10 councilors. Other key informants were interviewed at their offices after the workshop, each interview took 20- 30 minutes. An interview guide which consisted of semi-structured questions was utilized to guide the discussion and all data were note taken in the diary. During the interview the researcher managed to chair the discussion and clarified questions presumed to be not clear or contentious, to make sure information obtained are valid.

**Table 3.1 Stakeholders And Reasons for their Selection for Interview.**

|  |  |
| --- | --- |
| **INTERVIEWEE** | **REASON FOR INTERVIEWING** |
| Councilor’s | * To acquire information on vegetation characteristics, changes which mighty have occurred * To determine any change in climate in their respective wards |
| Forestry Extension Officer | * To acquire information on vegetation characteristics, changes which mighty have occurred. * To establish the relationship between rainfall, temperature and vegetation. |
| District Agriculture Officer | * To acquire information on changes in climate and its effects on vegetation, because he has more than 20 years of working experience in the district. * To establish the trend in change in precipitation or temperature because, they also record and keep records of precipitation and temperature. |
| Environmental Management Agency Officer | * As an environmental management organ, they are well informed of climate change and its implications, therefore the need to acquire information on climate change and its effects on vegetation. |

## 3.5 Secondary Data Sources

Secondary data involves the study and analysis of data about current and past events. The researcher used secondary data to get information on the past trend of precipitation and temperature in Mutoko District from Meteorological services department (MSD). The data was also obtained from State of Zimbabwe environment reports, environmental journal and forestry or vegetation documents on the internet. The aim of using secondary data by the researcher was to complement primary data and it is less expensive and time consuming.

## 3.6 Data Analysis and Presentation

According to Shamoo and Resnik (2003) data analysis is the procedure for systematically applying statistical and logical techniques to describe, categorize, illustrate, summarize and evaluate data. They provide a way of drawing inductive inferences from data and distinguishing the phenomenon of interest from the statistical fluctuations present in the data. In this investigation the researcher used descriptive statistics to summarize the measured vegetation parameters. The outcomes from the analysed data would be presented in tabular formats, statistics, linear and bar graphs.

### 3.6.1 Mann-Kendall Trend Test Analysis

Meteorological data obtained from the MSD on precipitation and temperature was analysed using the Mann-Kendall (MK) non-parametric analysis for trend to test whether there had been a significant change in annual precipitation and temperature in Mutoko District over the past 32 years (1978 to 2010). MK analysis allows probing on the presence of an inclination of long period in rainfall and temperature data without making an assumption about its distributional properties and less influenced by the presence of outliers in the data (Capodici et al 2008). The MK statistic (S) is referred to as the subtraction of the sum of the number of positive differences from the number of negative differences (Al-Mashagbah and Al-Farajat 2013) as shown below:

Three steps were involved in calculating the MK trend test.

* Step One. Determination of the S-statistic.

**Or simply**

*Whereas:*

*P = sum of numbers of positive differences.*

*M = sum of numbers of negative differences.*

**Source: Onoz and Bayazit (2003); Nenwiini and Kabanda (2013).**

The first step in MK trend analysis is to align ranks to data variables in their sequential time-series order, giving the highest data value rank of one up to the last data value and ties are given the same rank. To determine P for the first data value, start from second data value, count the number of ranks of data values that exceeded the rank of the first data value; for the second data value, start from the third data values, count the number of ranks that also exceeded the rank of the second data value. The process goes on and on to the last data value and then sum the values P.

To determine M for the first data value, start from second data value, count the number of ranks of data values that never exceeded the rank of the first data value; for the second data value, start from the third data values, count the number of ranks that also never exceeded the rank of the second data value. The process goes on and on to the last data value and then sum the values M. The difference between sum of Ps and sum of Ms is the S-statistic.

* Step 2. Normalization of the S-statistic

Precipitation and temperature data values exceeded more than 10 data values, which therefore mean that the sampling distribution of S-statistics for precipitation was calculated using the variance of S- statistic equation, as below because it has no ties:

*Where:*

*n = total number of data variables.*

**Source: Onoz and Bayazit (2003).**

In addition, another equation was also used to determine the sampling distribution of S-statistic for maximum and minimum temperature because of presence of ties in the data values, henceforth:

*Where:*

*n = total number of data variables.*

*t = total number of ties data values.*

**Source: Al-Mashagbah and Al-Farajat (2013**),

* Step 3. Determination of the normalized Z-statistic

If S-statistic is less than 0, (S > 0) then;

If the S-statistic is greater than 0, (S < 0) then;

**Source: Onoz and Bayazit (2003); Al-Mashagbah and Al-Farajat (2013**),

It calculates an S-statistic based on the sign comparisons of the pair and compares them to a standard Z frequency distribution. The positive values point out that there is an upsurge in rainfall and temperature while negative values indicate that there is a decrease in rainfall and temperature from 1978 to 2010. According to Al-Mashagbah and Al-Farajat (2013), the strength of the inclination is comparative to the magnitude of the S-Statistics, which therefore imply that larger magnitudes have stronger trends. The MK trend test checks null hypothesis of no trend as opposed to the alternative hypothesis of the existence of increasing or decreasing trend (Jain and Kumar 2012), at a confidence level of 95% (0.05) as shown in Table 3.2.

**Table 3.2. Approximate critical values for a two-tailed test**.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| alpha | n= 5 | n=10 | n=15 | n=20 | n=25 | n=30 | n=35 | n=40 |
| α=0.05 | 11 | 30 | 40 | 62 | 85 | 111 | 139 | 169 |
| α=0.1 | 7 | 29 | 34 | 52 | 71 | 94 | 117 | 142 |
| α=0.2 | 7 | 16 | 28 | 40 | 57 | 73 | 92 | 111 |

**Source: Hollander and Wolfe, Table A30 cited in Winkler (2004).**

* If the Z-statistic is negative and greater than the level of significance, the inclination is decreasing or
* If the Z-statistic is positive and greater than the level of significance, the inclination is increasing but
* If the Z-statistic is less than the level of significance, there is no trend.

**Source: Al-Mashagbah and Al-Farajat 2013.**

The regression analysis was used to determine annual maximum, minimum temperature and rainfall deviances from the mean and seasons of below normal and above normal were plotted using Microsoft Excel 2013. The data was presented using linear graphs because they clearly present the trend in a way easily interpreted and comprehended.

### 3.6.2 Vegetation Parameters Analysis

Vegetation parameters of paramount importance to the study include species diversity, density, species relative frequency, basal area (dominance), cover and tree height. Capodici et al (2008) is of the view that though numerous indices of diversity have been developed no standard index exists and no single index is necessarily better than another. Different techniques were used to analyze vegetation variables for instance

1. Plant species diversity was calculated using the Shannon Weiner Index (Ludwig and Reynolds 1988 cited in Mudyazhezha et al 2013).

’ =

1. Shannon Evenness Index was used to calculate species evenness,

*Where:*

*S = number of species*

*Pi = proportion of individual per species in the community made up of s species with known proportions p1; p2; p3…………ps.*

*H’ = species diversity*

1. Species relative frequency was determined by the formulae below

\* 100

*Where:*

*∑rp = number of plots in which each species occurs*

*Qs = total no of plots sampled*

1. Plant Species Richness was determined by counting the number of species identified in the inventory, a technique adopted from Mudyazhezha et al (2013).
2. Plant species density was calculated using a formulae from Mitchell and Hughes (1995), illustrated below
3. Step 1. Identifying of acreage to be used in density calculations

Acreage = (plot size) (number of plots)

Step 2. Calculating the density, D, of each species dbh class with the equation below

Dsp-dbh = number of trees sampled / Acreage sampled

Step 3. Calculating total density

*Where:*

*Dsp-dbh = density of species in each diameter at breast height.*

1. The total basal area cover per acre for the tree species in the woodland was determined by calculating the basal area conversion factor (BACF) and multiplied by total density of the tree species. The procedure was adopted from Mitchell and Hughes (1995), as illustrated below,

Step 1. The BACF for a tree species was determined first by using the midpoint value for the stem diameter (d) multiplied by the constant 0.005454 square inch (0.035187 cm2), which converts the diameter to cross-sectional area in square feet, as shown by equation below

Step 2. The basal area for a tree species was calculated using the formulae below,

Step 3. The total basal area (dominance) was determined by summation of all tree species basal area value, as illustrated by an equation below

Microsoft Excel 2013 was used to analyze woody vegetation structure data and the calculated data on vegetation density, basal area, species diversity, frequency, dominance was presented in statistics, tabular formats and bar graphs. In addition, data from key informant interviews were categorized by hand by the researcher. The findings from the analyzed data were presented using graphs, tables.

# CHAPTER FOUR: RESULTS AND DISCUSSION

## 4.1 Floristic Structure and Composition Physiognomies.

The researcher identified different species which constitute the vegetation structure and composition characteristics of Mutoko District. Vegetation considerations such as species diversity, richness, dominance, density and relative frequency among others were determined.

### 4.1.1 Species Richness, Diversity and Dominance.

A total of 57 plant species were recorded, of which 46 plant species were trees (as shown in Table 4.1) and 3 species were shrubs, 9 species were grasses. Of the 46 woody or tree species, the most abundant species were *Brachystegia Spiciformis, Julbernadia Globiflora, Erythrina Abyssinica, Burkea Africana, Combretum Molle, Lannea Discolor, Bauhinia Thonningii, Strychnos Spinosa/cocculoides, Munyada, Chibayamakono, Mumbumbu* etc*.* Also tree species such as *Garcinia Buchananii, Parinari Curatellifolia, Berchemia Zehyeri, Bauhinia Petersiana* and *Uapaca Kirkiana* were least dominant in the area (as shown in Table 4.1). The under layer of the canopy was dominated by *Brachystegia* species*, Burkea Africana*, *Dobeya Rotundifolins, Julbernadia Globiflora, Erythrina Abyssinica, Terminalia Sericea, Turraea Nilotica, Garcinia Buchananii, Pseudolachnostylis Maprouneifolia, Munyada, Mubarichirwa, Muzharoro*. Shrubs identified were from species such as, *Nania Edulis* (tsambatsi), *Anona Senegalensis* (maroro) and *Peltophorum Africanum* (muzeze). The floristic composition especially the grasses were dominated by species such as., *Cynodon Dactylon* (tsangadzi), *Hyparrhenia* species (dangaruswa), *Eragrostis* species (pisa imba), *Andropogon*, *Indigofera*, *Digitaria Ternata* (tsinde), *Scleria Foliosa* (jekacheka), *Cyperus Esculentus* (pfende).

**Table. 4.1. Tree species sampled, symbol (S), quantity (Q), Shannon Weiner index (H’) and their relative frequency (RF).**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **No**. | **Native Name** | **Botanical Name** | **S** | **Q** | **(H’)** | **RF** |
| 1 | Musasa | Brachystegia Spiciformis | BS | 121 | 0.245 | 58.7 |
| 2 | Munhondo | Julbernadia Globiflora | JB | 106 | 0.234 | 52.4 |
| 3 | Mutiti | Erythrina Abyssinica | EA | 52 | 0.149 | 30.0 |
| 4 | Mukarati | Burkea Africana | BA | 51 | 0.147 | 38.0 |
| 5 | Mumbumbu | - | MB | 47 | 0.139 | 30.0 |
| 6 | Mugodo | Combretum Molle | CM | 45 | 0.136 | 31.7 |
| 7 | Mushamba | Lannea Discolor | LD | 38 | 0.121 | 17.5 |
| 8 | Munyada | - | MU | 38 | 0.121 | 23.8 |
| 9 | Chibayamakono | - | CB | 37 | 0.119 | 23.8 |
| 10 | Mususu | Terminalia Sericea | TS | 35 | 0.114 | 17.5 |
| 11 | Mutamba | Strychnos Spinosa | SS | 32 | 0.107 | 20.6 |
| 12 | Muparamhosva | - | MP | 26 | 0.092 | 19.0 |
| 13 | Mucherekese | Swartzia Madagascariensis | SM | 25 | 0,089 | 14.3 |
| 14 | Mutsvitsviriondo | Dobeya Rotundifolins | DR | 23 | 0.085 | 15.8 |
| 15 | Mumbumi | Strychnos Cocculoides | SC | 23 | 0.085 | 17.5 |
| 16 | Mutukutu | Bauhinia Thonningii | BT | 23 | 0.085 | 15.8 |
| 17 | Mubarichirwa | - | MA | 22 | 0.081 | 15.8 |
| 18 | Mutufu | Vangueriopsis Lanciflora | VL | 20 | 0.076 | 9.5 |
| 19 | Muunze | Brachystegia Glaucescens | BG | 20 | 0.076 | 14.3 |
| 20 | Muchecheni | Ziziphus Mucronata | ZM | 19 | 0.073 | 11.0 |
| 21 | Mungongoma | Afzelia Quanzensis | MG | 18 | 0.070 | 11.0 |
| 22 | Muwara | - | MW | 15 | 0.061 | 14.3 |
| 23 | Munzvanzvara | Cata Edulis | CE | 15 | 0.061 | 12.7 |
| 24 | Muwanga | Pericopsis Angolensis | PA | 14 | 0.058 | 14.3 |
| 25 | Munhunguru | Flacourtia Indica | FI | 14 | 0.058 | 11.0 |
| 26 | Mukuyu | Ficus Capensis | FC | 13 | 0.055 | 17.5 |
| 27 | Mupfuti | Brachystegia Boehmii | BB | 13 | 0.055 | 11.0 |
| 28 | Nhenzvera | - | NH | 13 | 0.055 | 9.5 |
| 29 | Muzharoro | - | MZ | 13 | 0.055 | 15.8 |
| 30 | Munhengeni | Xmenla Caffra | XC | 12 | 0.052 | 11.0 |
| 31 | Mutsvonzvowa | Pseudolachnostylis Maprouneifolia | PM | 12 | 0.052 | 7.9 |
| 32 | Mutunduru | Garcinia Buchananii | GB | 11 | 0.048 | 9.5 |
| 33 | Mupangara | Dichrostachys Cinerea | DC | 11 | 0.048 | 12.7 |
| 34 | Chipindura | Turraea Nilotica | TN | 11 | 0.045 | 11.0 |
| 35 | Munzviru | Vangueria Infausta | VI | 10 | 0.045 | 11.0 |
| 36 | Musuka | - | MS | 09 | 0.041 | 7.9 |
| 37 | Mutsomo | Sclerocarya Caffra | SB | 07 | 0.034 | 7.9 |
| 38 | Mutsubvu | Vitex Payos | VP | 06 | 0.029 | 9.5 |
| 39 | Muhacha | Parinari Curatellifolia | PC | 05 | 0.026 | 1.5 |
| 40 | Mukute | Sygyzium Guineense | SG | 03 | 0.016 | 3.0 |
| 41 | Mutohwe | Azanza Garcekeana | AG | 02 | 0,012 | 1.5 |
| 42 | Mushinga | Lanca Discolor | LDs | 02 | 0.012 | 1.5 |
| 43 | Munyii | Berchemia Zehyeri | BZ | 02 | 0.012 | 1.5 |
| 44 | Mushenje | Diospros Mesplifomis | DM | 02 | 0.012 | 1.5 |
| 45 | Mun’ando | Bauhinia Petersiana | BP | 01 | 0.006 | 1.5 |
| 46 | Muzhanje | Uapaca Kirkiana | UP | 01 | 0.006 | 1.5 |

Out of the 46 tree species identified, 1038 **(Appendix 5)** trees were recorded from 63 sample plots, and the Shannon-Weiner Index (H’) of 3.814 **(Appendix 6)** therefore imply that the woodland has a higher woody plant species diversity and Shannon Evenness Index of 0.99 **(Appendix 7)** which henceforth indicated that there was complete evenness for the woodland. Plant species recorded to have contributed to high species diversity are illustrated in Table 4.1 in accordance with their (H’) diversity. The high value of H’ would be an illustration of a diverse and equally distributed community and a lower value denote less diversity (Giliba et al 2011). Comprehensively, the results suggests that diversity and evenness in the woodland are much greater as there are great quantities of species present however, individual species in the community were equitably and evenly distributed in the midst of these species.

From the interviews held by the researcher with Councilors and the FEO further confirms that the identified plant species such as *Brachystegia Spiciformis, Julbernadia Globiflora, Erythrina Abyssinica, Burkea Africana, Combretum Molle, Lannea Discolor, Bauhinia Thonningii, Strychnos Spinosa/cocculoides, Munyada, Chibayamakono, Mumbumbu,* *Garcinia Buchananii, Parinari Curatellifolia, Berchemia Zehyeri, Bauhinia Petersiana* and *Uapaca Kirkiana* among others are found in the district. They are evenly distributed and interspersed in the district, nevertheless species of miombo woodlands are the dominant species but intermixed with species from combretum/terminalia and acacia woodlands. Furthermore, in areas devoid of miombo woodland species, acacia woodland species intermixed with combretum and terminalia dominates.

The overall distribution of plant species especially grasses were distributed accordingly to wetness, implying that species such as *Andropogon*, *Scleria* *Foliosa* were dominant in wet areas such as wetlands whereas *Hyparrhenia* was also found in wetlands and dry areas but species such as *Eragrostis, Digitaria Ternata* and *Cyperus* *Esculents* dominated dry areas. In addition, areas considered to be the hottest and driest such as Hari, Mbudzi and Makosa among others are heavily degraded and they are dominated by species such as *combretum, terminalia* and *acacia*. Whereas areas considered to be wetter in the district for instance Hoyuyu, Gumbure-Mtambwe, Nyahondo, Nyadiri are dominated by species such as *Brachystegia Spiciformis, Julbernadia Globiflora, Erythrina Abyssinica, Burkea Africana, Combretum Molle, Lannea Discolor, Bauhinia Thonningii, Strychnos Spinosa/cocculoides, Munyada, Chibayamakono, Mumbumbu,* *Garcinia Buchananii, Parinari Curatellifolia, Berchemia Zehyeri, Bauhinia Petersiana* amongothers.

### 4.1.2. Species Density according to Diameter at breast height

The gathered data from the inventory suggested that vegetation in the district is composed of different species which are from different genera for instance *brachystegia, combretum* and *terminalia*. Of the collected species, it seemed as most species were ranged in diameter at breast height of 6 – 12cm. Most tree species such *as Brachystegia Spiciformis, Julbernadia Globiflora Erythrina Abyssinica, Burkea Africana, Combretum Molle* and *Lannea Discolor* dominated dbh-sp class 6, followed by dbh-sp 7 and 8. Lower dbh-sp classes were dominated by these species because they are often utilized in household livelihoods and they are evenly distributed and located near homesteads, hence they are felled frequently and with dry conditions prevailing in the district growth of indigenous trees would be sluggish, hence they have highest percentage total species density as illustrated in Figure.4.1. Species in larger dbh-sp classes were few but they were dominated by *Brachystegia Spiciformis, Julbernadia Globiflora* and *Combretum Molle* and these species were located near the hillside difficult to access, thus clarifying that the district consists of tree species in old growth and mixed ages but, most of the tree species dominates the lower dbh-sp classes meaning that the area consist of young growing tree species or it’s a rejuvenating district. The inverted “J” shape as illustrated in Figure.4.1 maybe an indication of active regeneration and recruitment (Phillip 1983 cited in Giliba et al 2011).

**Figure 4.1. Percentage total of species density according to dbh-sp class.**

### 4.1.3. Individual species density.

In addition, individual species density was dominated mostly by two species which consist of *Brachystegia Spiciformis* and *Julbernadia Globiflora* which were 18.78 trees per square metre and 16.45 trees per square metre respectively, while *Uapaka Kirkiana* and *Bauhinia Petersiana* were the least species with a density of 0.15 trees per square metre and 0.15 trees per square metre respectively. The main reason for dominance of *Brachystegia Spiciformis* and *Julbernadia Globiflora* might be that their seedlings can survive up to 12 days of severe dry conditions but very few miombo species can survive beyond these drought circumstances, whereas seedling for species such as *Uapaka* *Kirkiana* easily die from very severe dry conditions (Makoni 1992; Chidumayo 1993a cited in Campbell 1996). It therefore, indicated the impetus behind *Brachystegia Spiciformis* and *Julbernadia Globiflora* dominance in dbh-sp classes 6, 7, 8 and 9. Figure.4.2 shows how the total species density of 161. 19 trees per square metre was distributed among species. Individual species density in Figure.4.2 indicated that compositionally the district is dominated by miombo species which are *Brachystegia* species, *Julbernadia Globiflora, Burkea Africana*, *Erythrina Abyssinica* but also encompass other species from different woodlands, for instance, combretum/terminalia such as *Combretum Molle* and *Terminalia Sericea* among others.

**Figure.4.2. Distribution of species density according to specific species.**

### 4.1.4. Basal Area per acre (Dominance).

Figure.4.3 shows that dbh-sp classes 6-10 dominated the total percentage basal area hence, they cover the large area in the district. Irregardless of dbh-sp class 6 having the highest number of trees (275 trees), dbh-sp class 7 has the highest total percentage basal area, of which it has 258 trees, which therefore indicated that it covers a larger area in square meters per acre than species in dbh-sp class 6. Other dbh-sp class such as 28 have 2 trees (2.06%) but their total percentage basal area per acre is greater than other dbh-sp class with more than 2 trees such as 20 (0.53%), and 15 (1.16%) because of their larger dbh, they also cover larger area but has the same percentage with dbh-sp class 16 with 5 trees (2.06%).

**Figure.4.3. Percentage total of basal area according to dbh-sp class**

### 4.1.5. Individual species basal area per acre or Individual dominance.

Species such *as Brachystegia Spiciformis, Julbernadia Globiflora, Combretum Molle, Erythrina Abyssinica, Burkea Africana* and *Mumbumbu* have the highest individual species basal area per acre out of the 46 **(Appendix 10)** and have the highest number of trees sampled **(Appendix 5).** Plant species with low numbers of trees sampled also have low individual species basal area per acre such *as Uapaka Kirkiana, Bauhinia Petersiana, Berchemia Zeyheri and Diosporos Mespilifomis.* The lower the index value, the lower the dominance of a single species (Edward 1996 cited in Giliba 2011). Figure.4.4 illustrates that species with higher basal area per acre, are also the same species which dominates dbh-sp class 6-10, henceforth they cover a larger area than any other species, and thus they are dominant and evenly distributed in the district.

**Figure.4.4. Distribution of basal area per acre according to specific species.**

## 4.2. Changes in Climate in Mutoko District

The interviewed councilors, EMAO and DAO indicated that temperature is changing but it is generally increasing, however the EMAO and DAO further alluded that maximum temperature is increasing while minimum temperature is decreasing in Mutoko District. The increase in annual mean maximum temperature for Mutoko District is also similar to the increase in national annual mean maximum temperature. The councilors interviewed pointed out that precipitation has been decreasing for the past years, because it usually rain in October but currently it now starts in December. However, the Environmental Management Agency Officer and District Agriculture Officer indicated that precipitation is changing but it is increasing nevertheless the rain seasons are becoming shorter, even though rain falls in large quantities in a short epoch of time (December to Mid-February). Shumba et al 2012 also concluded that rain season in Mutoko would be shorter than 110 days. Therefore, changes in climate in Mutoko District are physical as the most imperative climatic variables, precipitation and temperature are changing.

### 4.2.1. Determination of trend on precipitation.

From the interviews conducted by the researcher, precipitation in Mutoko District is increasing irregardless of shifts and shortening rain seasons. Figure 4.5 illustrates a line graph displaying the seasonal precipitation totals as they deviate above or below the mean of 711mm for the district. Distinct fluctuations of dry seasons were observed from the late 1970s to early 2000s. Extreme dry seasons were detected during the 1979/80, 1981/82, 1982/83, 1983/84, 1990/91, 1991-1995, 2001/2, 2002/3, 2004/5, 2006/7 at which the precipitation was extensively below normal, the discrepancies in pattern seemed to follow the ENSO events (Gwimbi 2009; Feresu 2010) and some of these years were associated with droughts at national scale (Zambuko undated). The wettest seasons were detected during the 1980/81, 1984/85, 1996/97, 1998/99, 1999/2000. Irregardless of effects of ENSO events on precipitation, the trend-line in Figure.4.5 shows a positive trend on annual mean precipitation for Mutoko District from 1978-2010 which therefore indicated that precipitation in Mutoko District has been increasing for the past 32yrs (1978-2010).

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**Figure.4.5. Mutoko District annual precipitation anomalies from 1978-2010. (MSD)**

#### 4.2.1.1 Hypothesis Testing.

**H0. Assumes that there is no statistical significance in increase in annual precipitation from 1978-2010.**

**H1. Assumes that there is a statistical significance in increase in annual precipitation from 1978-2010.**

If the S-statistic exceeds the critical value then there is a significant trend (Winkler 2004) at 95% (0.05). The S-Statistic (90) is less than the critical values (139) nevertheless, it is positive, therefore reject **H1**then accept **H0**. In this case there is no statistical significant increase in annual mean precipitation from 1978-2010 for Mutoko District. The Z-Statistic also positive and greater than the level of significant, hence annual mean precipitation is increasing. MK trend analysis divulges an insignificant increasing trend in annual precipitation in Mutoko District from 1978-2010.

### 4.2.3. Determination of trend on annual mean minimum temperature

Figure.4.6 illustrates that annual mean minimum temperature analysis shows a distinct trend towards lower temperatures. The negative trend can be detected for annual mean minimum temperature times-series in Mutoko District from 1978 to 2010. The sturdy negative trend-line in annual mean minimum temperature maybe associated with the substantial upsurge in the incidence of winter months. The interviewees’ perceptions on diminution in annual mean minimum temperature in the district was that, winter months are increasing and their coldness are becoming very severe despite the fact that temperature is generally upsurging.

**Figure.4.6. Mutoko district annual minimum temperature anomalies from 1978-2010. (MSD)**

#### 4.2.3.1 Hypothesis Testing.

**H0. Assumes that there is no statistical significance in decrease in annual minimum temperature from 1978-2010.**

**H1. Assumes that there is a statistical significance in decrease in annual minimum temperature from 1978-2010**

If the S-statistic exceeds the critical value then there is a significant trend (Winkler 2004) at 95% (0.05). The S-Statistic (-160) is less than the critical values (139) but the strength of the trend is comparative to the magnitude of the S-statistic (Al-Mashagbah and Al-Farajat 2013) henceforth the larger the negative magnitude the stronger the trend, hence reject **H0** then accept **H1**. In this case there is a statistical significant decrease in annual mean minimum temperature from 1978-2010 for Mutoko District. The Z-Statistic is negative and greater than the level of significant, hence annual mean minimum temperature is decreasing. MK trend analysis divulges a distinct significant decreasing trend in annual mean minimum temperature in Mutoko District from 1978-2010.

### 4.2.5. Determination of Trend on Annual Mean Maximum Temperature

There were anomalies in the annual mean maximum temperature in Mutoko District, particularly after the 1979/80 season, as illustrated in Figure.4.7. The trend-line in Figure.4.7 illustrates a positive trend on annual mean maximum temperature in Mutoko District from 1978-2010, henceforth indicated that annual mean maximum temperature in Mutoko District has been increasing for the past 32yrs (1978-2010) towards higher temperatures. The increase in annual maximum temperature mighty be due to increase in frequency of incidences of hot days (Jain and Kumar 2012). From the interviews conducted by the researcher, the observations of respondents were that, night temperature and daytime temperatures are evenly becoming warmer in this district and summer months temperatures are correspondingly becoming warmer with an increase in the length of summer months. The increase in temperature in the district, was consistent with the general view of an increasing temperature at an average of 0.05 degrees per decade in Zimbabwe (Kandji et al. 2006 cited in Gwimbi 2009).

**Figure.4.7. Mutoko District annual maximum temperature anomalies from 1978-2010 (MSD)**

#### 4.2.5.1. Hypothesis Testing.

**H0. Assumes that there is no statistical significance in increase in annual maximum temperature from 1978-2010.**

**H1. Assumes that there is a statistical significance in increase annual maximum temperature from 1978-2010**.

If the S-statistic exceeds the critical value then there is a significant trend (Winkler 2004) at 95% (0.05). The S-Statistic (39) is less than the critical value (139) but it is positive therefore reject **H1**then accept **H0**. In this case there is no statistical significant increase in annual mean maximum temperature from 1978-2010 for Mutoko District. The Z-Statistic is positive and greater than the level of significant, hence annual mean maximum temperature is increasing. MK trend analysis divulges an insignificant increasing trend in annual mean maximum temperature in Mutoko District from 1978-2010.

### 4.2.6 Evidence of Climate Change in Mutoko District

Climate change in Mutoko District is now evidenced as frequency of occurrences of hunger and droughts in the past years have increased this can be supported from the analysis of precipitation data in Figure.4.5, for instance 1979/80, 1981/82, 1982/83, 1983/84, 1990/91, 1991-1995, 2001/2, 2002/3, 2004/5, 2006/7 were drought seasons. EMAO revealed that rivers which were perennial are no longer perennial as they now only flow during the rainy season, for example Nyadire and Nyabopota. The main reasons been that the rainy seasons are becoming shorter, of less than 100 days and maximum temperatures (Figure.4.7) are increasing and the district is dominated by sandy loam soils therefore, evapotranspiration rates are high. In addition, EMAO, DFEO and Councilors indicated that there were disappearances, mortalities and drying up of certain indigenous tree species such as mukute (*Sygyzium Guineense*), mun’ando (*Bauhinia Petersiana*) and muzeze (*Peltophorum Africanum*) and decrease in the quality of fruits were been related to climate change in the district. Zimbabwe is located in the dry miombo woodland which usually receives rainfall less than 900mm and Campbell (1996), indicated that for both dry and wet miombo woodlands annual mean precipitation and annual mean temperature ranges from 710 – 1365mm and 18.0 and 23.1°c respectively. However this might not be case in Mutoko District as annual mean precipitation ranges from 473.9 – 1078 mm and annual mean temperature range, minimum and maximum ranges from 13.0 – 14.7°c and 25.0 – 27.2°c respectively from 1978 - 2010. Hence, tree species and fruits have been circuming to simultaneous changes in feasible conditions as they experience both severely warmer, colder temperatures, wetter and drier within a short space of time and this might be evidence to show that the district might be in the transition phase and plant species are expected to be lost (Smith and Tirpak 1989 cited in Winnet 1998), they might be shifting to more suitable areas.

## 4.3 Local People’s Perception and Climate Change on Phenology

The researcher revealed that perceptions of local inhabitants of Mutoko District correlate climate change to impacts affecting vegetation, phenological seasons, processes and the quantity and quality of indigenous fruits.

### 4.3.2 Climate Change Related Modification on Phenological Seasons

As Mutoko District is dominated by miombo species, it therefore imply that most plant species should follow the five phenological seasons of miombo delineated by researchers such as Boaler 1966; Astle 1969; Malaisse 1974; Chidumayo 1993 cited in Campbell (1996). The phenological seasons includes September-October (warm, dry pre-rain season), November-December (early rain season), January-February (mid-rainy season), March-April (late rainy season), and May-August (cool dry season). However, this may not be case currently occurring in Mutoko District, as it is evidenced that there might be a shift in these phenological seasons due to climate change affecting the district. Particularly in Mutoko District, phenological seasons currently appears resembling only three of the five seasons, September-November (warm, dry pre- rain seasons), December- February (rainy season), March-August (cool dry season). Early rainy season (Nov-Dec) and late rainy season (Mar-Apr) seems like they are now part of phenological season’s warm, dry pre-rain season and cool dry season respectively. The responses indicates that it looks like phenological seasons such as warm, dry pre-rain, cool dry have been lengthened by more than 30 days and the rainy season has been shortened to less than 100 days. Almost 95% of the annual precipitation usually befall in a 5 – 7 single wet season (Campbell 1996), as shown in Table 4.2.

**Table 4.2. Alterations in phenological season.**

|  |  |
| --- | --- |
| **Delineated Phenological Seasons** | **Altered Phenological Seasons** |
| Warm, dry pre-rain season (Sep-Oct) | Warm, dry pre-rain season (Sep-Nov) |
| Early rain season (Nov-Dec) | - |
| Mid-rainy season (Jan-Feb) | Rainy season (Dec-Feb) |
| Late rainy season (Mar-Apr) | - |
| Cool dry season (May-Aug) | Cool, dry season (Mar-Aug) |

(**Source: Campbell et al 1996)** (**Source: Field Work, 2014)**

### 4.3.3 Climate Change related Modification on Phenological Processes.

The timing sequence of plant species associated to miombo woodlands are influenced by rainfall, temperature and seasonal variations in soil moisture (Campbell 1996). Temperature and rainfall are the most important climatic variables which determine soil moisture, processes either nutrient cycling or decompositional hence they are a prerequisite to form a niche or refugia for certain plant species. Therefore any change in temperature and rainfall, for instance occurring in Mutoko District imply that phenological processes of some fruit tree species may have been disrupted.Indigenous fruit tree species associated with miombo woodland, recorded in the inventory includes mushenje *(Diospros Mesplifomis),* mutufu *(Vangueriopsis Lanciflora)*, mumbumi *(Strychnos Cocculoides)*, munhunguru *(Flacourtia Indica)*, muhacha *(Parinari Curatellifolia)*, munzviru *(Vangueria Infausta)*, munyii *(Berchemia Zehyeri*), mutamba *(Strychnos Spinosa)*, munhengeni *(Xmenla Caffra)*, mutohwe *(Azanza Garcekeana)*, mutsvubvu *(Vitex Payos)*, muzhanje *(Uapaka Kirkiana),* mutsomo *(Sclerocarya Caffra)*, mukute *(Sygyzium Guineense)* among others. Some of these fruit tree species have different timing sequences but most of them follow the delineated sequence; leaffall, leafflush, flowering, fruiting and ripening.

Malaise (1978a), Ernst (1988) cited in Campbell (1996) asserted that most mast fruiting to be a biennial phenomenon, which therefore mean that most miombo fruit tree species phenological processes occur once in a year for instance fruition and ripening but these processes may occur throughout the year from July to June. The modification or shift in phenological processes in Mutoko District are not yet well pronounced but with the current transition in climate there are evidences of shifts, for instance *Uapaka Kirkiana* which was biennial in the district is now flowering at two intervals in March-April and August-September, henceforth there are possibilities of having two harvest in a year especially in August or December. Furthermore, other species such as *Diospros Mesplifomis, Vangueriopsis Lanciflora*, *Strychnos Cocculoides*, *Flacourtia Indica* and *Xmenla Caffra* have shifted from their normal months of ripening but differential accordingly with wards in the district, for example *Strychnos Cocculoides* usually ripens in August to October but currently in some wards it ripens from June to November. It looks like the length of these phenological processes seasons of occurrence to have been prolonged. Increase in temperatures are already affecting phenology in many species of fruit trees (Sugiura et al 2013). Table 4.4 shows the shift in the general timing sequence processes seasons.

**Table 4.3. Alterations in the timing sequence of processes.**

|  |  |  |
| --- | --- | --- |
| **Timing Sequence of Processes** | **Period of Occurring** | **Altered Phenological Seasons** |
| Leaffall | August - October | September - November |
| Leafflush | September-October | September - November |
| Flowering | September- October | March - November |
| Fruiting | July-June | July-June |
| Ripening | July-June | July-June |

**(Source: Field Work, 2014)**

### 4.3.4 Climate Change Impact on Fruit Production Quality and Quantity.

**Figure.4.8 Respondents’ perceptions on changes on aspects of indigenous fruit tree species.**

#### 4.3.4.1 Changes in Indigenous Fruit Yields Linked to Climate Change.

From the interviews held by the researcher, a 100% response pointed out that yields are changing and believe that climate change has been influencing productivity. Majority of the respondents have the perception that yields of indigenous fruits were decreasing. Of the total interviewees, 86% indicated that indigenous fruit tree species yields vary from year to year but generally they are decreasing in the district (as illustrated in Figure.4.8), because of climate change which has influenced the temperature and rainfall patterns to the extent that flowers and fruits fall due to lack of sufficient water, higher temperatures and severely cold winters, hence a reduction in yields, for instance *Uapaca Kirkiana, Azanza Garcekeana* and *Sygyzium Guineense* among others. Poor yields usually results from severely winter months which cause injuries on apple fruits (Caprio and Quamme 1999 cited in Basannagari and Kala 2013). However, 14% of the interviewees indicated that yields are increasing because the climatic conditions are becoming favourable.

#### 4.3.4.2 Changes in Indigenous Fruit Sizes Linked to Climate Change.

The perceptions of the interviewees on changes of fruit sizes varied with the expertise and athwart the district. Majority of the interviewees’ believed that changes in climate, particularly increment in temperature and rainfall were responsible for the changes in fruit sizes. About 72% of the respondents were of the view that indigenous fruit sizes were changing either to larger sizes or to smaller sizes and 28% of the respondents indicated that indigenous fruit sizes were not changing. Of the total interviewees, 57% indicated that climate change has deleteriously impacted the size of most these indigenous fruits, especially temperature as they now produce smaller sizes. The reason been that summer temperatures are increasing and rain falls for shorter time than it usually did in 1980s and 1990s, hence most of them do not reach maturity stage such as *Vangueriopsis Lanciflora*, *Uapaca Kirkiana, Strychnos Spinosa,* and *Azanza Garcekeana*. About 28% of the interviewees indicated that irrespective of changes in climate in the district indigenous fruit sizes were still normal, they are not changing. In addition, there were improvement of fruit sizes to larger sizes by 14% of the interviewees, as a result of changes in climate because, changes in rainfall and temperature have created more suitable conditions required to produce larger fruit sizes for example *Flacourtia Indica* and *Diospros Mesplifomis* (as illustrated in Figure.4.8). Usually summer temperatures and climatic circumstances influence the fruit sizes for instance apples in India (Basannagari and Kala 2013).

#### 4.3.4.3 Changes in Indigenous Fruits Textural Attributes linked to Climate Change.

Findings from the interviews conducted by the researcher, indicated that perceptions of interviewees also varied with the expertise and across the district. Most of the respondents indicated that changes in textural attributes of indigenous fruits were mainly due to changes in phenological seasons which have a causal-effect on temperature and rainfall required to produce quality fruits. About 72% of the respondents were of the view that indigenous fruit tree species textural attributes have changed and are producing either hardened or softer fruit products with meagre appearance and 28% of the respondents indicated that indigenous fruit tree species are producing the same fruits with unchanged textural attributes. Of the total respondents, 28% of the respondents acknowledged that textural attributes of indigenous fruits are not changing but 14% of the interviewees indicated that indigenous fruits textural attributes are changing as some fruit tree species such as *Diospros Mesplifomis* and *Vitex Payos* are now more soft and have better quality in terms of colour, shape whereas, 58% of the interviewees indicated that textural attributes of some indigenous fruit tree species such as *Vangueriopsis Lanciflora*, *Azanza* *Garcekeana,* *Vitex Payos*, *Xmenla Caffra* and *Flacourtia Indica* are changing as they are now producing hardened fruit products with deteriorated appearance as they have poor colour and spots, their shapes looks deformed (as illustrated in Figure.4.8), because of shifts in phenological seasons which therefore impact on phenological processes which have been extended more to dry cool season. The number of heating days might affect the softening of fruits (Blanke and Kunz 2003 cited in Sugiura et al 2013), fruits shapes are also influenced by climate and increasing temperature affect the fruit colour and quality (Goldschmidt 1997; Basannagari and Kala 2013). Sigiura et al (2013) concluded that climate change in Japan has caused textural attributes of apples to change. Figure.4.9 illustrates interviewees’ perceptions on how climate change has impacted on textural attributes of indigenous fruits.

**Figure.4.9 Respondents’ perceptions on changes of textural attributes of indigenous fruits.**

#### 4.3.4.4. Changes in Taste of Indigenous Fruits Linked to Climate Change

Usually the taste of a fruit is unique consequently to area of origin, because they would have adapted to the climatological and environmental conditions. From the interviews conducted by the researcher, 58% pointed out that the change in climate has negatively impacted on the taste of fruits in the district as the quality of taste has been deteriorating (as illustrated in Figure.4.8), for example on most of the fruits such as *Vangueriopsis Lanciflora*, *Strychnos Spinosa*, *Vangueria Infausta*, *Xmenla Caffra* and *Flacourtia Indica* among others. The main reasons been that temperatures are rising and the rain seasons are now shorter and have downpours therefore, adequate soil moisture would be available for only a shorter period and there are possibilities of loss of nutrients due to high erosion and leaching, hence most of these fruits reach maturity stage in dry and unfavourable circumstances which are not feasible to produce quality taste as they would be in need of ample water or nutrients. Rojas (2013) also pointed out that deterioration in taste of fruits might be a consequence of downpours and variations in temperature and Sugiura et al (2013) indicated that current warming in climate has caused changes in taste of apples in Japan. In addition, 28% of the interviewees’ indicated that irregardless of climate change taste of fruits is still normal, it is not changing and 14% of the interviewees’ indicated that the taste of these fruits particularly *Diospros Mesplifomis*, *Vangueriopsis Lanciflora*, *Berchemia Zehyeri* are now tasting sweeter, the quality of taste has been improving. Of the total interviewees, 72% acknowledged that taste is changing either to a better taste or to a bad taste and 28% of the respondents indicate that taste is not changing.

### 4.3.5. Pests and Climate Change

The change in phenological seasons and processes can make plant species more vulnerable to pest and diseases outbreaks (SCBD 2003). In Mutoko District issues of pests and diseases affecting vegetation could not be determined because, the local inhabitants were not aware of the pests and disease which affect indigenous trees, cannot quantify and determine types of insects/pests. Most of the respondents thought that indigenous plant species as wild and natural therefore, have no need to monitor pests and diseases, hence it was impossible to detect if there were any changes in frequency of occurrence which might be related to climate change but they are possibilities that vegetation might be been affected by pests/insects and diseases because indigenous fruits occur to have blights such as *Flacourtia* *Indica* (munhunguru) and *Xmenla* *Caffra* (munhengeni).

# CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

In Africa, particularly SSA countries little considerations have been done to assess the implications of climate change on vegetation, especially miombo woodland as it dominate more than 10 countries. It is clear from this research that miombo woodland dominates and climate is changing in Mutoko District as annual mean rainfall and maximum temperature are increasing but have insignificant trends, nevertheless annual mean minimum temperatures is decreasing but has a significant trend as from 1978-2010. The findings from the study are in conjunction with the conceptual framework (Figure.2.2) which illustrate that changes in rainfall and temperature leads to alterations on the ecosystem causing changes in the functioning of ecosystems, species richness, distribution, structure and composition. Climate changes, chiefly rain falls in a short period of time in large quantities and severely hot and cold temperatures were been related to mortalities, disappearances or drying of tree species such as *Sygyzium Guineense, Bauhinia Petersiana* and *Peltophorum Africanum.* In addition, this change in climate has altered five plant phenological seasons to three phenological seasons, which have sequentially impacted on phenological processes of many plant species to the extent that there is an extension in phenological processes by almost 30 days, for instance species such as *Strychnos Cocculoides,* *Diospros Mesplifomis, Vangueriopsis Lanciflora*, *Strychnos Cocculoides*, *Flacourtia Indica, Xmenla Caffra* and *Uapaka Kirkiana* etc*.* The change in phenological processes has caused yields of indigenous fruit tree species to generally decrease and change in textural attributes of most of the indigenous fruit tree species to the extent that they are producing hardened fruits with meagre appearances as they have poor colour, their shapes seems deformed, they have spots, small fruit sizes and untasteful and other indigenous fruit tree species are producing soft and good quality fruits of larger sizes, have attractable colour and are tasteful. Therefore, the researcher concludes that changes in climate have impacted on vegetation in Mutoko District.

## 5.2 Recommendations

* The Government of Zimbabwe and its parastatal boards involved in environmental issues such as FC and EMA in partnerships with NGOs and international organs such WWF, FAO among others, should spearhead an evaluation or assessment project to identify and measure the implication of climate change on individual indigenous plant species as plant species have differential scales of photo-periods and hydro-periods hence respond and adapt to changes in climate at different rates, which therefore make it difficult to ascertain actual extent of implication of climate change on vegetation at a general scale. Failure to ascertain the actual extent of change can negatively impact rural livelihoods and food security.
* There is a necessity for EMA, FC and NGOs to educate the rural folk on climate change and its implications on vegetation, as there is evidence of effects of climate change on vegetation. The rural folk depend most on forestry related resources and products for income generation, social, health and spiritual well-being etc.
* FC should create a database or implement projects from ward to district then national level that should record or take into account at annual scale the dates, months of occurrence of phenological processes such as leaffall, leafflush, flowering, ripening, in order to make it easier for researchers to access authentic data and have a precise and accurate results, as most local inhabitants in rural areas do not take in to account issues of phenology seriously.
* FC should have a database of rate of occurrences, types of pest, insects and diseases affecting indigenous tree species and they should educate local inhabitants in rural areas of different types of pests, insects and diseases to determine if any changes are occurring, hence make it easier for researchers who wish to study the impacts or anything related to insect, pest or diseases on indigenous tree species.

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# Appendices

**APPENDIX 1: Interview guide for Councilors**

1. How long have you lived in this area?
2. Which tree species can we find in this ward?
3. Which types of tree species dominates in this ward?
4. How are tree species distributed in this ward?
5. Which types of grasses can we also find in this ward?
6. How are grass species distributed in this ward?
7. How has precipitation been changing in this ward, since 1978?
8. What evidence is there on vegetation to show that precipitation is changing?
9. How has temperature been changing in this ward, since 1978?
10. Are there any changes in night temperature in this ward, if yes, what is happening?
11. Are winter months usually cold as they used to, if no, why?
12. What is happening?
13. Are there any changes in daylight temperatures in this ward, If yes, what is happening?
14. Are summer months usually hot as they used to, If no, why?
15. What is happening?
16. What evidence is there on vegetation to show that temperature is changing?
17. Which pests or diseases usually affects trees in this ward?
18. In your lifetime in this ward, have there been any changes on frequency of occurrences of pest or diseases on trees.
19. If yes, which pest or diseases rate of occurrence is changing and how?
20. Which tree species are mostly affected?
21. What do you think might be the cause of the change in rate of occurrence?
22. Which indigenous fruit tree species are mostly found in this ward?
23. Are these tree species yielding fruits as they used to, if no, why?
24. Are these yielded fruits sizes still the same, if no, why?
25. Is the firmness of these fruits still the same, if no, what is happening to them?
26. Are these fruits still tasting as they used too, if no why?
27. Are these fruits still following the timing sequence, they used to follow? If no,

* Which months of the year are they likely to flower?
* Which months of the year are they likely to have leaf fall?
* Which months of the year are they likely to ripen?
* Which months of the year are they likely to fruit?

1. Which months of the year were they used to?

* Flower
* Leaf fall
* Ripen
* Fruit

**APPENDIX 2: Interview guide for the FEO**

1. Which are the major tree species found in this district?
2. Which types of tree species dominates in this district?
3. How are tree species distributed in this district?
4. Which types of grasses can we also find in this district?
5. How are grass species distributed in this district?
6. How many types of woodlands are in this district and which type of woodland dominates?
7. What is the current situation on the status of vegetation?
8. What are the possible causes of changes in status of vegetation?
9. If yes, what are the possible causes of changes in status of vegetation?
10. Which pests or diseases usually affects trees in this ward?
11. Have there been any changes on frequency of occurrences of pest or diseases on trees.
12. If yes, which pest or diseases rate of occurrence is changing and how?
13. Which tree species are mostly affected?
14. What do you think might be the cause of the change in rate of occurrence?
15. Which indigenous fruit tree species are mostly found in this ward?
16. Are these tree species yielding fruits as they used to, if no, why?
17. Are these yielded fruits sizes still the same, if no, why?
18. Is the firmness of these fruits still the same, if no, what is happening to them?
19. Are these fruits still tasting as they used too, if no why?
20. Are these fruits still following the timing sequence, they used to follow? If no,

* Which months of the year are they likely to flower?
* Which months of the year are they likely to have leaf fall?
* Which months of the year are they likely to ripen?
* Which months of the year are they likely to fruit?

1. Which months of the year were they used to?

* Flower
* Leaf fall
* Ripen
* Fruit

**APPENDIX 3: Interview guide for EMA.**

1. How long have you worked in Mutoko District?
2. How has precipitation been changing in this ward, since 1978?
3. What evidence is there on vegetation to show that precipitation is changing?
4. How has temperature been changing in this ward, since 1978?
5. Are there any changes in night temperature in this ward? If yes, what is happening?
6. Are winter months usually cold as they used to, if no, why?
7. What is happening?
8. Are there any changes in daylight temperatures in this ward? If yes, what is happening?
9. Are summer months usually hot as they used to, if no, why?
10. What is happening?
11. What evidence is there on vegetation to show that temperature is changing?
12. What implications of climate change are evident in the District?
13. Which indigenous fruit tree species are mostly found in this ward?
14. Are these tree species yielding fruits as they used to, if no, why?
15. Are these yielded fruits sizes still the same, if no, why?
16. Is the firmness of these fruits still the same, if no, what is happening to them?
17. Are these fruits still tasting as they used too, if no why?
18. Are these fruits still following the timing sequence, they used to follow? If no,

* Which months of the year are they likely to flower?
* Which months of the year are they likely to have leaf fall?
* Which months of the year are they likely to ripen?
* Which months of the year are they likely to fruit?

1. Which months of the year were they used to?

* Flower
* Leaf fall
* Ripen
* Fruit

25. How is rainfall and temperature related to vegetation?

**APPENDIX 4: Interview guide for DAO**

1. You have worked for more than 20yrs in Mutoko District, are they any changes in climate?
2. What evidence is there to ascertain climate is changing, specifically focusing on temperature and rainfall?
3. What is the current situation on the status of vegetation?
4. What are the possible causes of changes in status of vegetation?
5. Which pests or diseases usually affects trees in this ward?
6. Have there been any changes on frequency of occurrences of pest or diseases on trees.
7. If yes, which pest or diseases rate of occurrence is changing and how?
8. Which tree species are mostly affected?
9. What do you think might be the cause of the change in rate of occurrence?
10. Which indigenous fruit tree species are mostly found in this ward?
11. Are these tree species yielding fruits as they used to, if no, why?
12. Are these yielded fruits sizes still the same, if no, why?
13. Is the firmness of these fruits still the same, if no, what is happening to them?
14. Are these fruits still tasting as they used too, if no why?
15. Are these fruits still following the timing sequence, they used to follow? If no,
16. Which months of the year are they likely to flower?
17. Which months of the year are they likely to have leaf fall?
18. Which months of the year are they likely to ripen?
19. Which months of the year are they likely to fruit?
20. Which months of the year were they used to;

* Flower
* Leaf fall
* Ripen
* Fruit

**APPENDIX 5: NUMBER TREES SAMPLED COMPUTATION**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **DBH (cm)** | **BS** | **JB** | **EA** | **BA** | **MB** | **CM** | **LD** | **MU** | **CB** | **TS** | **SS** | **MP** | **SM** | **DR** | **SC** |
| **6** | 32 | 26 | 14 | 15 | 4 | 5 | 16 | 10 | 19 | 7 | 17 | 7 | 8 | 6 | 13 |
| **7** | 25 | 20 | 12 | 10 | 12 | 13 | 10 | 5 | 9 | 9 | 10 | 7 | 5 | 6 | 8 |
| **8** | 20 | 19 | 10 | 6 | 12 | 9 | 4 | 4 | 5 | 5 | 5 | 6 | 7 | 4 | 1 |
| **9** | 14 | 17 | 6 | 10 | 9 | 5 | 6 | 7 | 2 | 5 | 0 | 3 | 2 | 2 | 1 |
| **10** | 13 | 8 | 2 | 6 | 6 | 4 | 1 | 2 | 2 | 2 | 0 | 2 | 2 | 5 | 0 |
| **11** | 5 | 6 | 1 | 2 | 2 | 0 | 0 | 2 | 0 | 3 | 0 | 1 | 1 | 0 | 0 |
| **12** | 4 | 4 | 2 | 1 | 1 | 2 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| **13** | 3 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| **14** | 0 | 4 | 4 | 0 | 0 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **15** | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **16** | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **18** | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **20** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **28** | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | **121** | **106** | **52** | **51** | **47** | **45** | **38** | **38** | **37** | **35** | **32** | **26** | **25** | **23** | **23** |
| **DBH (cm)** | **BT** | **MA** | **VL** | **BG** | **ZM** | **MG** | **MW** | **CE** | **PA** | **FI** | **FC** | **BB** | **NH** | **MZ** | **XC** |
| **6** | 5 | 6 | 6 | 1 | 8 | 5 | 3 | 5 | 4 | 3 | 0 | 2 | 6 | 2 | 3 |
| **7** | 4 | 9 | 5 | 2 | 3 | 8 | 6 | 5 | 5 | 7 | 1 | 4 | 4 | 9 | 1 |
| **8** | 5 | 4 | 4 | 2 | 4 | 3 | 3 | 4 | 1 | 2 | 2 | 1 | 2 | 2 | 1 |
| **9** | 2 | 2 | 2 | 4 | 3 | 2 | 2 | 1 | 4 | 1 | 2 | 1 | 1 | 0 | 2 |
| **10** | 3 | 1 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 2 |
| **11** | 0 | 0 | 0 | 3 | 1 | 0 | 1 | 0 | 0 | 1 | 2 | 1 | 0 | 0 | 2 |
| **12** | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| **13** | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **14** | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 |
| **15** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| **16** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **18** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **20** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **28** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | **23** | **22** | **20** | **20** | **19** | **18** | **15** | **15** | **14** | **14** | **13** | **13** | **13** | **13** | **12** |
| **DBH (cm)** | **PM** | **GB** | **DC** | **TN** | **VI** | **MS** | **SB** | **VP** | **PC** | **SG** | **AG** | **LDs** | **BZ** | **DM** | **BP** |
| **6** | 5 | 2 | 1 | 1 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **7** | 3 | 1 | 2 | 7 | 3 | 4 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| **8** | 2 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| **9** | 2 | 2 | 2 | 1 | 2 | 2 | 3 | 2 | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| **10** | 0 | 2 | 2 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| **11** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **12** | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **13** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| **14** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **15** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **16** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **18** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| **20** | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **28** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | **12** | **11** | **11** | **11** | **10** | **9** | **7** | **6** | **5** | **3** | **2** | **2** | **2** | **2** | **1** |
| **DBH (cm)** | **UP** |
| **6** | 0 |
| **7** | 0 |
| **8** | 0 |
| **9** | 0 |
| **10** | 1 |
| **TOTAL** | **1** |

**APPENDIX 6: Shannon-Weiner Diversity Index Computation.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | PLANT SPECIES | Ni | Pi | InPi | -(Pi\*InPi) |
| 01. | Musasa | 121 | 0.1166 | -2.10 | 0.245 |
| 02. | Munhondo | 107 | 0.1031 | -2.27 | 0.234 |
| 03. | Mutiti | 52 | 0.0500 | -2.99 | 0.149 |
| 04. | Mukarati | 51 | 0.0491 | -3.01 | 0.147 |
| 05. | Mumbumbu | 47 | 0.0453 | -3.09 | 0.139 |
| 06. | Mugodo | 45 | 0.0434 | -3.14 | 0.136 |
| 07. | Mushamba | 38 | 0.0366 | -3.31 | 0.121 |
| 08. | Munyada | 38 | 0.0366 | -3.31 | 0.121 |
| 09. | Chibayamakono | 37 | 0.0356 | -3.34 | 0.119 |
| 10. | Mususu | 35 | 0.0337 | -3.39 | 0.114 |
| 11. | Mutamba | 32 | 0.0308 | -3.48 | 0.107 |
| 12. | Muparamhosva | 26 | 0.0250 | -3.68 | 0.092 |
| 13. | Mucherekese | 25 | 0.0241 | -3.73 | 0,089 |
| 14. | Mutsvitsviriondo | 23 | 0.0222 | -3.81 | 0.085 |
| 15. | Mumbumi | 23 | 0.0222 | -3.81 | 0.085 |
| 16. | Mutukutu | 23 | 0.0222 | -3.81 | 0.085 |
| 17. | Mubarichirwa | 22 | 0.0211 | -3.86 | 0.081 |
| 18. | Mutufu | 20 | 0.0193 | -3.95 | 0.076 |
| 19. | Muunze | 20 | 0.0193 | -3.95 | 0.076 |
| 20. | Muchecheni | 19 | 0.0183 | -4.00 | 0.073 |
| 21. | Mungongoma | 18 | 0.0173 | -4.06 | 0.070 |
| 22. | Muwara | 15 | 0.0145 | -4.23 | 0.061 |
| 23. | Munzvanzvara | 15 | 0.0145 | -4.23 | 0.061 |
| 24. | Muwanga | 14 | 0.0135 | -4.31 | 0.058 |
| 25. | Munhunguru | 14 | 0.0135 | -4.31 | 0.058 |
| 26. | Mukuyu | 13 | 0.0125 | -4.38 | 0.055 |
| 27. | Mupfuti | 13 | 0.0125 | -4.38 | 0.055 |
| 28. | Nhenzvera | 13 | 0.0125 | -4.38 | 0.055 |
| 29. | Muzharoro | 13 | 0.0125 | -4.38 | 0.055 |
| 30. | Munhengeni | 12 | 0.0116 | -4.46 | 0.052 |
| 31. | Mutsvonzvowa | 12 | 0.0116 | -4.46 | 0.052 |
| 32. | Mutunduru | 11 | 0.0106 | -4.55 | 0.048 |
| 33. | Mupangara | 11 | 0.0106 | -4.55 | 0.048 |
| 34. | Chipindura | 10 | 0.0096 | -4.65 | 0.045 |
| 35. | Munzviru | 10 | 0.0096 | -4.65 | 0.045 |
| 36. | Musuka | 9 | 0.0087 | -4.74 | 0.041 |
| 37. | Mutsomo | 7 | 0.0067 | -5.01 | 0.034 |
| 38. | Mutsubvu | 6 | 0.0058 | -5.15 | 0.029 |
| 39. | Muhacha | 5 | 0.0048 | -5.34 | 0.026 |
| 40. | Mukute | 3 | 0.0028 | -5.88 | 0.016 |
| 41. | Mutohwe | 2 | 0.0019 | -6.26 | 0,012 |
| 42. | Mushinga | 2 | 0.0019 | -6.26 | 0.012 |
| 43. | Munyii | 2 | 0.0019 | -6.26 | 0.012 |
| 44. | Mushenje | 2 | 0.0019 | -6.26 | 0.012 |
| 45. | Mun’ando | 1 | 0.0009 | -7.01 | 0.006 |
| 46. | Muzhanje | 1 | 0.0009 | -7.01 | 0.006 |
| ***∑*** |  | **1038** |  |  | **3.814** |

**APPENDIX 7: Shannon Evenness Index Computation**

=

=

= **0.99**

**APPENDIX 8: Relative Frequency Computation.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Species name** | **No. of occurrence in plots** | **Plots sampled** | **Relative frequency** |
| Musasa | 37 | 63 | 58.7 |
| Munhondo | 33 | 63 | 52.4 |
| Mutiti | 19 | 63 | 30.0 |
| Mukarati | 24 | 63 | 38.0 |
| Mumbumbu | 19 | 63 | 30.0 |
| Mugodo | 20 | 63 | 31.7 |
| Mushamba | 11 | 63 | 17.5 |
| Munyada | 15 | 63 | 23.8 |
| Chibayamakono | 15 | 63 | 23.8 |
| Mususu | 11 | 63 | 17.5 |
| Mutamba | 13 | 63 | 20.6 |
| Muparamhosva | 12 | 63 | 19.0 |
| Mucherekese | 09 | 63 | 14.3 |
| Mutsvitsviriondo | 10 | 63 | 15.8 |
| Mumbumi | 11 | 63 | 17.5 |
| Mutukutu | 10 | 63 | 15.8 |
| Mubarichirwa | 10 | 63 | 15.8 |
| Mutufu | 06 | 63 | 09.5 |
| Muunze | 09 | 63 | 14.3 |
| Muchecheni | 07 | 63 | 11.0 |
| Mungongoma | 07 | 63 | 11.0 |
| Muwara | 09 | 63 | 14.3 |
| Munzvanzvara | 08 | 63 | 12.7 |
| Muwanga | 09 | 63 | 14.3 |
| Munhunguru | 07 | 63 | 11.0 |
| Mukuyu | 11 | 63 | 17.5 |
| Mupfuti | 07 | 63 | 11.0 |
| Nhenzvera | 06 | 63 | 09.5 |
| Muzharoro | 10 | 63 | 15.8 |
| Munhengeni | 07 | 63 | 11.0 |
| Mutsvonzvowa | 05 | 63 | 07.9 |
| Mutunduru | 06 | 63 | 09.5 |
| Mupangara | 08 | 63 | 12.7 |
| Chipindura | 07 | 63 | 11.0 |
| Munzviru | 07 | 63 | 11.0 |
| Musuka | 05 | 63 | 07.9 |
| Mutsomo | 05 | 63 | 07.9 |
| Mutsubvu | 06 | 63 | 09.5 |
| Muhacha | 01 | 63 | 01.5 |
| Mukute | 02 | 63 | 03.0 |
| Mutohwe | 01 | 63 | 01.5 |
| Mushinga | 01 | 63 | 01.5 |
| Munyii | 01 | 63 | 01.5 |
| Mushenje | 01 | 63 | 01.5 |
| Mun’ando | 01 | 63 | 01.5 |
| Muzhanje | 01 | 63 | 01.5 |

**APPENDIX 9: SPECIES DENSITY COMPUTATION**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **DBH (cm)** | **BS** | **JG** | **EA** | **BA** | **MB** | **CM** | **LD** | **MU** | **CB** | **TS** | **SS** | **SM** |
| **6** | **4.98** | **4.04** | **2.17** | **2.33** | **0.62** | **0.77** | **2.49** | **1.55** | **2.95** | **1.08** | **2.64** | **1.24** |
| **7** | 3.89 | 3.11 | 1.86 | 1.55 | 1.86 | 2.02 | 1.55 | 0.77 | 1.4 | 1.4 | 1.55 | 0.77 |
| **8** | 3.11 | 2.95 | 1.55 | 0.93 | 1.86 | 1.4 | 0.62 | 0.62 | 0.77 | 0.77 | 0.77 | 1.08 |
| **9** | 2.17 | 2.64 | 0.93 | 1.55 | 1.4 | 0.77 | 0.93 | 1.08 | 0.31 | 0.77 | 0 | 0.31 |
| **10** | 2.02 | 1.24 | 0.31 | 0.93 | 0.93 | 0.62 | 0.15 | 0.31 | 0.31 | 0.31 | 0 | 0.31 |
| **11** | 0.77 | 0.93 | 0.15 | 0.31 | 0.31 | 0 | 0 | 0.31 | 0 | 0.46 | 0 | 0.15 |
| **12** | 0.62 | 0.62 | 0.31 | 0.15 | 0.15 | 0.31 | 0 | 0.31 | 0 | 0.31 | 0 | 0 |
| **13** | 0.46 | 0 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0 | 0.31 | 0 | 0 |
| **14** | 0 | 0.62 | 0.62 | 0 | 0 | 0.15 | 0 | 0.62 | 0 | 0 | 0 | 0 |
| **15** | 0.15 | 0.15 | 0 | 0 | 0 | 0 | 0 | 0.15 | 0 | 0 | 0 | 0 |
| **16** | 0.31 | 0 | 0 | 0 | 0 | 0.31 | 0 | 0 | 0 | 0 | 0 | 0 |
| **18** | 0.15 | 0.15 | 0 | 0 | 0 | 0.15 | 0 | 0 | 0 | 0 | 0 | 0 |
| **20** | 0 | 0 | 0 | 0 | 0 | 0.15 | 0 | 0 | 0 | 0 | 0 | 0 |
| **28** | 0.15 | 0 | 0 | 0 | 0 | 0.15 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | **18.78** | **16.45** | **8.05** | **7.9** | **7.28** | **6.95** | **5.89** | **5.87** | **5.74** | **5.41** | **4.96** | **3.86** |
| **DBH (cm)** | **DR** | **SC** | **BT** | **MA** | **VL** | **BG** | **ZM** | **MG** | **MW** | **CE** | **PA** | **FI** |
| **6** | **0.93** | **2.02** | **0.77** | **0.93** | **0.93** | **0.15** | **1.24** | **0.77** | **0.46** | **0.77** | **0.62** | **0.46** |
| **7** | 0.93 | 1.24 | 0.62 | 1.4 | 0.77 | 0.31 | 0.46 | 1.24 | 0.93 | 0.77 | 0.77 | 1.08 |
| **8** | 0.62 | 0.15 | 0.77 | 0.62 | 0.62 | 0.31 | 0.62 | 0.46 | 0.46 | 0.62 | 0.15 | 0.31 |
| **9** | 0.31 | 0.15 | 0.31 | 0.31 | 0.31 | 0.62 | 0.46 | 0.31 | 0.31 | 0.15 | 0.62 | 0.15 |
| **10** | 0.77 | 0 | 0.46 | 0.15 | 0.46 | 0.31 | 0 | 0 | 0 | 0 | 0 | 0 |
| **11** | 0 | 0 | 0 | 0 | 0 | 0.46 | 0.15 | 0 | 0.15 | 0 | 0 | 0.15 |
| **12** | 0 | 0 | 0.15 | 0 | 0 | 0.46 | 0 | 0 | 0 | 0 | 0 | 0 |
| **13** | 0 | 0 | 0.15 | 0 | 0 | 0.15 | 0 | 0 | 0 | 0 | 0 | 0 |
| **14** | 0 | 0 | 0.31 | 0 | 0 | 0.15 | 0 | 0 | 0 | 0 | 0 | 0 |
| **15** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **16** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **18** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **20** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **28** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | **3.56** | **3.56** | **3.54** | **3.41** | **3.09** | **2.92** | **2.93** | **2.78** | **2.31** | **2.31** | **2.16** | **2.15** |
| **DBH (cm)** | **FC** | **BB** | **NH** | **MZ** | **XC** | **PM** | **GB** | **DC** | **TN** | **VI** | **MS** | **SB** |
| **6** | **0** | **0.31** | **0.93** | **0.31** | **0.46** | **0.77** | **0.31** | **0.15** | **0.15** | **0.62** | **0.31** | **0.15** |
| **7** | 0.15 | 0.62 | 0.62 | 1.4 | 0.15 | 0.46 | 0.15 | 0.31 | 1.08 | 0.46 | 0.62 | 0.15 |
| **8** | 0.62 | 0.15 | 0.31 | 0.31 | 0.15 | 0.31 | 0.46 | 0.46 | 0.15 | 0.15 | 0.15 | 0.15 |
| **9** | 0.62 | 0.15 | 0.15 | 0 | 0.31 | 0.31 | 0.31 | 0.31 | 0.15 | 0.31 | 0.62 | 0.46 |
| **10** | 0.46 | 0.15 | 0 | 0 | 0.31 | 0 | 0.31 | 0.31 | 0 | 0 | 0 | 0 |
| **11** | 0.31 | 0.15 | 0 | 0 | 0.31 | 0 | 0 | 0 | 0 | 0 | 0 | 0.15 |
| **12** | 0.15 | 0.15 | 0 | 0 | 0 | 0 | 0.15 | 0 | 0 | 0 | 0 | 0 |
| **13** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **14** | 0.15 | 0.31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **15** | 0.15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **16** | 0 | 0 | 0 | 0 | 0.15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **18** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **20** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.15 | 0 | 0 | 0 | 0 |
| **28** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | **2.61** | **1.99** | **2.01** | **2.02** | **1.84** | **1.85** | **1.69** | **1.69** | **1.53** | **1.54** | **1.7** | **1.06** |
| **DBH (cm)** | **VP** | **PC** | **SG** | **AG** | **LDs** | **BZ** | **DM** | **BP** | **UP** |
| **6** | **0** | **0** | **0** | **0** | **0** | **0.15** | **0** | **0** | **0** |
| **7** | 0.15 | 0.15 | 0 | 0.15 | 0 | 0 | 0 | 0 | 0 |
| **8** | 0.15 | 0 | 0 | 0 | 0 | 0.15 | 0.15 | 0 | 0 |
| **9** | 0.31 | 0 | 0.15 | 0 | 0.15 | 0 | 0 | 0.15 | 0 |
| **10** | 0.15 | 0.15 | 0.15 | 0 | 0 | 0 | 0.15 | 0 | 0.15 |
| **11** | 0.15 | 0.15 | 0 | 0.15 | 0 | 0 | 0 | 0 | 0 |
| **12** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **13** | 0 | 0.15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **14** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **15** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **16** | 0 | 0 | 0 | 0 | 0.15 | 0 | 0 | 0 | 0 |
| **18** | 0 | 0.15 | 0.15 | 0 | 0 | 0 | 0 | 0 | 0 |
| **20** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **28** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | **0.91** | **0.75** | **0.45** | **0.3** | **0.3** | **0.3** | **0.3** | **0.15** | **0.15** |

**APPENDIX 10: BASAL AREA PER ACRE COMPUTATION.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **DBH (cm)** | **BACF** | **BS** | **JB** | **EA** | **BA** | **MB** | **CM** | **LD** | **MW** | **CE** | **PA** | **FI** |
| **6** | 0.1963 | 0.97 | 0.79 | 0.43 | 0.46 | 0.12 | 0.15 | 0.48 | 0.09 | 0.15 | 0.46 | 0.09 |
| **7** | 0.2672 | 1.04 | 0.83 | 0.49 | 0.41 | 0.49 | 0.54 | 0.41 | 0.58 | 0.21 | 0.21 | 0.28 |
| **8** | 0.349 | 1.08 | 1.03 | 0.54 | 0.32 | 0.65 | 0.48 | 0.22 | 0.16 | 0.22 | 0.05 | 0.11 |
| **9** | 0.4417 | 0.96 | 1.16 | 0.41 | 0.68 | 0.62 | 0.34 | 0.41 | 0.12 | 0.06 | 0.27 | 0.06 |
| **10** | 0.5454 | 1.1 | 0.67 | 0.17 | 0.51 | 0.51 | 0.34 | 0.08 | 0 | 0 | 0 | 0 |
| **11** | 0.6599 | 0.51 | 0.61 | 0.09 | 0.2 | 0.2 | 0 | 0 | 0.09 | 0 | 0 | 0.09 |
| **12** | 0.7854 | 0.48 | 0.48 | 0.24 | 0.12 | 0.12 | 0.24 | 0 | 0 | 0 | 0 | 0 |
| **13** | 0.9217 | 0.42 | 0 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0 | 0 | 0 | 0 |
| **14** | 1.069 | 0 | 0.66 | 0.66 | 0 | 0 | 0.16 | 0 | 0 | 0 | 0 | 0 |
| **15** | 1.2271 | 0.18 | 0.18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **16** | 1.3962 | 0.43 | 0 | 0 | 0 | 0 | 0.43 | 0 | 0 | 0 | 0 | 0 |
| **18** | 1.7671 | 0.26 | 0.26 | 0 | 0 | 0 | 0.26 | 0 | 0 | 0 | 0 | 0 |
| **20** | 2.1816 | 0 | 0 | 0 | 0 | 0 | 0.33 | 0 | 0 | 0 | 0 | 0 |
| **28** | 4.2759 | 0.64 | 0 | 0 | 0 | 0 | 0.64 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | **16.0835** | **8.07** | **6.67** | **3.17** | **2.84** | **2.85** | **4.05** | **1.74** | **1.04** | **0.64** | **0.99** | **0.63** |
| **DBH** | **BACF** | **MU** | **CB** | **TS** | **SS** | **MP** | **SM** | **DR** | **FC** | **BB** | **NH** | **MZ** |
| **6** | 0.1963 | 0.3 | 0.58 | 0.21 | 0.52 | 0.21 | 0.24 | 0.18 | 0 | 0.06 | 0.18 | 0.06 |
| **7** | 0.2672 | 0.21 | 0.37 | 0.37 | 0.41 | 0.28 | 0.21 | 0.58 | 0.04 | 0.16 | 0.16 | 0.37 |
| **8** | 0.349 | 0.22 | 0.27 | 0.27 | 0.26 | 0.32 | 0.37 | 0.22 | 0.22 | 0.05 | 0.11 | 0.11 |
| **9** | 0.4417 | 0.47 | 0.12 | 0.34 | 0 | 0.2 | 0.12 | 0.12 | 0.27 | 0.06 | 0.06 | 0 |
| **10** | 0.5454 | 0.17 | 0.17 | 0.17 | 0 | 0.17 | 0.17 | 0.42 | 0.25 | 0.08 | 0 | 0 |
| **11** | 0.6599 | 0.2 | 0 | 0.3 | 0 | 0.09 | 0.09 | 0 | 0.2 | 0.09 | 0 | 0 |
| **12** | 0.7854 | 0.24 | 0 | 0.24 | 0 | 0 | 0 | 0 | 0.12 | 0.12 | 0 | 0 |
| **13** | 0.9217 | 0.14 | 0 | 0.28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **14** | 1.069 | 0.66 | 0 | 0 | 0 | 0 | 0 | 0 | 0.16 | 0.33 | 0 | 0 |
| **15** | 1.2271 | 0.18 | 0 | 0 | 0 | 0 | 0 | 0 | 0.18 | 0 | 0 | 0 |
| **16** | 1.3962 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **18** | 1.7671 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **20** | 2.1816 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **28** | 4.2759 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** |  | **2.79** | **1.51** | **2.18** | **1.19** | **1.27** | **1.2** | **1.52** | **1.44** | **0.95** | **0.51** | **0.54** |
| **DBH** | **BACF** | **SC** | **BT** | **MA** | **VL** | **BG** | **ZM** | **MG** | **XC** | **PM** | **GB** | **DC** |
| **6** | 0.1963 | 0.39 | 0.15 | 0.18 | 0.18 | 0.03 | 0.24 | 0.15 | 0.09 | 0.15 | 0.06 | 0.03 |
| **7** | 0.2672 | 0.33 | 0.16 | 0.37 | 0.21 | 0.08 | 0.12 | 0.33 | 0.04 | 0.12 | 0.04 | 0.08 |
| **8** | 0.349 | 0.05 | 0.27 | 0.22 | 0.22 | 0.11 | 0.22 | 0.16 | 0.05 | 0.11 | 0.16 | 0.16 |
| **9** | 0.4417 | 0.06 | 0.14 | 0.14 | 0.14 | 0.27 | 0.2 | 0.16 | 0.14 | 0.14 | 0.14 | 0.11 |
| **10** | 0.5454 | 0 | 0.25 | 0.08 | 0.25 | 0.17 | 0 | 0.14 | 0.17 | 0 | 0.17 | 0.06 |
| **11** | 0.6599 | 0 | 0 | 0 | 0 | 0.3 | 0.09 | 0.08 | 0.2 | 0 | 0 | 0 |
| **12** | 0.7854 | 0 | 0.12 | 0 | 0 | 0.36 | 0 | 0 | 0 | 0 | 0.12 | 0 |
| **13** | 0.9217 | 0 | 0.14 | 0 | 0 | 0.14 | 0 | 0 | 0 | 0 | 0 | 0 |
| **14** | 1.069 | 0 | 0.33 | 0 | 0 | 0.16 | 0 | 0 | 0 | 0 | 0 | 0 |
| **15** | 1.2271 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **16** | 1.3962 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.21 | 0 | 0 | 0 |
| **18** | 1.7671 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **20** | 2.1816 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **28** | 4.2759 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** |  | **0.83** | **1.56** | **0.99** | **1** | **1.62** | **0.87** | **1.02** | **0.9** | **0.52** | **0.69** | **0.44** |
| **DBH** | **BACF** | **TN** | **VI** | **MS** | **SB** | **VP** | **PC** | **SG** | **AG** | **LDs** | **BZ** | **DM** |
| **6** | 0.1963 | 0.03 | 0.12 | 0.06 | 0.03 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0 |
| **7** | 0.2672 | 0.28 | 0.12 | 0.16 | 0.04 | 0.04 | 0.04 | 0 | 0.04 | 0 | 0 | 0 |
| **8** | 0.349 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0 | 0 | 0 | 0 | 0.05 | 0.05 |
| **9** | 0.4417 | 0.06 | 0.14 | 0.27 | 0.2 | 0.14 | 0 | 0.06 | 0 | 0.06 | 0 | 0 |
| **10** | 0.5454 | 0 | 0 | 0 | 0 | 0.08 | 0.08 | 0.08 | 0 | 0 | 0 | 0.08 |
| **11** | 0.6599 | 0 | 0 | 0 | 0.09 | 0.09 | 0.09 | 0 | 0.09 | 0 | 0 | 0 |
| **12** | 0.7854 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **13** | 0.9217 | 0 | 0 | 0 | 0 | 0 | 0.14 | 0 | 0 | 0 | 0 | 0 |
| **14** | 1.069 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **15** | 1.2271 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **16** | 1.3962 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.21 | 0 | 0 |
| **18** | 1.7671 | 0 | 0 | 0 | 0 | 0 | 0.26 | 0.26 | 0 | 0 | 0 | 0 |
| **20** | 2.1816 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **28** | 4.2759 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** |  | **0.42** | **0.43** | **0.54** | **0.41** | **0.4** | **0.61** | **0.4** | **0.13** | **0.27** | **0.08** | **0.13** |
| **DBH** | **BACF** | **BP** | **UK** |
| **6** | 0.1963 | 0 | 0 |
| **7** | 0.2672 | 0 | 0 |
| **8** | 0.349 | 0 | 0 |
| **9** | 0.4417 | 0.06 | 0 |
| **10** | 0.5454 | 0 | 0.08 |
| **11** | 0.6599 | 0 | 0 |
| **12** | 0.7854 | 0 | 0 |
| **13** | 0.9217 | 0 | 0 |
| **14** | 1.069 | 0 | 0 |
| **15** | 1.2271 | 0 | 0 |
| **16** | 1.3962 | 0 | 0 |
| **18** | 1.7671 | 0 | 0 |
| **20** | 2.1816 | 0 | 0 |
| **28** | 4.2759 | 0 | 0 |
| **TOTAL** |  | **0.06** | **0.08** |

**APPENDIX 11: Mann Kendall Trend Analysis Computation - Annual Mean Precipitation**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| YEAR | TOTAL | RANK | P | M |
| 1978-79 | 726.5 | 16 | 15 | -16 |
| 1979-80 | 473.9 | 29 | 27 | -3 |
| 1980-81 | 1078.3 | 1 | 0 | -29 |
| 1981-82 | 532.9 | 25 | 22 | -6 |
| 1982-83 | 378.3 | 32 | 27 | -0 |
| 1983-84 | 448.1 | 30 | 25 | -1 |
| 1984-85 | 925.3 | 5 | 3 | -22 |
| 1985-86 | 771 | 12 | 9 | -6 |
| 1986-87 | 593.2 | 22 | 17 | -6 |
| 1987-88 | 649.8 | 21 | 16 | -7 |
| 1988-89 | 696.9 | 19 | 14 | -10 |
| 1989-90 | 750.8 | 14 | 10 | -1 |
| 1990-91 | 501.2 | 28 | 18 | -0 |
| 1991-92 | 419.9 | 31 | 18 | -8 |
| 1992-93 | 752.4 | 13 | 9 | -1 |
| 1993-94 | 532.6 | 26 | 15 | -0 |
| 1994-95 | 515 | 27 | 15 | -11 |
| 1995-96 | 877.6 | 6 | 3 | -13 |
| 1996-97 | 1073.2 | 2 | 0 | -9 |
| 1997-98 | 832.2 | 8 | 3 | -11 |
| 1998-99 | 998.4 | 3 | 0 | -10 |
| 1999-00 | 996.9 | 4 | 0 | -09 |
| 2000-01 | 840.2 | 7 | 0 | -02 |
| 2001-02 | 671.3 | 20 | 6 | -07 |
| 2002-03 | 815.5 | 9 | 0 | -01 |
| 2003-04 | 571.1 | 23 | 5 | -01 |
| 2004-05 | 712.6 | 18 | 3 | -02 |
| 2005-06 | 736.1 | 15 | 2 | -0 |
| 2006-07 | 565.7 | 24 | 3 | -02 |
| 2007-08 | 814.6 | 10 | 0 | -0 |
| 2008-09 | 774.6 | 11 | 0 | -02 |
| 2009-10 | 723.9 | 17 | 1 | -01 |
| TOTAL |  |  | **285** | **-195** |

**S-statistics**  = P – M

= 285 – 195

**= 90**

**Normalization of S-statistic**

Therefore number of variables are greater than 10 and have no ties, hence

=

**√***VARs* **= 61.6**

**Z-statistic**  = if the S-statistic greater than 0

=

**= 1.4**

Critical Value at 95% (0.05) for the S-statistic is 139 and for the Z- statistic level of significance is 0.367.

**APPENDIX 12:** **Mann Kendall Trend Analysis Computation - Annual Mean Minimum Temperature**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| YEAR | TOTAL | RANK | P | M | TIES |
| 1978-79 | 13.9 | 9 | 20 | -8 | 3 |
| 1979-80 | 14.2 | 6 | 10 | -16 | 4 |
| 1980-81 | 13.9 | 9 | 19 | -8 | 2 |
| 1981-82 | 13.8 | 10 | 21 | -3 | 4 |
| 1982-83 | 14.7 | 1 | 0 | -25 | 2 |
| 1983-84 | 14.6 | 2 | 2 | -23 | 1 |
| 1984-85 | 14.4 | 4 | 4 | -20 | 1 |
| 1985-86 | 14.0 | 8 | 12 | -9 | 3 |
| 1986-87 | 14.1 | 7 | 11 | -12 | 0 |
| 1987-88 | 14.7 | 1 | 0 | -21 | 1 |
| 1988-89 | 13.9 | 9 | 13 | -7 | 1 |
| 1989-90 | 14.5 | 3 | 2 | -18 | 0 |
| 1990-91 | 14.3 | 5 | 3 | -15 | 1 |
| 1991-92 | 14.7 | 1 | 0 | -18 | 0 |
| 1992-93 | 14.6 | 2 | 0 | -17 | 0 |
| 1993-94 | 14.0 | 8 | 6 | -8 | 2 |
| 1994-95 | 14.0 | 8 | 6 | -8 | 1 |
| 1995-96 | 14.3 | 5 | 1 | -13 | 0 |
| 1996-97 | 14.4 | 4 | 0 | -13 | 0 |
| 1997-98 | 14.2 | 6 | 0 | -9 | 3 |
| 1998-99 | 14.0 | 8 | 3 | -8 | 0 |
| 1999-00 | 14.2 | 6 | 0 | -8 | 2 |
| 2000-01 | 13.9 | 9 | 2 | -7 | 0 |
| 2001-02 | 14.2 | 6 | 0 | -7 | 1 |
| 2002-03 | 13.8 | 10 | 1 | -3 | 3 |
| 2003-04 | 13.0 | 12 | 5 | -0 | 1 |
| 2004-05 | 13.0 | 12 | 5 | -0 | 0 |
| 2005-06 | 14.2 | 6 | 0 | -4 | 0 |
| 2006-07 | 13.8 | 10 | 0 | -1 | 2 |
| 2007-08 | 13.6 | 11 | 2 | -0 | 0 |
| 2008-09 | 13.8 | 12 | 0 | -0 | 1 |
| 2009-10 | 13.8 | 12 | 1 | -0 | 0 |
| **TOTAL** |  |  | **149** | **-309** | **39** |

**S=statistic** = P - M

= 149 – 309

**= - 160**

**Normalization of the S-statistic**

Therefore number of variables are greater than 10 and there are ties, hence

√*VARs* = **- 55.0**

**Z-statistics** = if the S-statistic less than 0

= - 160 + 1/ -55.0

**= - 2.89**

**APPENDIX 13: Mann-Kendall Trend Analysis Computation - Annual Mean Maximum Temperature.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| YEAR | TOTAL | RANK | P | M | TIES |
| 1978-79 | 26.0 | 11 | 20 | -9 | 2 |
| 1979-80 | 26.2 | 9 | 13 | -14 | 2 |
| 1980-81 | 25.0 | 18 | 29 | -0 | 0 |
| 1981-82 | 25.7 | 14 | 23 | -4 | 1 |
| 1982-83 | 26.9 | 3 | 2 | -25 | 0 |
| 1983-84 | 26.5 | 6 | 5 | -20 | 1 |
| 1984-85 | 25.6 | 15 | 22 | -2 | 1 |
| 1985-86 | 25.1 | 17 | 24 | -0 | 0 |
| 1986-87 | 26.4 | 7 | 6 | -14 | 3 |
| 1987-88 | 26.2 | 9 | 11 | -10 | 1 |
| 1988-89 | 25.4 | 16 | 21 | -0 | 0 |
| 1989-90 | 26.1 | 10 | 12 | -6 | 2 |
| 1990-91 | 26.4 | 7 | 6 | -11 | 2 |
| 1991-92 | 27.2 | 1 | 0 | -18 | 0 |
| 1992-93 | 26.2 | 9 | 9 | -8 | 0 |
| 1993-94 | 26.1 | 10 | 9 | -6 | 1 |
| 1994-95 | 26.5 | 6 | 4 | -11 | 0 |
| 1995-96 | 26.1 | 10 | 8 | -6 | 0 |
| 1996-97 | 26.3 | 8 | 6 | -6 | 1 |
| 1997-98 | 27.0 | 2 | 0 | -12 | 0 |
| 1998-99 | 26.4 | 7 | 3 | -7 | 1 |
| 1999-00 | 25.9 | 12 | 6 | -3 | 0 |
| 2000-01 | 25.8 | 13 | 7 | -2 | 0 |
| 2001-02 | 26.7 | 4 | 0 | -7 | 1 |
| 2002-03 | 26.4 | 7 | 2 | -5 | 0 |
| 2003-04 | 26.0 | 11 | 3 | -2 | 1 |
| 2004-05 | 26.6 | 5 | 1 | -4 | 0 |
| 2005-06 | 25.6 | 15 | 4 | -0 | 0 |
| 2006-07 | 26.7 | 4 | 0 | -3 | 0 |
| 2007-08 | 26.3 | 8 | 0 | -2 | 0 |
| 2008-09 | 26.0 | 11 | 0 | -1 | 0 |
| 2009-10 | 25.7 | 14 | 1 | -0 | 0 |
| **TOTAL** |  |  | **257** | **- 218** | **20** |

**S-statistic**  = P – M

= 257 - 218

= **39**

**Normalization of the S-statistic**

Therefore number of variables are greater than 10 and there are ties, hence

√*VARs* = **53.4**

**Z-statistic =** if the S-statistic greater than 0

=

**= 0.712**