Table of contents

List of Figures

List of Tables

List of Appendices

List of Acronyms

AVHRR	Advanced Very High Resolution Radiometer
CBD	Convention on Biological Diversity
ENSO	El Niño Southern Oscillation
EVI	Enhanced Vegetation Index
FAO	Food and Agricultural Organisation
fPAR	Photosynthetically Active Radiation
GFW	Global Forest Watch
GHGs	Green House Gases
GLCC	Global Land Cover Characterization
IPCC	Intergovernmental Panel on Climate Change
LIDAR	Light Detection and Ranging
LMA	Leaf Area Mass
MEA	Millennium Ecosystem Assessment
MODIS	Moderate Resolution Imaging Spectroradiometer
MTE	Metabolic Theory of Ecology
NAS	National Academy of Sciences
NCAR	National Centre for Atmospheric Research
NCDC	National climate Data Centre
NCDC	National Climate Data Centre
NDVI	Normalised Difference Vegetation Index
RADAR	Radio Detection and Ranging
RS	Remote Sensing
SCBD	Secretariat of the Convention on Biological Diversity
SDG	Sustainable Development Goals
SPOT	Satellite for observation of Earth (
SVH	Spectral Variation Hypothesis
UNFCCC	United Nations Framework Convention on Climate Change
USNAS	United States National Academy of Sciences
WECD	World Commission on Environment and Development
WMO	World Meteorological Organisation
ZIMSTATS	Zimbabwe National Statistics Agency
ZMSD	Zimbabwe Meteorological Services Department

Abstract

Vegetative species diversity is under threat from environmental pressures, particularly climate change. As the impacts of climate change vary from place to place, response of vegetative species diversity to a changing climate also vary depending on geographical location. The response of vegetative species diversity under dry conditions in Zimbabwe is not well known. This study assessed the impact of climate change on vegetative species diversity under semi-arid conditions of Masvingo province in Zimbabwe. This was achieved by determining climate change trends over a period of forty years (1974-2014), and examining the relationship between vegetative species diversity and spatially interpolated climate data. The absence of historical diversity data prompted the use of remote sensing to enable the assessment of spatial and temporal changes. Thus, the Normalised difference vegetation index (NDVI) was used to assess vegetative species diversity changes after establishing a positive relationship between species diversity and NDVI. The mixed methods research design was used as the strategy of inquiry. The non-aligned block sampling design was used as the sampling framework from which 198 sampling points were identified. Meteorological data obtained from Zimbabwe Meteorological Services Department (ZMSD) and the National Climate Data Centre (NCDC) were used for climate change analysis. Data collected through image analysis, direct observations, questionnaire surveys and interviews were used to assess the impact of climate change on vegetative species diversity. Results indicate that all temperature and precipitation variables have significant ($p<0.05$) trends over the period under study. However, the trend for seasonal total precipitation was not significant but declining. The significant trends indicate that climate change occurred over the period under study. 93% of the respondents confirmed having experienced the climate change phenomenon. Results also show a significant relationship between climate elements (precipitation and temperature) and vegetative species diversity represented by Shannon Weaver Index (H). More so, there is a positive relationship between NDVI and H. Vegetative species diversity represented by NDVI decreased over the period under review. The results indicate that climate change has contributed to the decrease of vegetative species diversity in Masvingo province, thus it is a force behind many other factors contributing to biodiversity loss.

Key words

Title:

IMPACT OF CLIMATE CHANGE ON VEGETATIVE SPECIES DIVERSITY IN MASVINGO PROVINCE, ZIMBABWE

Keywords:

Climate change, vegetative species, species diversity, , remote sensing, Normalised Difference Vegetation Index (NDVI), Shannon weaver index, Simpson index, mixed methods, Non-aligned block sampling design, National Climate Data Centre, Masvingo province.

Chapter 1 : INTRODUCTION

1.1. Background of the study

Evidence that climate change is occurring as a consequence of anthropogenic activities is quite clear and well acknowledged by the vast majority of scientific opinion. The world's population is increasing and additional greenhouse gases (GHGs) are being emitted into the atmosphere as humankind endeavours to cope with the growing demand for food and energy. Increasing levels of GHGs influence the earth's radiation budget and the earth-atmospheric system has to adjust resulting in changes in the global climate (Shan *et al.*, 2013; Scafetta 2010). Apart from human activities, some natural processes such as solar energy variability, ocean currents, clouds and albedo are thought to be significantly contributing to climate change (Bast, 2010).

Although there has been debate on what is causing climate change, there is general consensus amongst several researchers that climate change is a result of both natural and human factors (Gornitz, 2009; Bast, 2010; Scafetta, 2010). It is not enough to understand the causes of climate change but its effects too, especially on ecosystems since they play a pivotal role in the survival of humanity through water purification, pollination of flowers, decomposition of wastes, maintaining soil fertility and perform various other functions that ensure sustainability of all support systems (MEA, 2005). Thus, there is prodigious scientific evidence that climate is changing but there is no scientific certainty, especially in the southern African region, about its effects on various ecological phenomena, vegetative species diversity included.

Global surface temperatures have increased by 0.8^0C since 1900 (Scafetta, 2010). In Southern Africa, records from various countries show an increase in temperature by over 0.5^0C over the past 100 years (Chenje, 2000). Rainfall patterns have been altered and there is a general decrease over the past 20 years (Chenje, 2000). The question is how has vegetation diversity responded to these changes? Several scholars have tried to answer the question but the multiplicity and variability of the approaches and results point to the fact that the issue is still veiled in obscurity (Schwallier *et al.,* 2016; Bellard *et al.,* 2012; Walther *et al.,* 2002; Beaumont *et al.,* 2007, Beaumont *et al.,* 2011; Pearson and Dawson, 2003).

The changing climate is beginning to have impacts that are threatening the conservation of biodiversity in semi-arid regions. According to the Secretariat of the Convention on Biological

Diversity (SCBD), the predicted effects of the climatic changes are generally known but their magnitude is still little understood (SCBD, 2010). An important body of literature has shown that climate change is one of many possible stressors on biodiversity. Hopkins *et al.* (2007) proclaim that climate is a significant factor that affects the behaviour, abundance and geographical spread of species. In addition, climate influences the ecology of habitats and ecosystems (Jewitt *et al.,* 2015; Chen *et al.,* 2011; Parmesan, 2006). The changes attributed to climate change are becoming more profound with time. Thus, climate change is interrupting the conventional functions of the ecosystems by influencing species diversity either positively or negatively.

Vegetative species diversity is essential for human well-being because it provides a plethora of benefits and services to humanity, such as food, medicines, clean water, soil stabilization and many others (Chenje, 2000; MEA, 2005; Perrings, 2010). Recent studies have shown that this diversity is under threat from climate change which poses a challenge by exacerbating the impacts of droughts, floods and desertification (SCBD, 2010). Theurillat and Guisan (2001) posited that there are basically three ways in which vegetation responds to climate change. First is that some species may adapt to the changing climate. Second is that species migrate to suitable environmental conditions and third is that the species will go extinct. These three ways of how vegetation responds to climate change will have a profound effect on species diversity, specifically richness and evenness.

At global level, human activities have negatively affected and will continue to affect species diversity through, *inter alia*; land use and land cover change. However, climate change exacerbates the influence of human activities. The current rate of species loss through climate change is greater than the natural background rate of extinction. The Convention on Biological Diversity (SCBD, 2010) identifies climate change as one of the main factors responsible for the current loss of biodiversity. An international collaborative study on four continents predicted that 10% of species would go extinct by 2050 because of climate change (Gitay *et al.,* 2002a). There is evidence that climate change is already affecting vegetative species diversity and will continue to do so (Gitay *et al.,* 2002b; Hannah *et al.,* 2002, Schneider & Root, 2002; Stenseth *et al.,* 2002; Walther *et al.,* 2002; Fischlin *et al.,* 2007).

Some studies have used species distribution models to study and understand the impacts of climate change on individual species (Yates *et al.,* 2010; Erasmus *et al.,* 2002). Yates *et al.,*

(2010) noted that modelling all species rooted in various ecosystems is not feasible hence the need to develop models that predict effects of climate change on ecoregions, specific environmental domains and distribution of communities. Thus, Hansen *et al.,* (2009) and Watson *et al.,* (2013) have studied effects of climate change on ecoregions while Saxon *et al.,* (2005) have studied impacts on environmental domains. Furthermore, Yates *et al.,* (2010) studied climate change impacts on geographical distribution of communities. There is need for studies that focus on specific administrative regions in specific climate classes in order to guide the designing and implementation of specific biodiversity policy instruments and conservation strategies so that communities continuously benefit from the diversity of plant species. Groves *et al*. (2012) reinforce this idea recommending the need to focus conservation efforts on specific geophysical environments to maintain and promote species diversity. Similarly, Beier and Brost (2010) advocate for the use of land facets. These approaches would promote conservation of diversity under current and future climates taking into consideration that the species making up the diversity may change over time given their capacity to track suitable conditions (Bellard *et al.,* 2012).

Ample evidence exists to the effect that ecological reactions are currently occurring in specific species. The incumbent task is thus, to synthesize the burgeoning list of such observations with a comprehensible body of theory that will facilitate prediction of the timing, location and consequences of the changes. Such predictions will enable the understanding of the consequences associated with the conservation and sustainable use of biodiversity and what humanity need to do practically to maintain those systems in the best possible condition. It is thus necessary to investigate the effects of climate change on biodiversity at the ecosystem level and to consider innovative emergent ecosystems composed of new species assemblages arising from differential rates of range shifts of species.

Research on ecosystem-level impacts of climate change is still in its infancy. Climate change is distressing biotic interactions and provision of ecosystem services (MEA, 2005). The speed and magnitude of these effects are generally unknown. New, nascent ecosystems are predicted to appear, and the provision of services compromised in already degraded systems.

Whilst literature seems to be available on the impacts of climate change on biodiversity around the globe, justice to the topic in the semi-arid areas of southern Africa has not been done. In particular, little has been done with regards to vegetative species diversity. Several studies indicate the existence of spatial and temporal changes in climatic conditions in Zimbabwe and Masvingo in particular (Musiyiwa *et al.*, 2014; Simba *et al.*, 2012; Unganai and Mason, 2002). However, its impact on vegetative species diversity has not been well studied and documented. There is paucity of scientific data on the impact of climatic changes on species diversity despite a wide range of studies conducted to understand the nature's *modus operandi* with regards to climatic change (Gitay *et al,* 2002b; Parmesan and Yohe, 2003). Understanding of the relationship between vegetative species diversity and climate change will provide a platform for devising strategies to enhance the resilience of ecosystems to climatic changes through the adoption of species based adaptive and mitigative strategies.

In Zimbabwe in general and Masvingo in particular, climate change impact on vegetative species diversity has not been studied and there has not been established a management system to increase adaptation or resilience of local flora. This research seeks to fill the gap and contribute scientific evidence of impacts of climate change on vegetative species diversity. The critical questions for this study are: How much change in ecosystem species might climate change have influenced? How much change has occurred and will occur in semi-arid ecosystems due to climate change? Can science quickly assess and model these changes by using remote sensing? What strategies should be put in place to enhance the mitigation and adaptive capacity of ecosystems?

1.2 Statement of the problem

The challenge in Masvingo province, Zimbabwe is that vegetative species diversity is under threat from climate change, which is exacerbated by other factors such as land use practices. The problem is accentuated by the fact that biodiversity management approaches in the face of climate change are not effective enough to maintain the much valued species diversity in the province. Further to this, there is a gap in knowledge about the relationship between climate change and vegetative species changes, knowledge of which may help to craft relevant and effective biodiversity management strategies. In addition, there is lack of capacity to assess vegetative species diversity status in the province to propose innovative solutions to the challenges caused by climate change related hazards such as droughts, floods and veld-fires. The immediate solution to the problem is to understand the magnitude of climate change in the province and the degree to which it has affected vegetative species diversity. Furthermore, the use of modern satellite remote sensing technology for quick biodiversity assessment becomes imperative.

Climate change is one of the environmental problems in Zimbabwe in general and Masvingo province in particular (Musiyiwa *et al.,* 2014; Simba *et al.,* 2012; Unganai and Murwira, 2010). It has affected vegetative species diversity through exacerbating the effects of other anthropogenic and natural factors. In some cases, it directly influences the range, abundance, composition and phenology of vegetative species (Hopkins *et al.,* 2007; Koskela *et al.,* 2007). The effects significantly compromise the ability of ecosystems to perform their conventional functions of, *inter alia,* water purification, flower pollination, waste decomposition, climate regulation and fulfilling social and cultural needs of humanity. The occurrence of climate change in the province implies that vegetative species could be experiencing similar changes. However, there is paucity of scientific evidence on how vegetation is responding to climate change in terms of diversity. Consequently, there is dearth of ecosystem and species specific mitigation and adaptation strategies in the province.

Parmesan *et al*. (2011) and Pereira *et al*. (2010) acknowledge the importance of predicting biodiversity response to climate change positing that it alerts science and policy to possible impending threats, provide a means to reinforce ascription of biological changes to climate change and can enable the designing of pre-emptive strategies to reduce climate change impacts on biodiversity (Bellard *et al.,* 2012). Given the impending repercussions of climate change on vegetative species diversity, there is need to put in place ecosystem and species specific adaptation strategies to ensure that the environment continues to benefit from the diversity of species. This would only be possible if there is an understanding of how the variety of vegetative species responds to climate change over time.

Climate change impacts on biodiversity have become a theme for active research (Dillon *et al*. 2010; Gilman *et al*. 2010; Pereira *et al*. 2010; Salamin *et al*. 2010; Beaumont *et al*. 2011; Dawson *et al*. 2011; McMahon *et al*. 2011). However, the use of satellite based remote sensing in such studies has been limited. This is despite the fact that remote sensing provides a rapid and synoptic analysis of phenomena and has become an important tool in quick decision making. According to Bellard *et al.,* (2012) there are a variety of approaches that have been applied to project biodiversity under different scenarios of global climate change to the extent that there is no uniformity in the results which are inconsistent, incompatible and difficult to follow. Moreover, most of the studies have combined floral and faunal diversity that have been characterised by methodological convolutions. There is therefore, a gap in knowledge on the use of low cost modern tools that offer quick analysis for rapid decision making when studying specific communities. This study, fills this gap by assessing the response of vegetative species diversity to climate change under semi-arid conditions in Masvingo province of Zimbabwe based on remotely sensed data.

1.3 Aim of the study

In order for human beings to maintain biodiversity in general and vegetative species diversity in particular and continue to benefit from its ecological, economic, socio-cultural and physical functions there is need to understand how it is being affected by climate change and related hazards. This enables the designing of species specific adaptive strategies. This study aims to assess the response of vegetative species diversity to climate change under semi-arid conditions in Masvingo province of Zimbabwe, using remotely sensed data for quick species diversity assessment.

1.4. Specific objectives

The specific objectives of the study include:

1. To determine climate change trends in Masvingo province over a period of 40 years (1974-2014).
2. To examine the relationship between vegetative species diversity and climatic elements.
3. To assess vegetative species diversity through the Normalised Difference Vegetation Index (NDVI) calculated from remotely sensed data.
4. To evaluate changes in vegetative species diversity as influenced by climate change over the period 1974-2014.

1.5 Research questions

1. What are the trends of climate change variables in Masvingo province over the period of 40 years (1974-2014)?
2. What is the relationship between vegetative species diversity and climatic elements?
3. What is the relationship between vegetative species diversity and NDVI?
4. What is the change in vegetative species diversity due to climate change over a 40 year period (1974-2014)?

1.6 Significance of study

In view of the preceding, on-going and impending ramifications of climate change on ecosystems, as established and predicted by various models, studies that assess the impact of changes in climatic elements on vegetative species diversity merit attention (Bellard *et al*, 2012; Parmesan *et al.,* 2011; Pereira *et al.,* 2010; Botkin *et al.,* 2007). The results would alert scientists and decision makers to possible future threats, working as a tool in biodiversity conservation in this era of climate change (Bellard *et al.,* 2012).

There is a general consensus amongst climate scientists that our understanding of the effects of global climate change on biodiversity and its different levels of response is insufficiently well developed (Bellard *et al*., 2012, Cahill et al., 2012). At global level, this study contributes to the existing body of literature on the impacts of climate change on vegetative species diversity at ecosystem level. It will contribute to the understanding of climate-biodiversity relationships.

Climate change is evident in Zimbabwe as already stated in literature (Musiyiwa *et al.,* 2014; Simba *et al*, 2012; Unganai, 1996). This study highlights the impacts of climate change on vegetative species diversity. Although there is a host of studies predicting the effects of climatic change on biological diversity, little has been done on measuring the magnitude of these effects and detail the changes in vegetative diversity particularly in Zimbabwe. This study goes further by determining how the phenomenon of climate change has affected species abundance, distribution and composition.

This study emphasizes on the understanding of the relationship between vegetative species diversity and climate change in semi-arid areas, providing a platform for devising strategies to enhance the resilience of ecosystems through the adoption of species based adaptive and mitigation strategies. In this regard, the study contributes to the achievement of Sustainable Development Goal (SDG) number 15 which calls for urgent and substantial action to halt biodiversity loss and protect species from extinction by nations. By managing and protecting species diversity, we are building the capacity of ecosystems to resist climate change and be resilient to its impacts. It is in this regard that the study also contributes to the attainment of SDG 13 which advocates for urgent action to combat climate change and its impacts.

Biodiversity has remained as one of the central themes of ecology since many years. However, after the 2012 Rio's Earth Summit, it became the main theme not only for ecologists, but also for biologists, environmentalists, planners and administrators. As many countries, including Zimbabwe, are party to the Convention on Biological Diversity (CBD), each nation has the solemn and sincere responsibility to record the species of plants and animals occurring in their respective countries and assess the biodiversity properly and implement suitable management strategies for conserving the biodiversity which is often described as the Living Heritage of Man. It is imperative therefore to understand how the biodiversity is being affected by the long term environmental changes that are taking place. Thus, this study will contribute through provision of data on plant species being affected by climate change in Masvingo Province.

According to the USNAS (2012), the fundamental science of greenhouse gas-induced climate change is simple and compelling but genuine and important uncertainties remain. For example, the response of clouds, ecosystems, and the Polar Regions remain unknown. This study seeks to assess how ecosystems, with specific reference to vegetative species, respond to climate change to deal with some uncertainties as predicted by the National Academies of Sciences. By this, the study contributes to the body of literature that addresses the some of the important uncertainties in the world of science.

1.7 Study Area

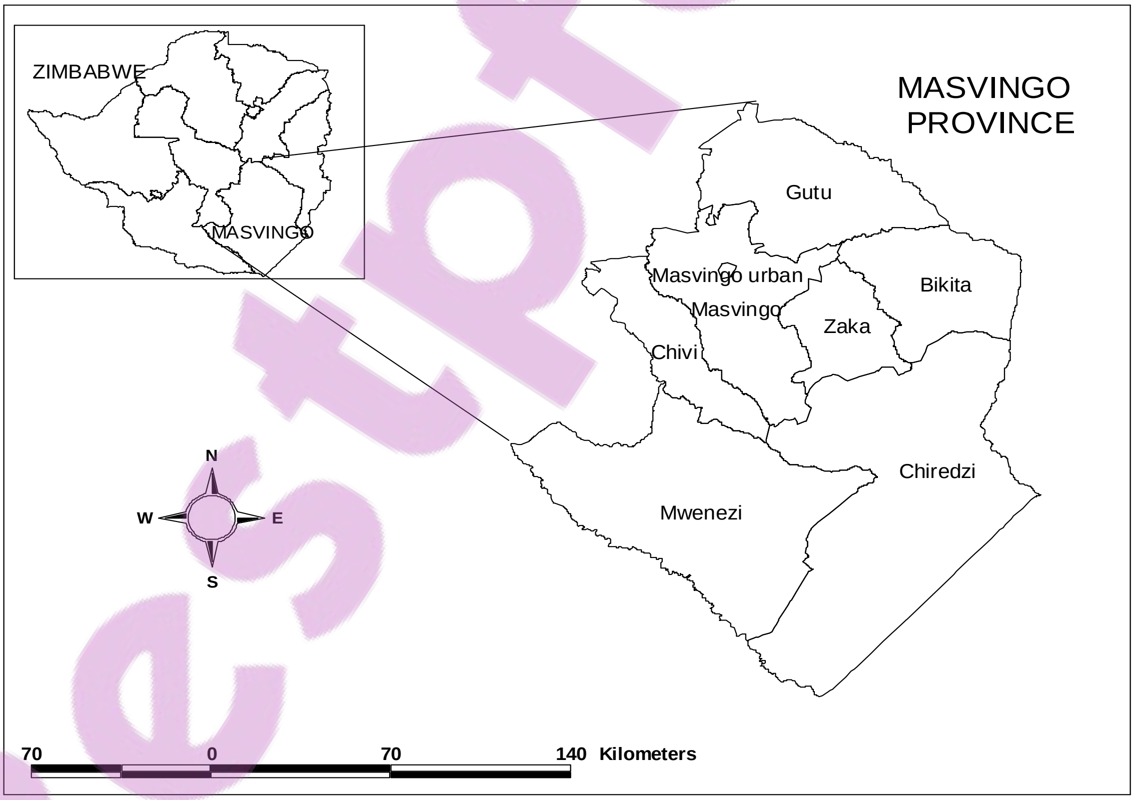


Figure 1.1. Location of the study area (Masvingo Province
Source: Produced by author

The study was conducted in Masvingo province, shown in Figure 1.1. This area was selected because it is one of the semi-arid regions in southern Africa where impacts of climate change on vegetation species diversity have not been well studied and documented. The province is located in the south-eastern part of Zimbabwe, bordering Mozambique on the east and the provinces of Matabeleland South to the south, Midlands to the north-west and Manicaland to the north east. The province is divided into seven administrative districts namely Masvingo, Chiredzi, Chivi, Mwenezi, Gutu, Bikita and Zaka (Figure 1.1). The area occupies the drier Lowveld expanse in the south of Zimbabwe and extents for 56,566 km^2 in area.

1.7.1 Physical environment

1.7.1.1 Climate

Masvingo Province falls under agro-ecological zones III, IV and V according to Vincent and Thomas (1960) classification system (Figure 1.2). The northern parts of Gutu, Zaka; north-western Bikita and eastern parts of the province fall under region III which receives rainfall that ranges between 650 and 800mm per annum. Region IV climates which receive below 800mm per annum and experience severe summer droughts are found in the southern and northern parts of Masvingo and Chivi, southern parts of Zaka and Gutu and Bikita central. The rest of Chiredzi, most of Mwenezi and some central parts of Chivi and southern parts of Bikita fall into region V which receives less than 450mm of rainfall per annum. Figure 1.2 is a map of Masvingo showing the distribution of agro-ecological regions (Vincent and Thomas, 1960)

However, Chikodzi and Mutowo (2012) noted that the agro-ecological zones proposed by Vincent and Thomas (1960) have since shifted due to climate change. Throughout the province, effective rainfall probability levels are very low (Bernardi and Madzudzo, 1990; Makadho, 1996). The province experiences sub-tropical climate with distinct summer and winter seasons. Rainfall is highly variable and uncertain making the province prone to droughts and inappropriate for rainfed agriculture (Mudzengi *et. al.*, 2013, Makadho, 1996). High rainfall is received in summer between November and March and averages between 600 mm-800 mm, annually. The province experiences very high temperatures averaging 22^{o}C. As a result of changing and variable rainfall and temperatures across the province, climate classification has been distorted and various physiological changes have occurred (Chikodzi *et al.*, 2012). On that note, there is need for re-assessment of the physical and socio-economic profile of the province.

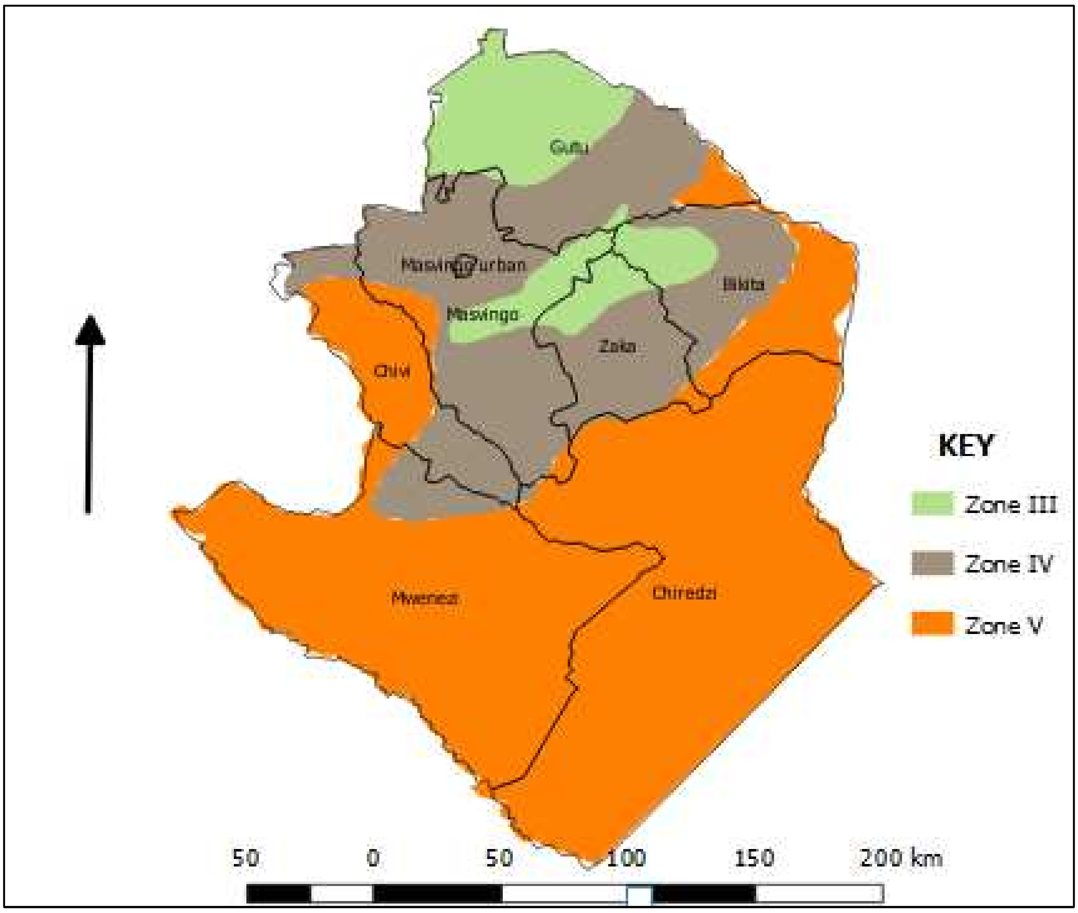


Figure 1.2. Climate of Masvingo Province as defined by agro-ecological regions
Source: Vincent and Thomas, 1960

1.7.1.2 Topography

The terrain is highly variable with gently undulating to rolling common rock out-crops and dissections that contribute to the nature of the drainage system shown in Figure 1.3.

The drainage is dominated by the Save, Mwenezi, Runde and Mutirikwi river systems. Rivers and streams generally flow in the south-eastern direction and most of them feed into Runde and Save Rivers which confluence at the edge of the province in the south eastern side and drain into Indian Ocean. Altitude ranges from 450 m to 1240 m. Major land features are characterized by moderate slopes that are steeper on the southeast than North West. Kopjes, hills and mountain ranges are dotted throughput the province. The province is characterised by steep landforms such as inselbergs, castle kopjes, dwalas and mountains (Zhou, 2004).

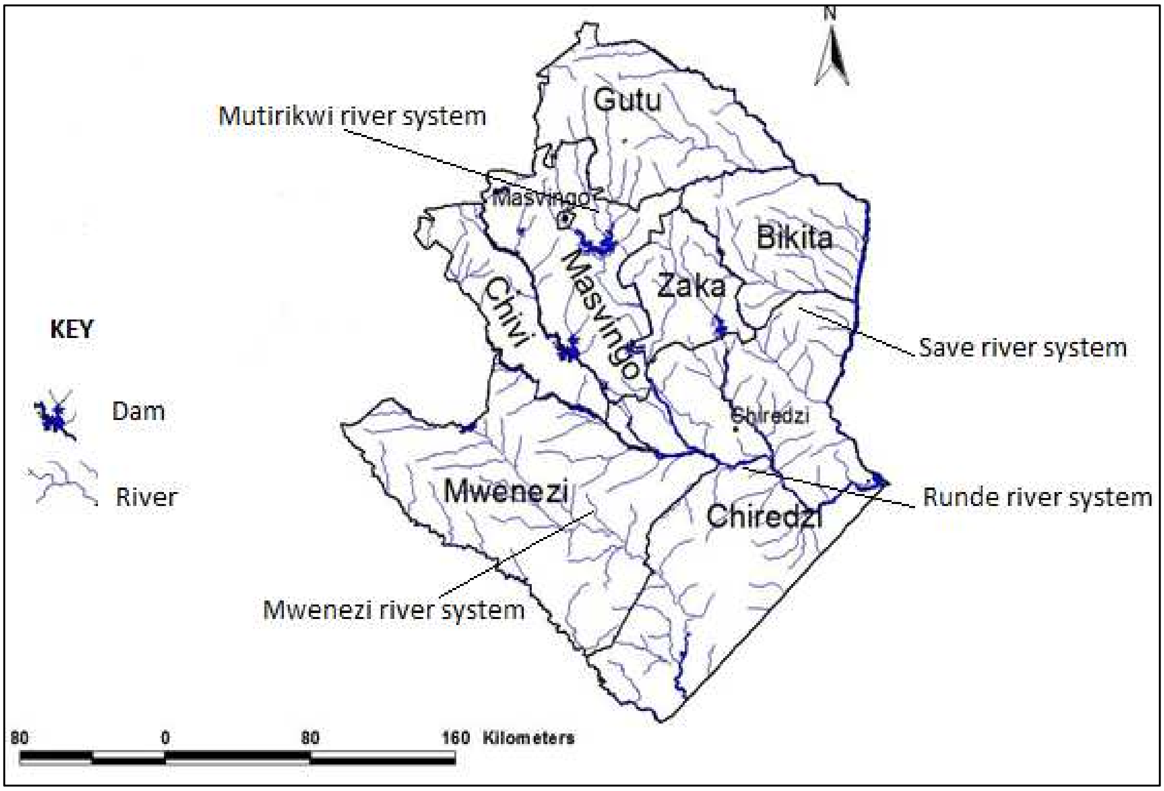


Figure 1.3. The drainage system of Masvingo Province.
Source: Produced by Author

1.7.1.3 Soils

All the districts have distinct soils whose characteristics are closely related to the geology, climatic regime and topography (Thompson and Purves, 1978). Granitic rocks cover most parts of the province forming major parent materials. Soils are moderately shallow to moderately deep or deep, coarse textured sandy soils and sub-soils that range between coarse sand and sandy clay (Zhou, 2004). According to the Zimbabwe soil classification system, the soils are classified under the *fersiallitic, siallitic families* of the *kaolinitic* order (Zhou, 2004). The province is characterized by *siallitic soils* in the south-east Lowveld, *orthoferralitic* soils in Bikita area (Chenje, *et. al*, 1998). Masvingo district is dominated by *ferrallistic* soils. Moderate to strongly leached soils with clay fractions (Murwendo and Munthali, 2008) dominate Gutu District.

1.7.1.4 Vegetation

The vegetation in Masvingo province is predominantly savannah bushveld dominated by *Peltophorum africanum and Acacia karoo* with continuous or discontinuous grass cover depending on the soil moisture regime (Zhou, 2004). Grasslands are dominated by

Hyparrhenia fillipendula, Themeda triandra and Hyperthelia dissolute (Vincent and Thomas 1960).Vegetation species composition is mainly determined by rainfall pattern, topography, soil type and human disturbance. Miombo woodlands dominate the wetter parts while Mopane trees, which are drought tolerant and sturdy, are found throughout the province. Thus, *Brachystegia spiciformis*, and *Julbernardia globiflora species*, which comprise Miombo woodlands (Campbell *et al*, 2000), make part of woody vegetation in the wet northern part of the province. *Parinari curatellifolia* can also be found in pure stand or in combination with *Burkea Africana* and *Terminalia sericea* and they are mainly found in well drained middle slopes and on upland soils. However, few vegetation species of this type remains in its pristine state due to clearing of land for agriculture especially in communal areas. Undisturbed forests can be found in commercial farmlands and designated wildlife areas (Chenje *et. al*, 1998). In dry areas of the south-eastern Lowveld, woody tree species are dominated by the drought tolerant Mopane (*Colophospermum Mopane*), baobab (*Adansonia digitata*), *Commiphora* spp, *Kirkia cuminate* and *Acacia* tree species (Zhou, 2004; Chenje, *et al*, 1998). Continuous vlei or dambo grassland savannah with scattered scrublands also form an important component of the landscape as part of vegetation catena (Nhandara *et al.*, 1991).

1.7.2 Socio-economic profile

1.2.2.1 Population

Masvingo province has a total population of 1 485 090 comprising approximately 697 992 males and 787 098 females (ZIMSTATS, 2012). Population density is about 26 persons per km^2. The economically active age group comprises 73 percent of the total population. Figure 1.4 shows the distribution of population across the province both in urban and rural areas.

Most people in the province (approximately 90 percent) reside in rural areas. The large number of people living in the rural areas could be one of the key determinants of vegetation composition and distribution. The Karanga tribe, which is the most populous tribe in Zimbabwe, dominates the province. They are a sub-group of the Shona speaking tribes that also include the Zezuru, Manyika and Ndau (ZIMSTATS, 2012).

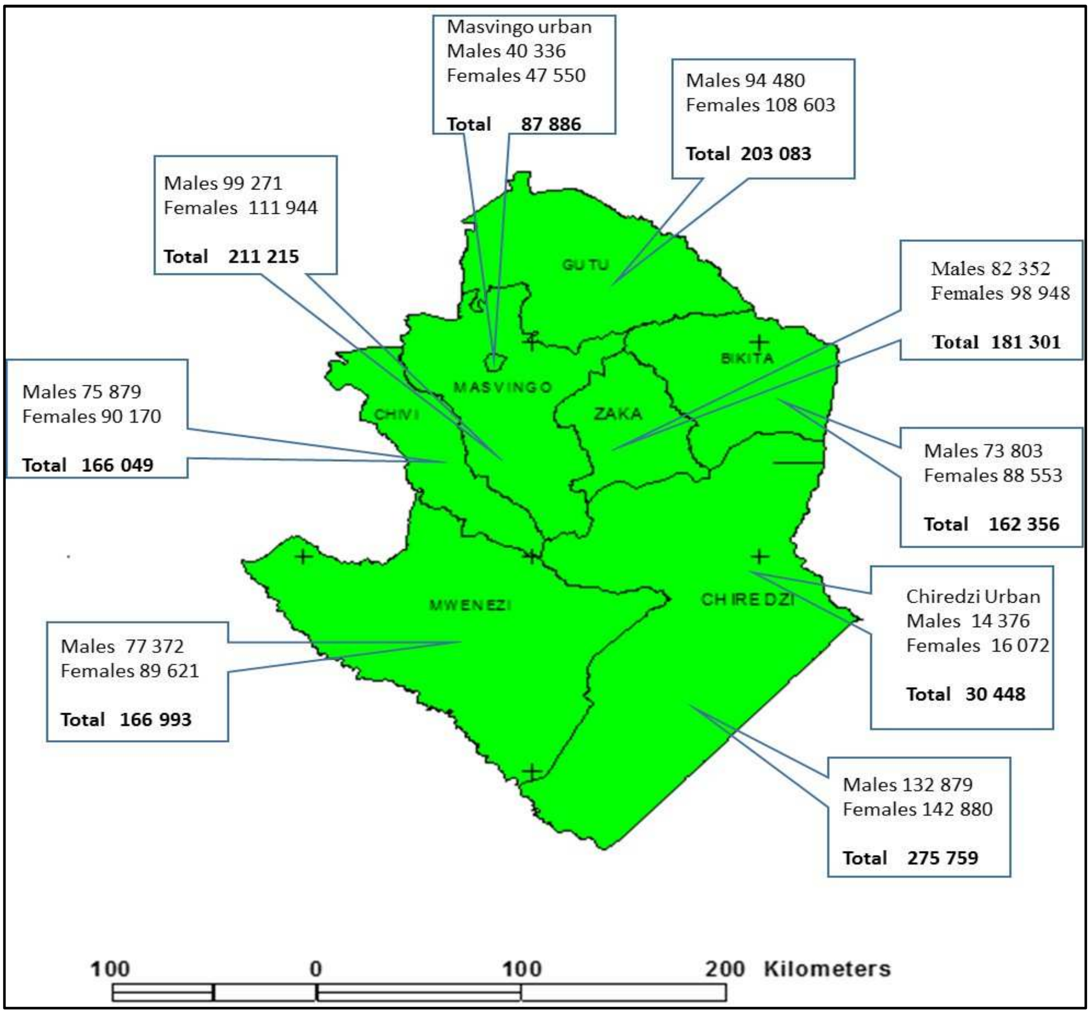


Figure 1.4. Population distribution in Masvingo province.
Source: ZIMSTATS 2012

1.7.2.2 Agriculture

Figure 1.5 shows the agricultural productivity map for Masvingo province. Most of the province is unsuitable for crop production due to low rainfall received. The province is mainly conducive for wildlife production and cattle ranching, and small stock farming. Nonetheless, subsistence farming is the main economic activity. The main crops grown include drought resistance varieties of maize, cotton, sorghum, cotton, sorghum, finger millet, sunflower and pumpkins (Murwira, 2000).

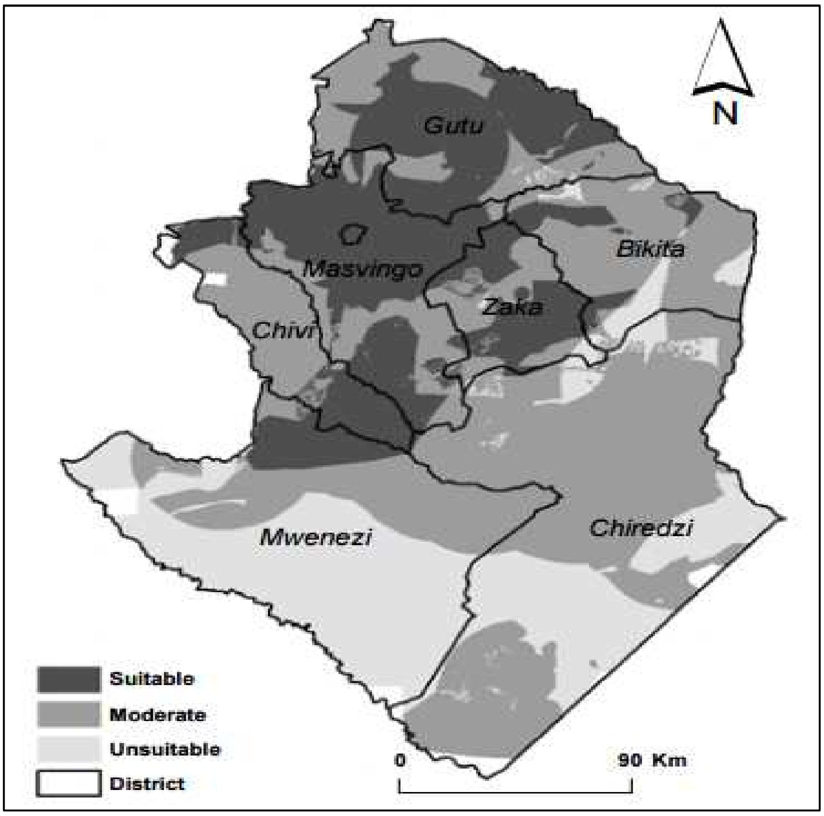


Figure 1.5. Agricultural productivity map for Masvingo province
Source: Chikodzi and Mutowo (2012)

Table 1.1 shows agricultural zones and suitable activities for each zone. Only 25 percent of the land is suitable for arable farming. Most of the land in the province require supplementary water through irrigation to enable productivity.

Table 1.1 Agricultural zones, their size and suitable activities in Masvingo province

Zone	Hectares	Suitable agricultural activities
Suitable	1 390 782.75	Early maturing maize varieties, winter wheat, market gardening, horticulture, floriculture.
Moderate	2 792 404.89	Small grains e.g. millet, rapoko, sorghum. Sugarcane, cotton, citrus fruits, sweet potatoes, groundnuts, round nuts, cassava
Unsuitable	1 337 946.17	Extensive cattle and game ranging. Crop agriculture not suitable even the most drought resistant

(Source: Chikodzi and Mutowo 2012)

The government has assisted in setting up some irrigations schemes in the province to enable arable farming for example, the Rozva irrigation scheme in Bikita, Hippo valley estates in Chiredzi, and Triangle use water from Lake Mutirikwi for irrigation purposes. In addition, the Tokwe Mukosi irrigation scheme is currently being developed.

1.7 Scope of study

1.7.1 Geographic scope

The study is confined to the whole Masvingo Province in Zimbabwe, located at 20.6242^0S and 31.2626^0E, only excluding urban areas owing to the assumption that vegetative species diversity in urban centres has been largely subjected to human modification other than to climate change. Thematically, the study focuses on the climatological and biophysical aspects within Masvingo Province. Remote sensing is the main tool used to assess the changes in vegetation species diversity over time. This was possible after establishing a positive correlation between vegetation species diversity and a satellite derived vegetation index (NDVI). Downloaded satellite images covering a period from 1972 to 2014 for both the wet and dry seasons were analysed. For the wet season, images analysed were for 1972, 1987, 1998, 2006 and 2014. For the dry season, images analysed were for 1986, 1998, 2006 and 2014. The choice of years was mainly influenced by availability of the images for analysis although the author made sure that each decade is represented.

1.7.2 Conceptual scope

Over the past forty years, extreme climatic events such as droughts, floods and heat waves are reported to be increasing in frequency and severity globally (John *et al.*, 2013). The semi-arid regions of southern Africa have been the most affected and the region has been described as a climate hot-spot (Shan *et al.*, 2013). These recurring extreme events are affecting all levels of biodiversity, from organism to biome levels (Parmesan, 2006; Bellard *et al.*, 2012). Figure 1.6 shows the multiple components of climate change and their link to biodiversity changes at all levels. This brings to context the conceptual framework for this study, which focuses on how changes in temperature and rainfall influence diversity of vegetation species at ecosystem level.

Climate change has the tendency to decrease genetic diversity through directional selection and rapid migration (Meyers and Bull, 2002; Botkin *et al.*, 2007). This affects ecosystem functioning and resilience and consequently the diversity of species within the ecosystem. However, Bellard *et al.*, (2012) claim that a deluge of studies has focused on impacts at higher levels while genetic effects of climate change have been examined only for a very few species. There is therefore need for further studies to consider a wider spectrum of species to ascertain the impacts of climate change components on genetic diversity under different geographic conditions.

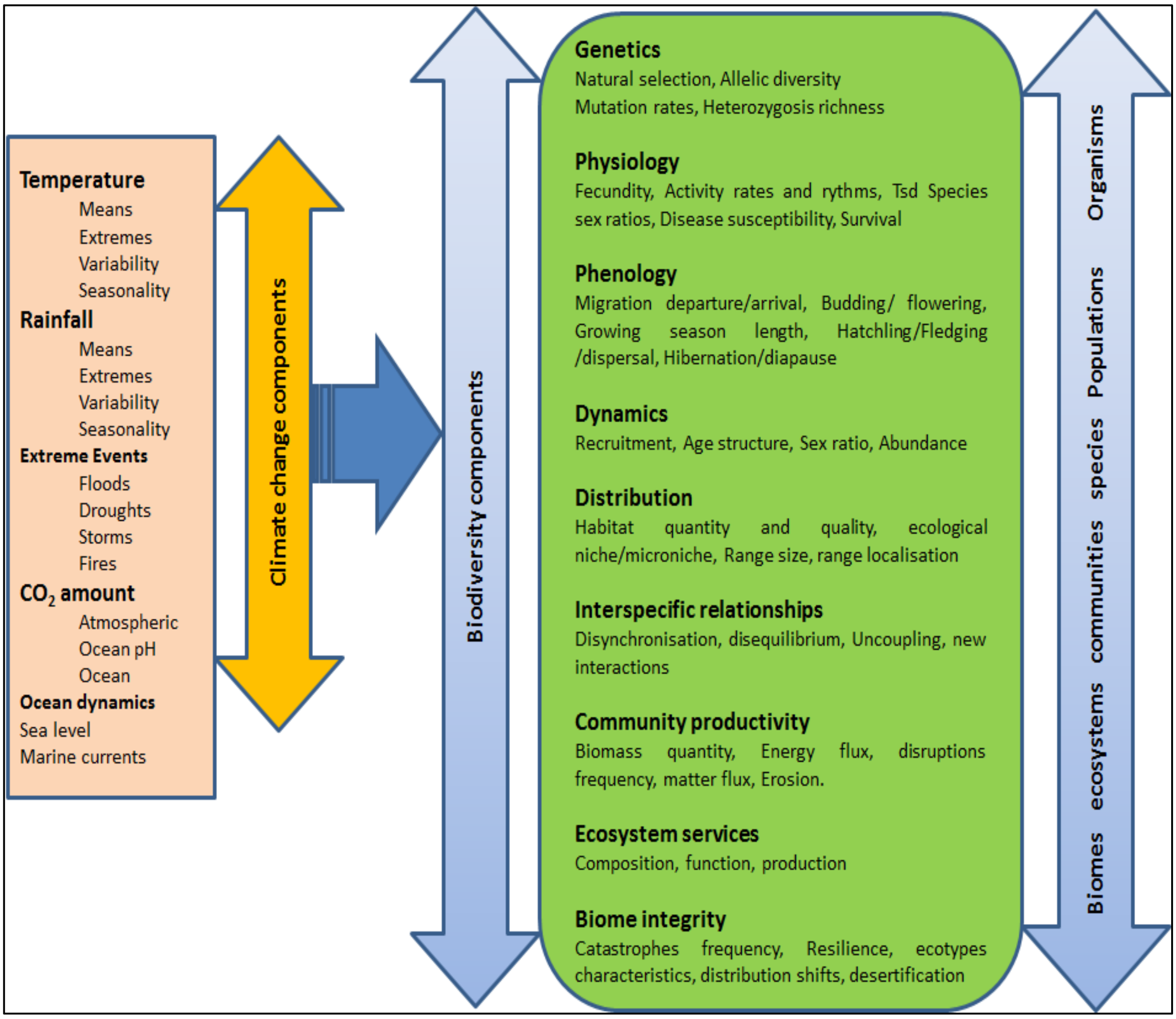


Figure 1.6. Aspects of climate change and likely effects on different levels of biodiversity.
Adapted from Bellard et al, 2012

Climate change, through its various mechanism and components, will directly and indirectly affect interactions of species at community (local) level (Gilman *et al*. 2010; Walther, 2010). In essence, species will respond to climate change indirectly through impacts on other species they depend on. Koh *et al.* (2004) buttresses the foregoing argument, providing evidence from a study of 9,650 interspecific systems where 6,300 species disappeared following the extinction of their associated species. Although a plethora of studies (Thuiller *et al.*, 2005; Van Vuuren *et al.*, 2006; Randin *et al.*, 2009; Yang and Rudolf., 2010; Ziska *et al.*, 2011) has analysed the impact of climate change on interactions of species in different communities, no satisfactory coverage has been done on the diversity of communities and none has focused on vegetation communities, especially in Masvingo province, Zimbabwe.

Bellard *et al*. (2012) argue that the main effects of climate change on species diversity are impacts on food and habitat on which the species depend on. Climate change will impact negatively on water availability and soil fertility, these in turn will affect vegetative biodiversity components from the genetic to biome levels.

Climate change triggers phenological changes in vegetative species which consequently lead to diversity alteration. Kiers *et al.,* (2010) and Rafferty and Ives, (2010) concur that climate change results in phenological shifts in flowering and insect pollinators, producing misalliances between plant and pollinator populations leading to extinctions of both the plant and the pollinator with predictable consequences on the structure of plant-pollinator networks. Further modifications can be induced through interspecific relationships that modify community structure and consequently diversity. Although several studies (Lafferty, 2009; Walther, 2010; Yang and Rudolf, 2010) have analysed the impact of climate change on interspecific relationship, they have not expressed the effects with regards to biodiversity changes. Thus, scientific studies coverage of this area is far from satisfactory especially under semi-arid conditions in southern Africa.

At the biome level of diversity, climate change imposes changes that may result in irreparable biome shifts (Leadley *et al.,* 2010). A 5-20% shift of the Earth's terrestrial ecosystems has been predicted by the Millennium Ecosystem Assessment (Sala *et al.,* 2005). Lapola *et al.,* (2009) suggest that in tropical South America, large areas of the Amazonian forest could be replaced by tropical savannahs. Alo and Wang, (2008) projected a northward and upward shift of alpine and boreal forests at higher latitudes and altitudes at the expense of low stature tundra and alpine communities.

While satisfactory research has been done on climate change and biodiversity and a clear link established between climate change and biodiversity components as shown in the conceptual framework (Figure 1.6), there is still need for more detailed regional component specific understanding of the climate change-biodiversity nexus. In fact, there is a contextual, geographical and temporal gap in knowledge that exists with regards to the specific climate change elements and their effect on specific biodiversity components. It is in this context that this study contributes further information on how long term changes in temperature and rainfall influence vegetative species diversity under semi-arid conditions. Figure 1.7 provides the contextual framework covered by this study.

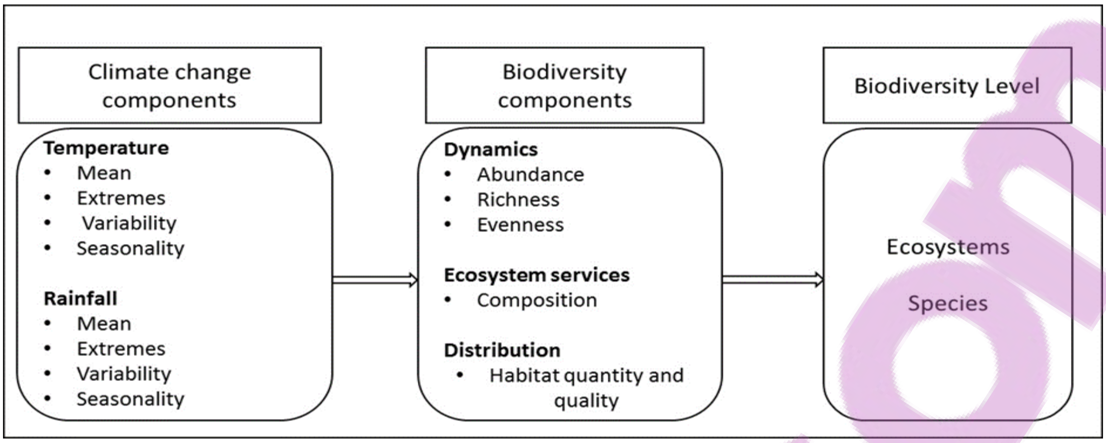


Figure 1.7. Conceptual framework for the study.
Source: Bellard et al (2012)

As shown in figure 1.7, focus is on temperature and rainfall related climate change components. Ocean dynamics and CO_2 patterns in the region are not going to be discussed and the basic assumption is that while these contribute to climate change, temperature and rainfall dynamics are the most important determinants of climate conditions in the region of concern. While there is a deluge of biodiversity components that can be affected by changes in the temperature and rainfall patterns, the study focuses on issues related to abundance, richness and evenness of vegetation species. Compositional aspects will also be covered as well as habitat quality and quantity. Climate change affects various levels of biodiversity but the study focuses on the ecosystem and species level.

1.7.3 Theoretical scope

The study was premised on three theoretical perspectives to assess impact of climate change on vegetative species diversity and the use of remote sensing in the assessment. These are:

1. The metabolic theory of ecology (MTE) (Brown *et al.*, 2004) which states that temperature affects metabolic processes. Metabolic processes include chemical reactions that determine the state of a living organism. MTE suggests that the metabolic rate of an organism is an essential rate that controls most observed patterns in ecology (West *et al.*, 1997).Thus, any change in temperature will result in physiognomic, phenological and genetic changes in plant species.
2. The biomass-biodiversity hypothesis (Guo, 2006), which postulates that high biomass is correlated with high species diversity. Some researchers have reported a positive correlation between the two (Loreau and Hector 2001; Hector *et al*. 1999; Tilman *et al.*, 1996) but others have reported a hump–shaped relationship where low levels of biomass

coincide with low species diversity, intermediate biomass levels are associated with high species diversity while high levels of biomass coincide with low species diversity (van Ruijven and Berendse 2005; Fargione *et al.,* 2007).

3. The spectral variation hypothesis (SVH) (Palmer *et al.,* 2000) which is founded on the postulation that spectral heterogeneity of remotely sensed images is positively related to the spatial variation within the ecosystems particularly variation of plant species and communities.

1.8 Thesis outline

The thesis is made up of five chapters:

- **Chapter one** provides a background, highlighting the research gap from general to specific and from global to local contexts. The overriding problem, its location and possible solution as well as the contribution that the study seeks to make is presented. The focus of the study is also highlighted in this chapter through its aim and specific objectives, research questions and the significance of the study. It also provides a background description of the study area and scope of the study.
- **Chapter two** provides a detailed review of theoretical and empirical literature on the issue of climate change as a global phenomenon with climate change trends and impacts on ecological species diversity as observed at various geographical scales. It further reviews literature that is related to the stated objectives and research questions. The concepts of remote sensing and its use in predicting species diversity are also discussed as well as ecosystem climate change adaptation strategies from a regional and context specific perspective.
- **Chapter three** provides details about the epistemological and entomological configuration of the study, the research design, data collection strategies, instruments and procedures. It also provides details about data analysis techniques used in producing the research results.
- **Chapter four** presents data and discussion of research findings.
- **Chapter five** provides a summary of the thesis, conclusions and recommendations for sustainable biodiversity management under the threatening climate change and related human activities. Suggestions are also provided for future research towards further enriching the body of knowledge related to climate change impacts on vegetative species diversity under semi-arid conditions.

Chapter 2 : LITERATURE REVIEW

2.1 Introduction

Chapter 2 reviews literature to provide the theoretical framework and empirical background to inform the study. The reviewed literature covers a comprehensive spectrum of aspects, ranging from the actual and projected changes in climate and its influence on biodiversity particularly plant species diversity at global, regional and local scales. It discusses the theoretical underpinning for each specific objective for the study. Trends in climate change at global, regional, local as well as in semi-arid regions are discussed based on studies conducted by various scholars. Current and projected changes in biodiversity and specifically plant species diversity as indicated in scientific studies and models are also reviewed to put this study into context. In addition, the usefulness of remote sensing products in general and vegetation indices in particular, in estimating plant species diversity is also discussed based on studies done by a diversity of researchers. A discourse on the methodological approaches used by various scholars in climate change impacts and biodiversity assessments is provided to inform the methodological framework adopted in this study.

2.2 Global climate change: Concepts and trends

Climate change relates to the long term continuous change, whether decrease or decrease, in the long term average weather conditions (Hansen *et al.*, 2011; Keely, 2011; IPCC, 2007a). It occurs gradually over decades and cannot be ascertained without scientific records (Keely, 2011). Furthermore, Keely (2011) proclaims that climate has been changing in the past and it will continue to do so due to changes in the Earth's environment and there is nothing inherently wrong with that. However, the current concern amongst scientists is that it is changing at a faster rate than previously experienced in the last 800,000 years (Keely, 2011). The rate at which climate is changing is resulting in a plethora of consequences on all facets of life, *inter alia*, biodiversity on which humanity depends on for survival.

According to Barry and Chorley (2003), the realisation that climate was far from being constant only came in the 1840s when indisputable evidence of former ice ages was obtained. Climate has changed over the years to affect ecosystems and other forms of life. The study of past climate began in the 1920s and more actively in the 1950s. Weather records span only approximately the last hundred years (Barry and Chorley, 2003). However, proxy indicators of the past climates are used in obtaining paleo-climatic data (Barry and Chorley, 2003). Some of the proxy indicators include tree rings, pollen in bog, ocean foraminifera and lake sediments among others. Thus, if a *relationship* is established between vegetative species diversity and climate, plant species diversity could be useful as a proxy indicator for climate change. If a positive relationship is also established between remote sensing indices such as NDVI and species diversity (Ustin, 2016; Cavender-Bares *et al.,* 2016; Graves *et al.,* 2016; Revermann *et al.,* 2016; Wang *et al.,* 2016a), then the impact of climate changes on plant diversity can be understood through the use of remotely sensed data.

It is valuable to first consider the nature of climatic changes. The World Meteorological Organisation (WMO) proposes thirty years as the standard interval for climatic statistics (Goose, 2015). However, for historical records and proxy indicators of climate, longer, arbitrary time intervals may be used (Barry and Chorley, 2003). Tree rings and ice cores can provide seasonal/annual records, while peat bog and ocean sediments may provide records with only 100 to 1000-year time resolution. Hence short term changes and true rates of change may not be identifiable. Climate change can occur in several different ways (Brown *et al.,* 2012; Barry and Chorley, 2003; Hare, 1979), which include an abrupt shift in the mean of climatic variables, a gradual change in the trend of the mean, periodic variability and a progressive trend in the mean (Barry and Chorley, 2003).

Global temperature records as from 1881 to date indicate a considerable but irregular increase of between 0.3 and 0.6 ^{0}C (Jones and Briffa, 1992). This trend is least in the tropics and greatest in the regions of high latitudes. Winter temperatures are the most affected. According to Barry and Chorley (2003), the general temperature rise has not been continuous and four phases can be identified:

a. 1881 to 1920- No consistent trend but the mean annual fluctuation was within extreme limits of 0.4^{0}C.
b. 1920 to mid-1940s- Warming to mean temperatures of 0.4^{0}C.
c. Mid 1940s to early 1970s- The northern hemisphere cooled while the southern hemisphere warmed. Oscillations were within extreme limits of less than 0.4^{0}C.
d. Mid 1970s to 2000-There was noticeable general warming of around 0.50^{o}C except for areas of the North and south pacific, North Atlantic, Europe, Amazonia and Antarctica. In some areas the warming exceeded 1^{0}C.

Based on balloon soundings, the global tropospheric temperature increase since 1950s has been about 0.1^{0}C/decade, similar to that at the surface (Barry and Chorley, 2003). However, the satellite records of tropospheric temperature show a lesser rate of warming than the surface air temperature: 0.050 +/- 0.1^{0}C/decade versus 0.15 =/-0.05/ decade. The differences are mainly in the tropics and subtropics and are not fully explained (Barry and Chorley, 2003).

Available data shows that global temperatures on average are increasing. The warmest years on record were 1998, 2001, 1995 and 1990 (IPCC, 2007b). In the southern hemisphere there has been an irregular warming of around 0.5^{0}C since 1930. The twentieth century global warming was approximately 0.75^{0}C, which appears to exceed natural trends of 0.3^{0}C/100 years as estimated from statistical modelling (IPCC, 2007b; Barry and Chorley, 2003). There is a wide consensus that this warming is a result of increases in greenhouse gases, principally carbon dioxide. The warming is associated with dire consequences on man-made and natural systems. Ecosystems and their functions have not been spared. Bellard *et al.,* (2012) projected that plant species diversity may also alter due to these changes. It is therefore important to understand the impact of temperature changes and changes in other climatic elements over time on plant species diversity.

Climate change is the most significant environmental challenge facing humankind today (WCED, 1991, Weart, 2004). Although several theories have been propounded with regards to the causes of climate change, it is generally agreeable and no longer a myth that, besides natural climatic variability, human activities are significantly contributing to the earth's climate change process (IPCC, 2001, 2007b; Bellard *et al.,* 2012; Pereira *et al.,* 2010; USNAS, 2014). However, Bast (2010) argues that the assertions that human beings are causing climate change are extreme due to the complexity of the climate system. There is a lot that is not yet known in the climate system and several mechanisms are not yet included in the climate models considered by various scientists (Bast, 2010). In spite of this view, there is enough evidence linking human activities to climate change. The US National Academy of Sciences (USNAS, 2014) agrees that climate change is a result of complex processes within the climate system but it is now more definite than always, based on practical evidence, that humankind is the key driving force behind the problem of climate change. Several scientists (Mirza, 2003; Rosenzweig *et al.,* 2001; Reason and Keibel, 2004; Reason, 2007; Warburton *et al.,* 2005) are of the opinion that the increased frequency of extreme events associated with climate change may be attributable to increasing greenhouse gas (GHG) emissions through human activities.

The Intergovernmental Panel on Climate Change (IPCC, 2007a) states that climate change could be due to natural variability or as a result of human activity. The United Nations Framework Convention on Climate Change (UNFCCC, 2002), views climate change as a shift in long term atmospheric conditions ascribed directly or indirectly to human activities and natural variability that alter global atmospheric composition. For this study, whether climate is caused by natural processes or human activities could be of no consequence but the reality on the ground is that climate is changing with evident environmental consequences *inter alia,* ecosystems modification characterised by biodiversity changes.

Climate change is depicted by several factors, some of which are observed and projected changes in mean global temperatures and rainfall, and the associated impacts, such as increase in extreme weather events; melting of icebergs, glaciers and permafrost; sea level rise; and changes in the timing and amount of rainfall. (Kandji *et al.,* 2006; Schneider *et al.,* 2007; Daze *et al*, 2009; Brown *et al.*, 2012). Yanda (2010) buttresses this view asserting that climate change and variability are occurring as a result of natural and anthropogenic processes altering atmospheric composition which in turn changes the meteorological conditions and processes. These changes have conveyed significant modifications of rainfall and temperature patterns, which become evident through frequent droughts, dry spells and floods. The IPCC (2007a) avers that the mean temperature of the earth’s surface has increased by 0.74°C since the late 1800s and proclaims that the temperatures are likely to rise to 4°C by the year 2100 if the current trend continues unabated. Such increase is too fast and intense in geological time. Tol, (2005) and Christensen *et al.,* (2007) are of the opinion that even if it gets another slight increase from the current levels, it would be an increase larger than any century-long trend in the last 10,000 years.

These projected changes are part of the key potential vicious cycles of climatic perturbations that might characterise the globe. Warming might occur at a rate that is beyond human imagination. Yohe and Schlesinger, (2002) and Agrawal (2005) reiterated that the increase in the use of fossil fuels in the quest for development and the fact that virtually all human activities produce greenhouse gases will increase the complexity of climate change problem and intricately tie it with poverty and economic development.

Climate change has had a diversity of impacts on the ecological systems, including all forms of species diversity. Both flora and fauna species have tolerance ranges for environmental gradients such as temperature and rainfall. If the tolerance range is not reached or exceeded, the species will not be able to produce and survive. This often results in ecosystem imbalances that are associated with other impacts that may affect human beings directly and indirectly. There is still paucity of scientific evidence in most developing economies on whether climate change has influenced the tolerance ranges of vegetation species resulting in changes in vegetative species diversity. The situation in developing countries is exacerbated by low adaptive capacity and poor technological development, affecting both economic growth and environmental protection. While direct effects from climate change vary widely across the globe with some areas projected to get wetter, much of southern Africa is getting drier and hotter (Yanda, 2010). This aggravates the impacts beyond the capacity of the ecosystems to cope with the potential and known changes.

While climate change already poses significant impacts on the environment, affecting ecosystem stability and agricultural production, there has been little commitment to make adaptation and resilience national priorities among sub-Saharan African (SSA) countries (Levina, 2006; Chagutah, 2010). In most cases, adaptation has been taking place at local level through involuntary migration (Black *et al.*, 2011; Tacoli, 2009), as well as changes in the sectoral structure of production, and changes in cropping patterns (Kotecha, 2010). The key role of the government is to provide information, incentives, and the economic environment to facilitate such changes. However, there has generally been very little effort to address climate change impacts in most developing countries. These drawbacks in adaptation are attributed to; low scientific development and poor social and economic infrastructures as well as Africa's fragmentation into small countries and ethnic groups, and also poor business environments.

The realisation that there is overwhelming evidence of human induced climate change which is associated with dire implications on the global community led to the formation of the UNFCCC. The convention was in response to evidence of warming and related consequences and the need to take immediate action (Schneider *et al.*, 2007).

2.3 Projected global climate change and impacts on biodiversity

In the absence of mitigation measures, the continued increase in emission rates is projected to warm the globe by 4^0C in 2100 (World Bank, 2012). If the current increase in GHGs remains unabated, the next few centuries will experience pronounced warming. This will be characterised by an increased recurrence of heat waves, severe droughts and huge floods, accompanied by deleterious impacts on ecosystems and related services (World Bank, 2012 MEA, 2005). As with the current situation, the impacts will not be evenly distributed across the globe. This means that different geo-climatic regions are likely to experience different climate change impacts. The World Bank, (2012) projects that warming will be more pronounced in the next centuries if the current increases remain unabated. Projections show that extremely high summer temperatures are expected in many parts of the globe (World Bank, 2012). Extreme heat waves experienced in Russia in 2010, for example, are likely to become new normal summer characteristics in a 4^0C warmer world (World Bank 2012).

The projected increase of 4^0C will have monumental impacts given that the effects in a scenario of 2.5^0C warming are severe, with observable ecosystem changes expected on every continent (Heyder *et al.*, 2011). Only small biome shifts in temperate and tropical regions are expected if temperature increase in limited to 2^0C coupled with a slight decrease in precipitation. Cold and tropical climates will experience considerable change if temperatures increase by 3^oC while at 4^oC, large scale biome shifts will occur and temperate zones will be substantially affected. De Groot *et al.*, (2012) and Farley *et al.,* (2013) note that such changes would result in extensive loss of biodiversity and reduced land cover. Climatic variables are significant factors in influencing plant structure and ecosystem composition (Reu *et al.*, 2011).

The abrupt rise in global temperatures will result in massive changes in various ecosystems due to their failure to adapt to changed conditions. Biodiversity shifts and species losses are likely to be the order of the day. The World Bank (2012) reports that large scale species losses and ecosystem changes have been associated with climate change. Climate change will exacerbate the impacts of other ecological stressors leading to massive species extinctions, declining species abundance, or widespread shifts in species and biome distributions (Leadley *et al.,* 2010; Campbell *et al*., 2009; Inouye, 2008; MEA, 2005). Furthermore, it is projected that major changes in ecosystem structure, species ecological interactions and shifts in species geographical ranges with primarily adverse impacts on biodiversity will occur in future (World Bank, 2012; Leadley *et al.,* 2010). It is estimated that about 20 to 30% of plant and animal species assessed to date are at risk of extinction due to climate change and this will be exceeded if warming continues according to projected trends (World Bank, 2012). Fischlin *et al.,* (2007) project losses in forest species due to droughts, wildfire and agricultural expansion whose roots are in climate change.

In addition, Rahel and Olden, (2008) and Hellamann *et al.,* (2008) foresee the potential of climate change in facilitating the spread of invasive species with implications on biodiversity and its functions. Similarly, Barnosky *et al.,* (2012) proclaim that climate change has the potential to catalyse abrupt shifts in ecosystems that may cause significant biodiversity changes. Wernberg, *et al.,* (2012) and Thibault and Brown (2008) buttress this view adding that the extreme climatic events will drive dramatic ecosystem changes. It is predicted that the risk of wildfire occurrence will increase significantly due to climate change. This will lead to significant biome shifts resulting in changes in carbon fluxes and vegetation composition (Barnosky *et al.,* 2012; Heyder *et al.,* 2011; Lavorel and Garnier, 2002). Furthermore, Fernandez-Gonzalez *et al.,* (2005) reiterated that on the basis of current climate observations and 21st century forecasts, poleward shifts of biomes of up to 400 km are inevitable. This implies massive changes in vegetative species diversity at global level and consequent changes in ecosystem functions which may directly or indirectly affect human beings. Mountain-top ecosystems may experience high levels of extinction under the projected climatic scenarios (La Sorte and Jetz, 2010). Species at continental edges and at islands may fail to migrate and adapt resulting in their massive extinctions (Hof *et al.,* 2011; Campbell, *et al*. 2009).

The results of geographical shifts propelled by climate change and related forces would be found in reduced species richness and species turnover. In a study of 5,197 African plant species, Midgley and Thuiller, (2011) observed that, 25 to 42 percent of the species could mislay suitable ranges by 2085. In addition, competition for spatial dominance between plant species and human agriculture in the 21st century has potential to prevent vegetation expansion and the consequence is extinction, which will lead to loss of biodiversity (Zelazowski *et al.,* 2011).

Changes in the composition of biological species, specifically vegetation species can lead to structural changes of the whole ecosystem. For example, the increase in lianas in tropical and temperate forests as observed by Phillips *et al.,* (2008), and the advance of woody plants in temperate grasslands as proclaimed by Ratajczak *et al.,* (2012) and Bloor *et al.,* (2008). Under such circumstances, graminae and herbaceous species may go extinct. This may further influence diversity of fauna as grass eating herbivores will also be affected.

It has been noted that ecosystems and consequently species vulnerability to climate change depends on the climate zone and type of the ecosystem. Heyder *et al.*, (2011) propounded that Boreal-temperate ecosystems are experiencing large scale forest die-back due to heat and frequent droughts. This has been observed in North American boreal forests (Allen *et al.,* 2010) where heat and drought stress lead to increased mortality at the brink of the forests. Reu *et al.,* (2011) observed changes in plant functional richness in the transitional zones between boreal and temperate forest and also between boreal and polar biomes due to climate change and related environmental perturbations. Small changes in forest species pose risks to biodiversity as different plant types gain dominance (Scholze *et al.,* 2006).

The World Bank (2012) found out that humid tropical forests are increasingly becoming vulnerable to climate change. Under the 4^0C temperature increase scenario, the land area for humid tropical forest is expected to reduce by approximately 25% (Zelazowski *et al.,* 2011). For most species in these ecosystems, water availability is the key determinant of environmental suitability. Thus, reduction in the amount of water available will result in stress and die-back. In India and the Philippines close to 30% of the total humid tropical forest niche is projected to be susceptible to retreat under climate change (Zelazowski *et al.*, 2011).

Substantial scientific debate is ongoing over the risk to Savanna and grassland ecosystems of abrupt climatic change. This threat has been classified as a ‘possible planetary tipping point’ at 3.5-4.5^0C warming rate, which, if exceeded, would result in a major biodiversity losses and significant shrinking of major terrestrial carbon sink, which will result in further increase in atmospheric CO^2 concentrations (World bank, 2012; Kriegler *et al.,* 2009; Lenton *et al.,* 2008; Cox, *et al.,* 2004;). However, there is substantial uncertainty as to the magnitude of risks of abrupt warming in these ecosystems. This justifies the need to carry out assessments of climate change impacts on specific facets of biodiversity in the Savanna areas.

2.4 Climate Change in southern Africa

There is an ever accumulating evidence of climate change in southern Africa as assessments at various levels are almost always indicating significant changes. Long term trend analysis of climatic variables such as temperature, rainfall and evapotranspiration as climate proxies have shown that climate change is occurring in the region (Kruger and Shongwe, 2004; Warburton and Schulze, 2005; Mohammed, 2005; Warburton *et al.,* 2005; New *et al.,* 2011; Chishakwe 2010; Archer *et al* 2010; Malisawa and Rautenbach, 2012). Remote sensing derived evidence and directly observed temperature and rainfall records in southern Africa show a warming and decreasing trend respectively over the past few decades (Hughes and Balling, 1996; Unganai, 1996). Overall, the result shows a warming environment in southern Africa.

The warming trends are consistent with the global trends of temperature increase in the 1970s, 1980s and the 1990s (Kusangaya *et al., 2013*). Temperature increased by over 0.5^{0}C in the past 100 years (Smith *et al.,* 2001). Namibia is experiencing an increase of temperature at a rate of 0.023^{0}C per year, and the Indian Ocean, which drives most of the atmospheric phenomena over southern Africa has experienced warming of more than 1^{0}C since 1950 (NCAR, 2005). Increase in temperatures are associated with a downward trend in rainfall which is already very low causing severe droughts (NCAR, 2005). Glantz *et al*. (1997) reports that over 15 drought events of significant severity were experienced in the region between 1988 and 1992. Chenje and Johnson, (1996) and Chagutah, 2010 echoed the same sentiments claiming that in the early 1990s the region experienced rainfall that was 20% lower than that of 1970s and significant droughts were experienced in the 1980s, early 1990s, and in 2002. The 2015/16 El Niño Southern Oscillation (ENSO) induced drought is described as the worst drought to affect the region in living memory as it impacted on the water, food and energy security (Gizaw and Gan, 2016).

Besides the increasing temperatures and decreasing rainfall, SSA is experiencing climate variability. Ziervogel and Calder (2003) found out that the year to year variability ranges between 30 and 35%. According to Davis and Joubert (2011) the current climate in the region is largely semi-arid, with high inter-seasonal and intra-seasonal variability in precipitation. The INGC (2005) postulated that extreme hydro climatic events have been frequent features of the early warning systems in the region. Davis and Joubert (2011) aver that the rainfall of southern Africa shows seasonal characteristics with the largest part of the subcontinent experiencing a summer rainfall season usually starting in October/November and tapering off in February/March. Other studies (Tadross, *et al.,* 2003; Tadross, *et al.,* 2005; Usman *et al.,* 2005; Tadross *et al.,* 2009; Crespo, *et al.,* 2011; Landman *et al.,* 2011) have shown variability in season onset, cessation and dry spell frequency, both spatially and temporally.

2.5 Climate change in Zimbabwe

Studies have shown that climate is Zimbabwe is shifting in a directional incremental mode, with values of climatic elements significantly deviating from the mean (Musiyiwa, 2014; Rekacewicz, 2005; Unganai, 1996; Simba *et al.*, 2012). There is an increase in the number of hot days and a decrease in the number of cold days. Precipitation is deviating from the mean more frequently over the years. Unganai (1996) used historical instrument records and global circulation models to study climate change phenomenon in Zimbabwe and found out that there is an increase in both minimum and maximum annual temperatures over several decades. Figure 2.1 shows the changes in annual maximum temperatures over time.

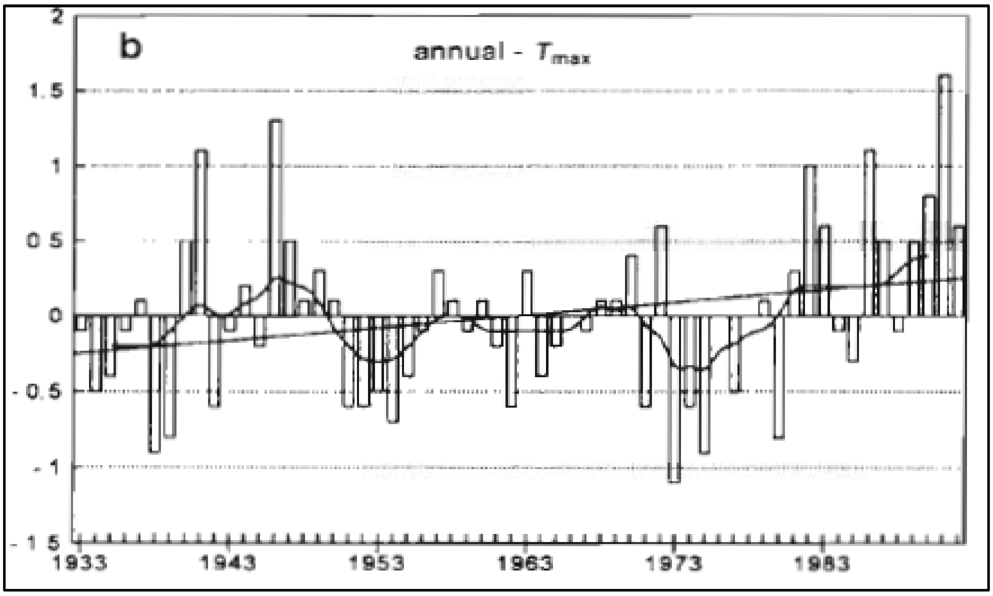
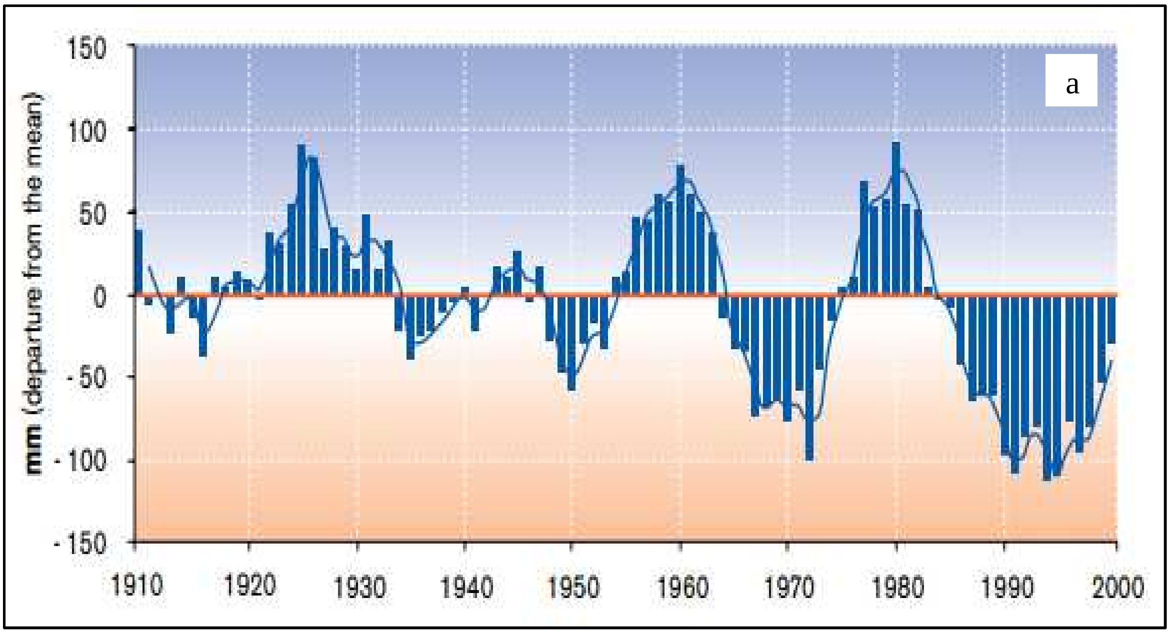


Figure 2.1. Zimbabwe annual maximum temperature variation between 1933 and 1993
Source: Unganai, 1993

The increase in minimum and maximum annual temperatures have been associated with a decrease and high inter-seasonal variability of rainfall. Figure 2.2a shows national deviation of rainfall from the mean while Figure 2.2b shows changes in the number of cold and warm days.

Daily temperatures are predicted to have risen by up to 0.8°C since the start of the century translating to a 0.l°C rise per decade (Simba *et al.,* 2012). From 1900 to 1993, precipitation declined by up to 10% on average, which is about 1% per decade (Unganai, 1996).



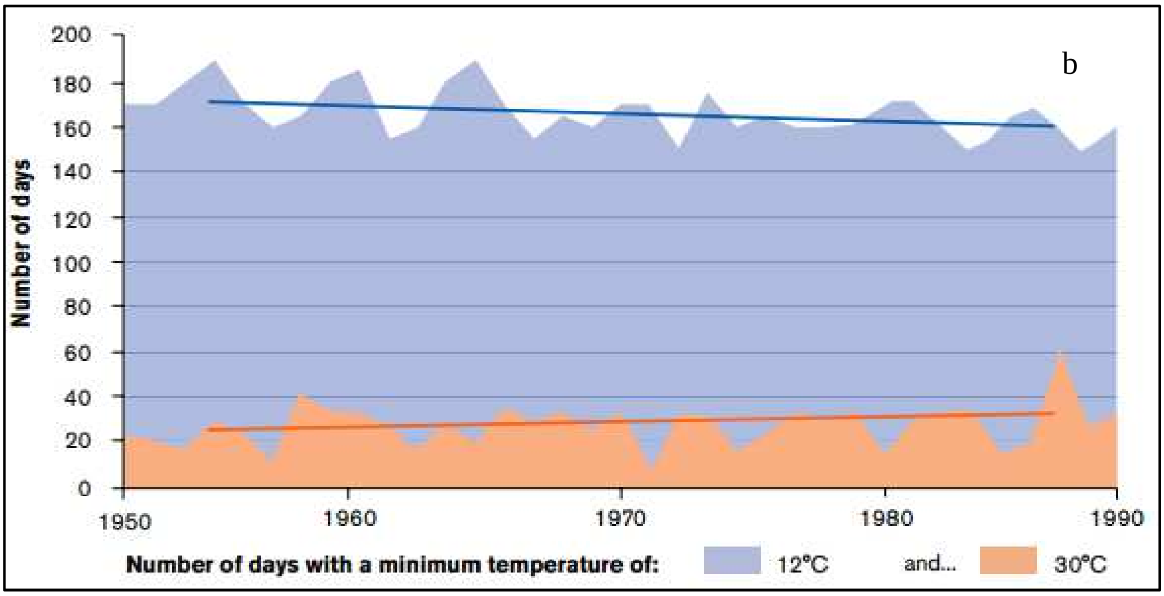


Figure 2.2. a) Zimbabwe rainfall deviation, and (b) changes in the number of cold and warm days.
Source: Zimbabwe Department of Meteorological Service (ZMSD)

Zimbabwe lies in a semi-arid region experiencing dry conditions. In general, the spatio-temporal climatic changes are considerably experiencing variability in rainfall, shifts in rainfall seasons and the recurrence of extreme weather events (Unganai, 2009). The warmest years in Zimbabwe since 1987 are (90/91, 91/92, 92/93, 93/94, 94/95, 97/98, 01/02, 02/03, 04/05, 06/07) (Russell 2008). These years are also marked by severe droughts.

Drought recurrence is exacerbating aridity in most provinces across Zimbabwe. This has resulted in the shifting of agro-ecological zones (Brown *et al.*, 2012). There is a marked progression in the deterioration of rainfall patterns and crop production from region 1 to V.

Brown *et al*. (2012) report changes in parts of Mashonaland west province from agro-ecological region II to agro-ecological region III. On the same note, some parts of the Midlands province have shifted from region III to region IV. Furthermore, the size of region I, which is the wettest, has significantly been reduced (Brown *et al.,* 2012). Agro-ecological zone II has moved further east whilst region III has shifted northwards. The climate of Zimbabwe is generally regionally differentiated but all regions are experiencing an increase in warmer conditions and erratic rainfall patterns. These changes have been associated with significant impacts on various sectors of the economy. Table 2.1 shows some of the projected sectoral impacts of climate change in Zimbabwe.

The signing and ratification of the UNFCCC by the Government of Zimbabwe is an acknowledgement that climate change is regarded as a serious issue in the country. However, the challenge for the country is coming up with effective adaptation and mitigation strategies for specific sectors given the complex nature of the problem. This could be emanating from the problem of lack of scientific understanding of the link between climate change and sector specific variables. There is considerable literature on the impact of climate on other sectors such as agriculture, water, energy and human health (Chagutah, 2010; Simba *et al.,* 2012). However, only little has been done to understand how vegetative species diversity is affected. This has led to a void in strategies to enhance the adaptive capacity of natural vegetation communities across the country. Whilst climate change issues have been included in the National Environmental Policy of Zimbabwe (Environmental Management Act 20:27), they do not adequately address issues of its impact on vegetative species diversity.

Table 2.1. Sector based impacts of climate change in Zimbabwe

Sector	Projected climate change impacts
General	▪ Predicted warming of around 2^0C by 2080 ▪ Present southwest-northeast-east rainfall gradient will become steeper
Agriculture	▪ General vulnerability of communal agriculture to climate change and variability ▪ Generally, maize suitable areas will decrease by 2080, while cotton and sorghum suitable areas will increase by 2080 ▪ In the south western parts of the country, sorghum and maize will become increasingly vulnerable to climate change while cotton will become less vulnerable ▪ In the north central and eastern parts of the country, maize, sorghum and cotton will become less vulnerable
Water	▪ Overall, surface water resources are projected to be reduced significantly by 2080 irrespective of the scenario used. ▪ North eastern and the eastern parts of Zimbabwe are predicted to experience a surplus in surface water while the western and southern parts of Zimbabwe are projected to experience a drying up. ▪ Runoff will decrease significantly in the Umzingwane, Shashe, Nata, and Save catchments.
Health	▪ The area under high to extremely high malaria hazard will tend to increase by 2080. ▪ High malaria hazard will be concentrated in the low lying parts of the country including the Zambezi valley, and the South-east Lowveld.
Forestry and biodiversity	▪ Expected minimum pressure on plant diversity for best and worst case scenarios is 42%.
Rangelands	▪ Net Primary Production (NPP) will decrease from the current average maximum of over 8 tons per hectare per year to just over 5 tons per hectare per year by 2080. ▪ This translates to decreased rangeland carrying capacity for both livestock and wildlife. ▪ Southwest and north-western parts of Zimbabwe will experience more reductions in NPP than in other parts of the country
Human settlement	▪ Increased water scarcity
Tourism	▪ With decreasing rainfall and rising temperatures, significant declines in biodiversity are expected to occur in most parts of the country especially the western regions where most of the park estates are located. ▪ Lower resilience of ecosystems to other global environmental changes

Source: Murwira (Unpublished)

2.6 Climate change in Masvingo province

Climatic changes being experienced at global, regional and national levels filter down to provincial level (Musiyiwa *et al.*, 2014; Simba *et al.*, 2012; Unganai, 1996). The province is prone to frequent and severe droughts due to low and erratic rains. Its average annual rainfall, 650 mm, is less than potential evapotranspiration (PET) which averages between 600- 1000 mm per annum (Chikodzi *et al.,* 2013). PET thus, exceeds rainfall in the province showing water deficiency and scarcity. The aridity index is around 0.2 -0.5 which denote a semi-arid region (Chikodzi *et al.,* 2013). Simba *et al.,* (2012) point out that the province has seen a slight decrease in the amount of rainfall over years. However, there is a significant increase in inter and intra-seasonal variability.

The long term changes in rainfall and temperature and their increased seasonal variability are resulting changes in plant species changes in both human modified and natural ecosystems. For example, Simba *et al.,* (2012) report the influence of climatic changes and variability of productivity of maize and other small grains. While some past research done in the province concentrated on the impact on human modified ecosystems, little has yet been done on the impact on natural ecosystem with regards to vegetative species diversity.

2.7 Definition of Biodiversity

The definition of 'Biodiversity' has been debated for quite some time. As a result, Swingland (2001) had to conclude that there is no a universally agreed definition and the term is often redefined according to the context and purpose of the author. It is agreeable however that the world is endowed with an assortment and abundance of living organisms both flora and fauna. These organisms together are referred to as biological diversity or in short biodiversity (Scholes *et al.,* 2012; Swingland, 2001). Biodiversity is categorised into genetic variation within populations, the number, relative abundance and uniqueness of species and the variety, extent and conditions of an ecosystem. Biodiversity provides a variety of development opportunities to humanity (Schores *et al.*, 2012). It is the basis for indispensable environmental services upon which life depends. Thus, its conservation and sustainable use are of critical importance.

At global scale, ecosystems are organised in a latitudinal pattern (White, 1983), with increasing species richness towards the equator (Mutke and Barthlott, 2005). However, some seasonal variations in biodiversity also occur where, for example, plant species richness increases in the winter-rainfall Mediterranean climate regions of Northern Africa and the southern Cape (Cowling *et al.,* 1996). The subtropical deserts are generally characterised by low diversity where, for example a large area of the Sahara Desert, Ténéré, constitute only 20 plant species in an area of about 200 000 km^2. In between are the subtropical deserts, which are generally zones of lower diversity (Scholes *et al.,* 2012). In spite of the latitudinal distributions, pockets of rich biodiversity exist particularly in tropical montane areas (Rahbek, 1995). Mountains contain several centres of endemism for birds, mammals and plants (Fjeldsa and Lovett 1997, De Klerk *et al.*, 2002).

Environmental conditions of an area, particularly water availability, determine the richness of plants and animals (Mutke *et al.,* 2001). This explains the high richness of plants and vertebrates towards the equator. However, Davis *et al.,* (1994) observed some exceptional cases in which harsh climates like the Namib Desert and the Karoo in the west of South Africa have an estimated 4500 plant species of which most of them are endemic. Topographic variations also play a significant role in biodiversity distribution. It is however important to note that spatial patterns of diversity vary for different species. A case in point is the Cape Province in South Africa where there is high plant diversity of global importance, but the diversity of animal species is not significant. In addition, the Central Zambezian Miombo woodlands located in Zambia, the Democratic Republic of the Congo (DRC) and Tanzania has high bird diversity, but not plant diversity.

A host of definitions for biodiversity shows that the term could mean different things, depending in the context one uses. Under such a scenario, it is important to make use of a working definition. Thompson *et al.,* (2009) proposed that, in the simplest terms, biodiversity can be considered as the number of species in a specific area. Thus, by simply counting the species in a community we are able to determine how diverse it is in terms of living organisms, both flora and fauna. The Convention on Biological Diversity (CBD), defined biodiversity as "*the variability among living organisms from all sources including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, among species, and of ecosystems"* (EASAC, 2005). A much broader definition was propounded by Allen and Hoekstra (1992) that biodiversity includes the multiplicity of life at numerous scales of ecological organisation, including genes, species, ecosystems, landscapes and biomes. A more general understanding of biodiversity is that it is a description of biological richness of a specific ecosystem.

Some studies have considered functional redundancy as an important component to consider in biodiversity assessments (Thompson *et al.,* 2009; Hooper *et al.,* 2005). This is where diversity is considered in terms of functions of the species. Some species simply disappear but their functions will be performed by other remaining species to the extent that ecosystem functions are not changed. There exist some functional groups within plant communities, which are assemblages of species that perform the same roles in a system such as pollination, production and decomposition therefore providing redundancy to the ecosystem. It is important to note that functional diversity is not essentially correlated with species richness (Hooper *et al*. 2005; Diaz and Cabido, 2001). In many cases, species that dominate ecosystem functions are not the most populous in the system (Diaz *et al.*, 2003; Hooper and Vitousek, 1997,). Thus, it is important for biodiversity assessments to establish the species that contribute significantly in maintaining the 'sanctity' of goods and services provided by the ecosystem if management or protection is the objective of the assessment.

Changes induced by climate change or any other environmental factor may result in changes in functional roles for species. Species that have limited functional capacity may become functionally dominant (Thompson *et al.*, 2009). They change from "passenger" species to "driver" species. In most cases, this helps in buffering the plant community or ecosystem against significant alterations and enables resilience (Walker, 1995). Chapin *et al.*, (1997) have referred to this variable response as 'functional response diversity' which is critical in determining the resilience of an ecosystem to climatic vagaries and other environmental perturbations. Significant ecosystem changes and possible collapse occurs when there is loss of functional species in the absence of redundancy (Chapin *et al.*, 1997). Hooper *et al.*, (2005) noted that there is a clear need for continued research into the relationship between species richness and ecosystem stability.

Several studies (Thompson *et al.*, 2009; Bodin and Wimen, 2007; Drever *et al*. 2006; Hooper *et al.*, 2005; Loreau *et al.*, 2001; Peterson *et al.*, 1998; Walker, 1995) observed that the ability of an ecosystem to resist changes depends on the biological diversity of the system and the capacity of that biodiversity to maintain the ecosystem. Biodiversity controls most of the ecosystem processes although the ability of species in enabling and maintaining the processes varies from one species to another (Diaz *et al.*, 2003; Walker, 1995,).

In this study biodiversity is referred to in terms of the variety of tree species within Masvingo province. Although fauna species are very important, this study focuses on vegetative species. The standard metrics, including species richness that relate to the dominant plant species that characterize a given plant community or ecosystem are considered. The study makes reference to terms that describe the vegetation structure (height, density, complexity) (Thompson *et al.*, 2009). Consideration of vegetation structure in this study is based on the fact that climate change and other environmental factors may simply affect the structure and not the number of species yet the ecosystem functions of those species have been changed due to changes in structure.

2.8 Vegetative species diversity

Plant species diversity is considered important in determining societal values, determining the aesthetic value of the environment and the value of goods and services supplied (Tomback *et al*., 2016; Naeem, 2009; Duffy, 2003). The preservation of ecological functions, processes and disturbance regimes are as important as preserving species, their populations, genetic structure, biotic communities and landscapes (Oran, 2016).

Vegetation is generally regarded as the foundation of biodiversity due to its influence on virtually all facets of any ecosystem (Naeem *et al.,* 2009). Most of the biophysical processes and functions depend on vegetation condition, of which its variety plays the most important role. In fact, vegetation is the key determinant of terrestrial biodiversity. Vegetative species diversity can be regarded as the variety of plant species; the genetic variety among the species, communities, ecosystems and the landscapes in which they occur (West, 1995; Noss and Cooperlider, 1994). Vegetation is a significant component of ecosystems due to its role as the major reservoir of terrestrial biodiversity. In addition, it contains about 50% of the global carbon stocks (Thompson *et.al*, 2009; IPCC 2007b, FAO 2000). In light of this, the management of vegetative species diversity contributes significantly to climate change mitigation.

Species richness in an ecosystem is a function of climatic conditions, edaphic characteristics and other biotic factors (Ayyappan and Parthasarathy, 1999; Malanson *et al*, 2017). As such, species diversity, with regards to richness is highest in areas that receive significant amount of rainfall whereas in arid regions species richness is low. Tripathi and Singh, (2009) observed that riverine forests have the highest species richness due to high soil moisture content in these ecosystems. Climatic differences between continents also greatly influence differences in plant species richness. For example, plant species on the mainland African continent range between 40 000 and 60 000. Of these species 35,000 are predicted to be endemic while richness for South America is approximately 90 000 plant species in an area 40 per cent smaller (Frodin, 2001). Barthlott *et al.,* (2005) notes that parts of the Congo basin have moderate levels of plant species richness, compared to some Central European ecosystems. This can be attributed to major extinction events due to historic climate variations (Davis *et al.,* 1994; Wiens, 2016).

However, while Africa is dominated by arid and semi-arid conditions that do not promote rich diversity, it contains 5 of the 20 rich sites of plant diversity (Groombridge and Jenkins, 2002). Barthlott *et al.,* (2005) postulated that there are over 3 000 plant species per 10 000 km^2 in the Cameroon-Guinea, Madagascar, Capensis, Maputaland-Pondoland, and Albertine Rift centres. Groombridge and Jenkins, (2002) claim that more than a sixth of the world's approximated 270 000 plant species are endemic to Africa. Barthlott *et al.,* (2005) aver that approximately 9000 vascular plant species occur in a 90,000 km area at the Cape Floral Kingdom, a global centre of plant endemism. This assertion is supported by Goldblatt and Manning (2000) who added that about 69 per cent of these species are endemic. Davis *et al.,* 1994) also point out that Madagascar contains more than 12,000 plant species of which at least 81% are endemic.

In the southern African region, plant species diversity is high mainly in the six phyto-regions namely the Flora Zambeziaca, Karoo-Namib, Cape Floristic, Afromontane, Indian Ocean Coastal Belt and the Kalahari-Highvelt transitional zone (Beenje, 1996). Patterson *et al.,* (2007) put forward that the Flora Zambeziaca region has the highest species richness in the region. The region dominates greater part of Zimbabwe. The greatest endemism in Zimbabwe is found in the eastern highlands particularly in Chimanimani Mountains, Nyanga and Chirinda forest, which forms part of the Afromontane region. Furthermore, in Nyanga Mountains, there is occurrence of vegetation with characteristics of the Cape Floristic region such as fynbos (fire bush). Although the other phyto-regions do not extend into Zimbabwe, remnant species are also found. This diversity of plant species is reported to be evolving with time due to the influence of various factors, most of which are related to climate change (Patterson *et al.,* 2007). For example, invasion by alien species has led to the changes in species composition as well as species richness and evenness. *Acacia mearnsii* in the eastern highlands, *Pinus patula* in Nyanga National Park and *Psidium cattlensis* in Chirinda forest have invaded indigenous species as the environmental conditions become more favourable for the proliferation of alien species. Some indigenous species such as *A. nilotca* and *Dichostrychus cinera* are reported to have invaded some degraded sites and pasture lands swamping the natural vegetation (Richardson and Petr, 2006).

In Zimbabwe, plant species diversity comprises forests, woodlands and grasslands. Forests are found in the Eastern Highlands and they are mainly Montane while grasslands are mainly found on high altitude areas in the same region as well as on serpentine formations along the Great Dyke (Zhakata *et al.*, 2016). Woodlands include Acacia, Biakiaea, Terminalia/ Combretum, Miombo and Mopane (Wild and Barbosa, 1967). Figure 2.3 shows the distribution of plant species diversity across the country.

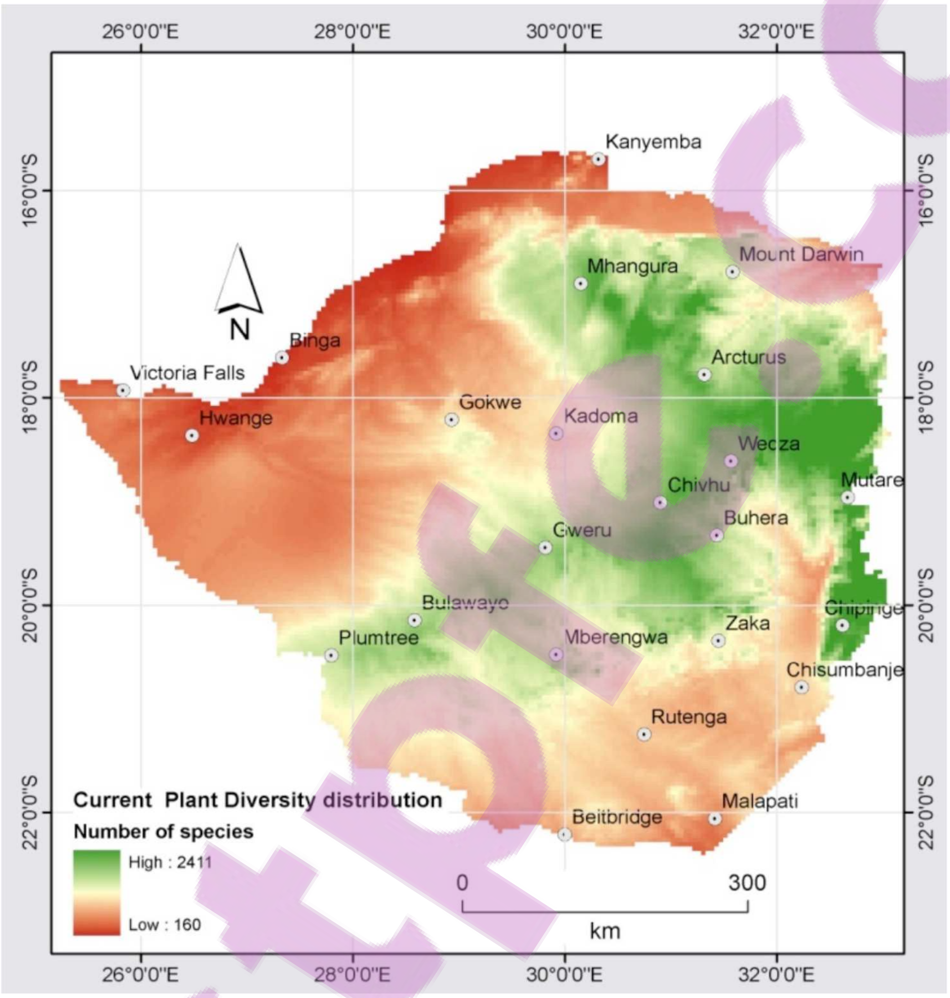


Figure 2.3. Spatial variations in tree species diversity in Zimbabwe.
Source: Zhakata et al., 2016

Zhakata *et al.*, 2016 report that changes in plant species diversity follows the pattern of rainfall and generally there has been a decrease with decreasing annual rainfall.

2.9 Global Climate change and biodiversity

Species distributions, phenology and species composition are being manipulated by global climate change (Chen *et al.*, 2011; Parmesan, 2006). Climate change, besides influencing species diversity directly, also exacerbates the impact of other pressures such as fragmentation, invasive species, overexploitation, habitat loss, pollution and diseases (Jewitt *et al.*, 2015;

Mantyka-Pringle *et al.,* 2012, MEA, 2005). It is projected that in the next century, the continuous increase in the concentration of carbon dioxide in the atmosphere, which is the known principal cause of climate change, will become the greatest driver of biodiversity loss (Heller and Zavaleta, 2009).

Climate influences the rate of photosynthesis and respiration (Thompson *et al.,* 2009; Law *et al*. 2002; Woodward *et al*. 1995) as well as other processes in vegetation species through elements such as temperature and moisture regimes over time (Thompson et al, 2009). Climatic conditions also influence makeshift processes which have consequences on diversity, for example, they determine occurrence of wildfire, herbivory and species migration. The implication of these climatic impacts on vegetation is that, as the global climate is changing, vegetation ecosystems will change as a result of exceeded physiological tolerances (Malhi *et al.,* 2008, Kellomaki *et al.,* 2008, Olesen *et al.,* 2007).

Vegetation ecosystems such as shrub-land, forests and grassland are complex and have a plethora of natural processes that respond autonomously to internal and external drivers. In the case of climate change, for example, where the amount of water declines in an ecosystem, water availability becomes a limiting factor that would possibly affect the height and density of the tree canopy (Berry and Roderick, 2002). A significant change in climatic elements will naturally change the diversity of vegetation at genetic, species and ecosystem level. For example, some vegetative species may reach a threshold beyond which morphology cannot be changed. There are also associated changes in the dominant taxonomic composition of the vegetation ecosystem (Stephenson, 1990). Extreme changes may result in the replacement of forests by savannas or grasslands. In addition, temperature increase may result in the replacement of open taiga forest by boreal forests (Kellomaki *et al.*, 2008).

Changes in the global climatic elements, mainly rainfall and temperature have influenced and will continue to affect a variety of plant species, communities and ecosystems (Parmesan & Yohe, 2003). The effects are taking different forms depending on the location and characteristics of species, community or ecosystem as well as the magnitude of change in the climatic elements. Human modifications also determine the extent and form of change. In some cases, the effects take the form of loss which may lead to extinction of some species in an ecosystem (Hughes, 2000; Walther *et al.,* 2002). In other cases, they take the form of expansion and relocation while in some instances, phenological and physiological modifications take place (Hughes, 2000; Walther *et al.*, 2002; Bellard *et al.*, 2012). Alterations in biotic interactions may also occur due to climate change and this will have consequences on biological diversity at all levels (Hughes, 2000).

Several projections (Peterson *et al.,* 2002; Thomas *et al.,* 2004; Thuiller *et al.,* 2005 indicate that these effects may be widespread in the future and affect both fauna and flora globally. In light of the fact that species differ in the manner in which they respond to climatic vagaries, these effects could be the key driver of biological diversity changes. Huntley, (1990) and Webb and Bartlein (1992) postulate that there is sufficient evidence from the Quaternary showing that plant species responses to past climate change have been characterised by large-scale shifts in geographical distributions of species. This assertion is supported by Araújo *et al*., (2005) who observed that plants have a tendency to suit the existing climate regimes. Thus, changes in climate imply changes in plant species characteristics. In fact, some authors (Woodward, 1987; Fernández-González, 1997) have observed that there is a relationship between vegetation characteristics (e.g. structure, primary productivity and distribution), and climatic elements. Climate classifications have attempted to fit vegetation characteristics to values of some climatic elements. The various classifications tend to coincide in the importance of temperature and rainfall variables on climatically fitting the distribution of plants or vegetation types.

Changes in vegetative species diversity due to climate change or any other factors will affect functions and benefits derived from plant communities (Chapin *et al.*, 2007). Maintaining and restoring vegetation species diversity's resilience to climate change is cited as a necessary societal adaptation mechanism (Thompson *et al.,* 2009; Millar *et al.*, 2007; Chapin *et al.*, 2007). Resilience in this case is the ability to maintain the species diversity status quo with regards to composition, phenology, morphology and other characteristics of species within an ecosystem. Thompson *et al.,* (2009) argue that, under non-catastrophic disturbances, forests are more resilient to change than other types of plant communities. Thus, they are resilient to environmental changes, such as weather patterns, owing to redundancy at various levels among functional species. Redundancy in this case refers to the overlap and duplication in ecological functions performed by the diversity of species in an ecosystem. Some plant communities might be highly resilient but less resistant to particular climate change related perturbations. For example, grassland communities are highly resilient but less resistant to fire. Nonetheless, some communities are both resilient and resistant, for example, well established, primary old forests (Drever, *et al*. 2006; Holling, 1973). Thus, the magnitude of impact of climate change on vegetative species diversity will greatly be influenced by the level of resistance and resilience.

2.9.1 Biodiversity responses to climate change

Owing to changes in the patterns of climate elements at a place, vegetative species may fail to adapt to different environmental conditions and may thus fall outside its favoured climatic niche (Bellard *et al.*, 2012). To survive, species are bound to produce adaptive responses, which can either be plastic or genetic. Of significant importance is understanding whether or not species will be able to adapt quickly to match the rapid pace of changing climate (Lavergne *et al.,* 2010; Salim *et al.*, 2010). Whatever the adaptive responses, the underlying mechanisms are either due to micro-evolution or plasticity (Bellard, *et al.,* 2012). Micro-evolution is when "species can genetically adapt to new conditions through mutations or selection of existing genotypes" (Salamin *et al.*, 2010). Plasticity concerns the intraspecific deviation in morphological, physiological or behavioral qualities, which can occur within individual plants on different time scales in a geographical area (Botkin *et al.*, 2007; Chevin *et al.,* 2010). Hoffman and Sgro, (2011) posit that plastic contribution is more important than genetic. Lavergne *et al*, (2010) argue that evolution can be very rapid as seen in the case of introduced species, for which selection-driven phenotypic changes have changed the invasive potential.

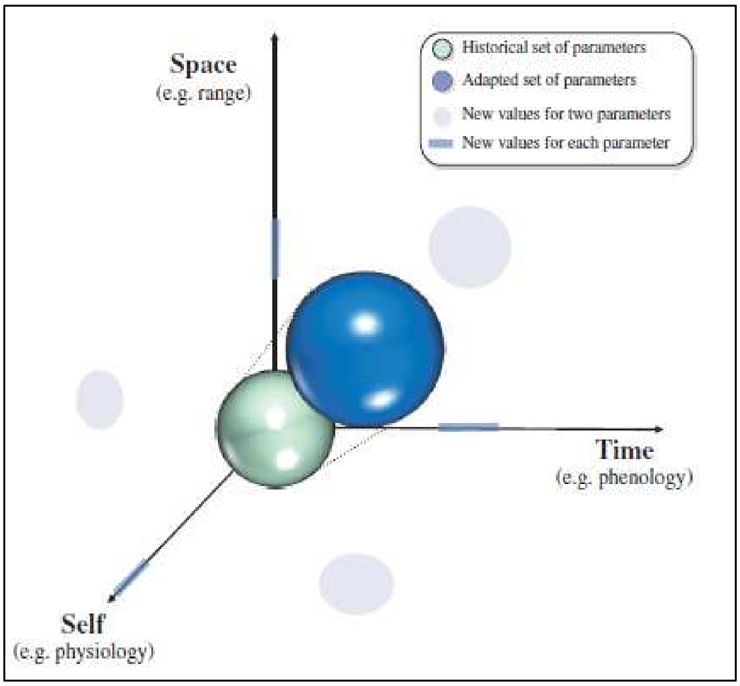


Figure 2.4. Three directions of responses to climate change
Source: Bellard et al., (2012)

The mechanism of response to climate change may not be so important but what is critical is that changes in species are occurring and it has been observed that the changes are taking place along three distinct but non-exclusive axes as shown in Figure 2.2. Parmesan (2006) asserts that the spatial and temporal changes are easily observable and well documented responses to climate change. 'Self' changes occur less visibly in the physiology and characteristics of species to adapt to the new climatic conditions in the same geographical frame.

2.9.1.1 Spatial Response to climate change

Vegetative species, just like all other types of biological species can track suitable environmental conditions in space and follow them. In addition, shifts may also occur to a different habitat at the local or micro-environment level where conditions are more favourable (Bellard *et al.,* 2012). This mainly occurs through dispersion. Parmesan (2006) notes that one of the best documented responses of biological species to climate change is the latitudinal and altitudinal shift of more than 1,000 species tracking suitable climatic conditions at regional level.

2.9.1.2 Temporal response to climate change

Biological species can respond to climate change through shifts in time. This may result in phenological changes. Phenology is amongst the utmost pervasive responses to the 20th century temperature increases (Parmesan, 2006). Root *et al.,* (2003) report a shift in fundamental phenological events of 5.1 days earlier per decade over the past 50 years after a meta-analysis of a multitude of flora and fauna species. The phenological changes can increase the species capability to keep synchrony with cyclical environmental factors but they can also be disruptive leading to extinction. Temporal shifts also occur at small temporal scale e.g. "with activity patterns adjusted in daily activity rhythms to match the energetic costs of different climatic conditions" (Bellard *et al.,* 2012).

2.9.1.3 'Self' response to climate change

Species may move along the "Self" axis (Figure 2.2) due to physiological alterations that allow species to tolerate warmer or drier conditions. Behavioural modifications may also lead to "self" changes. As these changes vary from one species to another, the diversity of the ecosystem is also being modified. While physiological responses are often less obvious than changes in space and time, they have been reported during the 20th century climate change (Johansen and Jones, 2011). However, phenotypic responses reach a physiological limit in extreme environments e.g. body/ structure size or metabolic rate cannot increase or decrease indefinitely under increasing extremity in environmental change (Chevin *et al.,* 2010).

Species' failure to adapt along one or several of the three axes will result in extinction. Important to note is the fact that under a changing climate, both adaptation along the axes and extinction will result in biodiversity changes. Thus, there is a plethora of changes in species that may occur to cope with climate change. Botkin *et al.,* (2007) postulate that adaptation has been superseding extinction so far, indicating that relatively few taxa went extinct following climate change. However, Bellard *et al.,* (2012) posit that responses of many species are likely to be incapable to stand the speed and magnitude of current climate warming and variability.

As presented in the foregoing discussion, biodiversity and climate change literature is showing that, due to alterations in characteristics of climatic elements, the globe is facing an irrefutable biodiversity crisis, either through morphological, physiological and phenological changes or through going extinct. This implies loss of the value and benefits associated with the pristine nature and status of biodiversity. The number of species that may disappear due to warming has become a major concern. There is need for a deep and further understanding of the effects of climate change on various forms of biological life at different scales and geographical locations to facilitate policy action that would ensure support for climate change mitigation and adaptive options.

2.9.2 Vegetative species diversity response to climate change

Plant communities respond differently to climate change (Thompson *et al.,* 2009). Taxonomic composition, ecosystem processes and vegetation structure are dependent on the capacity of the plant community to cope with the extent of change. To that extend, it is important to consider the resilience of an ecosystem or plant community in trying to understand the impacts of climate change on vegetative species diversity. Thus, the impact is dependent on the type of the community, its resilience to climatic disturbances and perturbations. Characteristics of a plant community can be used to define its ecosystem state. For example, a forest community state is measured in terms of the existence of tree species as the dominant component of an ecosystem, together with the functional purposes of the species and the characteristic vegetation structures such as the height, layers and stems density at maturity.

Scientific literature has distinguished between "engineering resilience" and "ecological resilience" to climate change (Thompson *et al.,* 2009; Gunderson 2000; Peterson *et al.,* 1998; Holling 1973). Thompson *et al.,* (2009) note that engineering resilience relates to the ability of a plant community or ecosystem to assume it's original pre-disturbance state with the assumption that there is only one steady state. For example, in the event of a meteorological drought the community will recover from drought impacts with minor or no changes in species composition. On the other hand, ecological resilience relates to the ecosystem's capacity to engross impacts before a threshold is reached where the plant community changes to a different state. For example, in the case of a meteorological drought, the plant community will be able to withstand a protracted drought before being converted into a different vegetation ecosystem with different species types. The successive community might however be able to provide functions provided by the initial community.

Plant community or ecosystem state of interest are determined by dominant floristic composition and stand structure but it is also important to consider the capacity of a community to continue to provide ecosystem goods and services despite the changes in composition and structure due to climate change.

It has generally been observed that vegetative species distribution, phenology and ecosystems composition are being altered by global climate change (Jewitt *et al.,* 2015; Chen, *et al.,* 2011; Parmesan, 2006). This has consequences on vegetation diversity at genetic, species and ecosystem level (Bellard *et al.,* 2012). Climate change will exacerbate the impact of other stressors such as over-exploitation, habitat loss, invasive species, pollution and disease (Mantyka-Pringle, *et al.,* 2012; MEA, 2005). In addition, Heller and Zavaleta, (2009) propounded that climate change, through increase in levels of carbon dioxide and other greenhouse gases, especially methane and nitrous oxide is expected to become the key driver of biodiversity loss.

The impacts of climate change on vegetation species diversity can occur directly through two antagonistic effects (Fernandez-Gonzalez *et al.,* 2005). The first one is warming, which prolongs the period of activity and encourages plant productivity in cold regions. The second one is the reduction in water availability, which will result in the desiccation and disappearance of some plant species, especially in arid and semi-arid regions. Thus, the effects are primarily dependent on the climatic region within which specific species and ecosystems exist. Fernandez-Gonzalez *et al.,* (2005) highlighted this impact in Spain showing that there is the "Mediterraneisation" of the northern parts of Iberian Peninsula and the mountains and the "aridification" of the southern half of Spain due to climate change.

Sensitivity to climate change relates to the extent to which species are responsive to climate stimuli (Gill *et al.,* 2013). Some tree species thrive under high temperatures while others, if exposed to high temperatures, will experience carbon starvation and hydraulic failure that may cause species mortality. Plaut *et al.,* (2012) reported on the mass mortality of *Pinus edulis* species in North America due to high temperatures that led to carbon starvation. Under the same conditions, there were no effects on populations of the *Juniperas monosperma* species. Gill *et al.,* (2013) reiterated that direct mortality of trees is more pronounced when the key climatic elements (temperature and rainfall) combine. Thus, an ecosystems' species richness could be a function of the sensitivity of individual species to climate change. The higher the number of sensitive species the greater the degree of biodiversity changes under the influence of climate change.

Some vegetative species depend on temperature to produce seeds and prompt germination. However, some species' seed production and germination is hampered by increase in temperature. Clark *et al.,* (2011) aver that temperature increases in northern USA during spring suppressed seed production in species from certain genera, such as *Magnolia*, *Ulmus*, *Pinus and Fagus*, resulting in fewer seeds than in cooler springs. Similarly, Maltitz and Scholes (2006) claim that in Karoo national park, South Africa, species that depend on cooling periods to germinate are negatively affected by spring warming. This also applies to species that require freezing to start germination. Thus, the diversity within ecosystems, especially with regards to species richness and or evenness is dependent on the sensitivity of the reproduction system of species to climatic vagaries.

In addition, certain vegetative species have low phenological plasticity, for example, they are less able to adjust flowering period in response to temperature increase or decrease. Such species fail to track climate change while their competitors that manage to respond positively thrive. This influence the abundance of certain species within ecosystems and therefore affect species diversity (Willis *et al.,* 2008). Moreover, Rodrigo *et al*., (2000) is of the view that climate change has recently been characterised by changes in frost frequency which affects some species' flowering behaviour. Rodrigo *et al*., (2000) notes that some tree species have flowering parts that are prone to spring frosts whilst others are tolerant to the frost.

Climate change is reported to have increased ecosystems' susceptibility to fire regimes. Some species are more tolerant to fire than others. The difference in adaptation to fire conditions emanates from species variations in bark thickness and post-fire recovery mechanisms. Brando *et al.,* (2012) claim that vegetative species with thin layer barks are more vulnerable to fire than those with thicker 'insulating' barks. Mckenzie and Tinker (2012) also observed that 're-sprouters' or species that store extra energy in their roots to enable recovery and regrowth after fire outbreak are tolerant and more resilient to climate change than those that store less energy. Similarly, the 're-seeders' or trees that produce seeds after fire, according to Mackenzie and Tinker (2012) are more fire tolerant than others. For example, in Montana, USA, great fire incidence increased the abundance of *Populus tremuloides* and *Pinus contorta* while the populations of other species declined significantly.

A deluge of indirect impacts can also occur in all geographic regions depending on environmental conditions. The most notable indirect impacts are derived from changes in edaphic characteristics and fire regimes (Fernandez-Gonzalez, *et al.*, 2005). The interface between climate change and other components of global environmental change such as land use dynamics, land cover modification and alteration of atmospheric composition constitutes another imperious potential source of impacts. In addition, the other indirect impacts of climate change on plant species diversity are realised through interactions among species, for example, through competition, asynchronies, herbivory, pests and invasions. Furthermore, Fernandez-Gonzalez *et al., (*2005) projected structural simplification of vegetative communities and the widespread occurrence of local extinction of plant species as some of the recognised impacts of climate change.

Sensitivity to climate change related droughts varies between species within the same ecosystem. Some vegetative species are more sensitive to increased drought frequency and severity than others. Sade *et al.,* (2012) and McDowell *et al.,* (2008) propounded that tree species, for example, have two different mechanisms with which they tolerate droughts. One group is more vulnerable to prolonged drought periods while the other is more prone to extreme drought conditions. In times of drought, isohydric species close their stomata to reduce transpiration and desiccation (Sade *et al.,* 2012). This effectively works under extreme droughts, but in the event of prolonged droughts, carbon starvation will occur due to reduced stomatal conductance, leading to mortality of such species (McDowell *et al.,* 2008). On the other hand, anisohydric species keep stomatal pores open, allowing transpiration and carbon sequestration to continue. However, keeping stomatal pores open poses a water loss hazard on these species and increase chances of hydraulic failure in times of extreme drought (Sade *et al.,* 2012). Once more, the photosynthetic mechanisms used by vegetative species determine their vulnerability to climate change related dry periods. Trees that use C_3 carbon fixation are generally less drought tolerant than species using C_4 carbon fixation system. C_4 plants open stomatal pores and absorb carbon dioxide at night reducing water loss during times of stress (Sage and Kubien, 2007).

Climate change in some regions is characterised by changes in the rainfall patterns that exhibit heavy downpours that may result in logging. Water logging by nature reduces soil aeration, creating anaerobic conditions which may not be tolerated by some vegetative species. Oxygen starvation may lead to desiccation. However, there are some species that are more tolerant to waterlogging than others (Smith *et al.,* 2001). The difference of tree species in tolerating water logged conditions result in ecosystem modification with regards to species richness and evenness. Furthermore, some species rely on rainfall related cues to produce seed and germinate. For example, in South East Asia, Sakai *et al.,* (2006) identified the *Dipterocarpaceae* family which only flowers following lengthy periods of wet conditions that are succeeded by drought. Changes in the amount of rainfall received will affect their reproductive capacity and therefore diversity within respective ecosystems.

Climate change has resulted in the proliferation of plant pests and diseases particularly in forest ecosystems (Hushaw, 2015). Most species have become susceptible to emerging diseases. Differences in susceptibility to emerging climate related diseases and pests result in changes in vegetative species diversity. Parker and Gilbert (2004) argue that there is no clear evidence on the characteristics of species that are more vulnerable to climate change related diseases but it is likely that species that occur in small populations and those with low genetic variation are more sensitive to emerging pests and diseases. For example, a mystery disease affected Zimbabwe's baobabs trees during the 2015-2016 drought (Mambondiyani, 2016).

The foregoing discussion has shown the different mechanisms with which climate change influences vegetative species diversity. As highlighted, sensitivity of species to different climate change related variables leads to changes in diversity. So, species may be sensitive to one or just two of the climate change variables. However, some species are sensitive to any type of climate change. Specifically trees that occur in small populations, species that are dependent on other species for pollination are most vulnerable to climate change. For example, the Joshua tree (*Yucca brevifola*) and the Shasta ground sloth have been unable to track climate change and have gone extinct for many years respectively (Cole *et al.*, 2011; Kenneth *et al.*, 2011).

There is need for global response to circumvent the losses of biodiversity caused by climate (Fernandez-Gonzalez *et al.,* 2005). However, for effective action, region specific characterisation of the impacts on different types of species is necessary as it will identify species and ecosystem specific adaptation strategies. Fernandez-Gonzalez *et al.,* (2005) reiterated the need for future research to focus on three main interconnected issues: monitoring of current changes, species and community responses to climate change and predictive modelling based on climate projections. This would sanction the adoption of mitigation measures for the anticipated impacts. It is in line with this research gap that this study aims to assess the response of vegetative species diversity to climate change under semi-arid conditions.

Changes in the diversity of vegetative species under the influence of climate change point to the ineffectiveness of the current biodiversity management practices. It points again to the lack of effective species specific mitigation and adaptation capacities to climate change (Jewitt *et al.,* 2015; Pressey *et al.,* 2007). Spatio-temporal shifts in species and ecosystems need to be incorporated into biodiversity conservation planning. Understanding how climate change impacts on species diversity contributes significantly to the crafting of effective management practices that promote the adaptive capacities of species and ecosystems. In addition, sound projections of future climatic impacts on species diversity are needed to guide adaptation and conservation planning (Jewitt *et al.*, 2015).

2.9.3 Genetic diversity and climate change

The status of a plant community in terms of species richness or other measures of diversity can be attributed to various levels of organisation of biodiversity but genetic composition of the species is the key determinant (Thompson *et al.*, 2009). Expressions of biodiversity, particularly vegetative species diversity at different scales across a landscape is represented by community diversity, species diversity in a vegetated area, and molecular genetic diversity within a species. The adaptive capacity and ability to resist change under climate change conditions of tree species are determined by the process of natural selection which is based on individual species that comprise populations at each level of ecological organisation

(Thompson *et al.*, 2009; Muller- Starck *et al.*, 2005). Diversity at each level has nurtured natural regeneration of plant communities and enabled their adaptation to climatic vagaries (DeHayes *et al.*, 2000). Genetic variance within a species is key to the natural selection of genotypes within populations and species as they respond or adapt to environmental changes (Schaberg *et al*. 2008; Reusch *et al*. 2005; Etterson, 2004; Burdon and Thrall, 2001; Burger and Lynch 1995; Pease *et al*. 1989; Pitelka, 1988; Fisher, 1930).

The major determinant of adaptive capacity of plant communities is the *in-situ* genetic variation within each population of a species (Bradshaw, 1991). If the capacity to adapt is exceeded by the rate environmental change, species are bound to disperse and others may be condemned to extinction (Burger and Lynch, 1995; Lynch and Lande, 1993). Genetic diversity regulates the array of essential eco-physiological tolerances, resistance and resilience of a species. In addition, it controls inter-specific interactions that combine with dispersal mechanisms to constitute the ultimate determinants of species responses to climate change or any other environmental perturbations (Halpin, 1997; Pease *et al.*, 1989).

Davis and Shaw (2001) are of the view that plant communities in the past have responded to changes in climatic variables through adaptation and migration. Thus, such response in one way or another results in changes in the structure and richness of species within a community. It is thus a fact that climate change results in vegetative species diversity change. The level of change is however dependent on species genetic characteristics and the magnitude of environmental change. The implication for these changes is that changes in diversity may result in changes in the ecosystem functions. Given the important role played by biodiversity to support life on earth, there is need to come up with species specific adaptive mechanisms or management options that will help to maintain species diversity under a changing climate so that humanity continues to benefit from the existing biological diversity.

Vegetative species capacity to migrate for long distances through seed dispersal is particularly important in the event of rapid environmental change as a consequence of climate change. Despite morphological dispersal syndromes that would indicate adaptations for short distance dispersal, the generality of species is capable of long distance seed dispersal (Cwynar and MacDonald 1987, Higgins *et al.*, 2003). Thus, long distance dispersal may result in complete change in species composition of plant communities. This implies that no community has immunity to species composition changes, it depends, to a greater extent, on the severity of the drivers of change. Given that climate change predictions indicate projected rapid increase in temperatures by almost 4^0C in the next century (World Bank, 2012), shifts in species diversity and consequently ecosystem functions and stability might be inevitable. In this case, the need for climate change mitigation efforts arises so that there is control on the severity of the drivers of change.

There is no significant difference between the modes of dispersion, for example, Wilkinson (1997) and, Higgins *et al.,* (2003) found no significant difference between wind and animal dispersed plants. All plants have the proclivity to long distance dispersal. However, a plethora of factors determine migration. Higgins and Richardson (1999) view long distance migration as a function of habitat suitability. Thus, the rate of migration increases and becomes more visible if the rate of change in habitat suitability increases rapidly under scenarios of rapid climate change.

The retreat of glaciers in the northern temperate forests resulted in massive dispersals of tree species in the process of recolonisation. However, there were incongruities between estimated and observed migration rates due to underestimation of long distance dispersal rates and events (Cain *et al*. 1998, 2000; Clark, 1998; Brunet and von Oheimb, 1998). It is worth noting therefore that climate change influences habitat suitability which then influences species migration consequently affecting species diversity in the sending and receiving ecosystems. However, there are concerns that tree species migration and adaptation rates will be outpaced by the projected global warming (Malcolm *et al*., 2002; Collingham *et al*., 1996; Dyer 1995; Huntley, 1991; Davis, 1989). It is however arguable that the models used in the projections refer to fundamental niches and generally ignore the ecological interactions that also regulate species distributions.

Millar *et al*., (2007) and Ledig and Kitzmiller (1992) concur that in dealing with an unknown future there is need for the use of diverse approaches to management due to the fact that no single approach can ever fit all situations. This applies to the management of plant communities or ecosystems management strategies. In the environmental science realm, conserving species and genetic diversity addresses the need to be prepared for all sorts of environmental changes that might occur, and this is important to the concept of ecosystem resilience to climate change.

Vegetative species adapt to change through dispersal or propagation in the direction of a more suitable environmental condition. Alternatively, they can modify their gene frequencies in favour of genotypes that are better adapted to the changed environmental conditions (Reusch *et al.,* 2005; Burdon and Thrall, 2001,). Some vegetative species adapt through phenotypic plasticity, if their genetic constituents entail a range of acceptable responses that are appropriate to the new conditions (Nussey *et al.,* 2005). In addition, the adaptation process may involve simultaneous occurrence of dispersal and gene frequency modification. The two processes will interact during the process of adaptation. For example, in vastly fragmented vegetation communities, dispersal habitually promotes gene flow. This maintains within-population levels of genetic diversity and prevents genetic diversity loss that may occur within small and fragmented plant populations (Thompson *et al.,* 2009; Farwig *et al.,* 2008; O'Connell *et al*. 2007; Degen *et al.,* 2006; Mosseler *et al.,* 2004).

Dispersal occurs through various agents such as water, wind and animals (Thompson *et al.,* 2009). Thus, climatic vagaries play a significant role in the determination of dispersal agents and their magnitude directly and indirectly. This will contribute in the modification of diversity in plant communities. Cwynar and MacDonald (1987) noted that seeds can disperse over long distances within a short period of time. For example, light-seeded vegetative species such as conifers, specifically *Picea mariana, Pinus resinosa* and *Pinus rigida* have the propensity for travelling long distances over snow and ice from their original population centres (Cwynar and MacDonald, 1987). Ritchie and MacDonald (1986) are of the view that wind dispersal over snow explains the long distance post-glacial migrations of conifers such as *Picea glauca*. It has also been noted that long distance seed dispersal can be enhanced by birds (Wilkinson 1997).

Long distance dispersal can only happen to light seeded species. Heavy seeded species have difficulties in travelling across landscapes. For example, species found in mangrove and highly fragmented environments such as the *Juglans spp and Carya spp* have long distance dispersal difficulties (Geng *et al.,* 2008). Conversely, other heavy seeded species such as *Quercus spp* and *Fagus grandifolia are* capable of fast and extensive dispersal given the presence of certain animal species (Bennett, 1985; Davis, 1981; Skellam, 1951).

Seed and pollen dispersal by plant communities helps to maintain genetic diversity and consequently long term resilience to manipulation by climate change and related disturbances over space and time. In other words, dispersal enables species to establish themselves in other climatically favourable environments. It is however important to note that the occurrence of dispersal, although it promotes genetic diversity, it promotes changes in species richness in other ecosystems. The impact of anthropogenic activities cannot be overemphasized. Human activities may change the landscape and gene pools to reduce the capacity of genetic dispersal. Fragmentation of habitats can potentially adversely affect reproduction amongst species.

Environmental scientists should also be concerned with the phenomenon of *in-situ* resilience, based on genetic adaptation to fully understand and manage the climate change-diversity nexus. The concern is on the ability of a plant community or ecosystem to maintain itself *in-situ* following a climate change related disturbance such as drought, flood or fire. Thus focus is on the role of genetic diversity as a factor in the capacity to adapt to a disturbance. Genetic adaptation, in which vegetative species' gene frequencies are changed to stimulate growth and reproduction in a changed environment, has short and long-term components. Within a plant community or ecosystem, individual plant species respond differently to environmental changes due to genetic differences. To understand the impacts of climate change on diversity, it is important to comprehend the different rates at which individual species and populations respond to environmental changes.

Hamrick and Godt (1996) noted that trees are amongst the most genetically diverse organisms in an ecosystem. This diversity underpins population stability in climatically changing environments (Gregorius 1996). Burdon and Thrall (2001) have demonstrated this concept with respect to pest populations. Furthermore, Cantin *et al*. (1997); Kull *et al*. (1996) and Bazazz *et al*., (1995) demonstrated the concept with regards to adaptation to potential pollutants and to various other physiological stresses. Thompson *et al.*, (2009) propounded that high genetic diversity within a larger, local population, for example, the savanna biome populations allows for a comparatively quick adaptive response to environmental changes including those influenced by climate change. Thus, it is expected that the more genetically diverse the ecosystem the less the impact of climate change.

As already alluded, in an ecosystem, species respond differently to climate change and other related environmental disturbances. The disparities in survival ability are due to natural selection pressures and may result in the narrowing of gene pools to promote genotypes that are best able to survive disturbances, such as climate change and related phenomena (Thompson *et al.*, 2009). Some local plant communities contain subsets of genotypes that are ‘pre-adapted’ to environmental changes (Jump and Penuelas, 2005; Davis and Shaw, 2001). In an experiment, Bazazz *et al*. (1995) demonstrated the potential for *Betula alleghaniensis* to respond to fluctuating levels of CO_2. The experiments also show that genetic complexity and the magnitude of genetic responses can be affected by density and competitive interactions within plant communities. In addition, the experiments demonstrated the general capacity for resilience of plant populations to projected CO_2 increases (Berrang *et al*., 1989) based on the existent levels of genetic diversity within populations at any given time. It has been shown through such experiments, however, that it is difficult to predict the way in which species will respond to human induced changes, or to other environmental changes in the future (DeHayes *et al*., 2000; Bazazz *et al*., 1995).

There are concerns within the scientific community that the predicted changes in temperature and rainfall across the globe are likely to occur in a rapid fashion that would not allow species time and space to adapt (IPCC 2007a, MEA, 2005; Jump and Penuelas, 2005; Davis and Shaw, 2001; Huntley 1991). Conversely, genetically diverse species have the dexterity for rapid evolution (Geber and Dawson 1993). Several species have already repeatedly adapted to rapid climate related environmental changes over geological time by means of dispersal and genetic changes. Geber and Dawson (1993), Huntley and Birks (1983), Davis (1983), Bernabo and Webb (1977) noted considerable evidence of adaptation in the geological and fossil record. The adaptation has been demonstrated following past glacial and interglacial episodes, which were characterized by rapid climate change (Huntley and Webb 1988).

Despite the overwhelming evidence and arguments supporting the ‘environmental change-genetic diversity’ nexus, there is common misapprehension of the nature of genetic adaptation in species with long generation times (Thompson *et al.*, 2009). There exists a general perception that the long-generation times of some species disadvantage them with regards to rapid response to environmental perturbations. However, it is apparent that plant species or specifically trees, are not exclusively reliant on their generation time to rapidly adapt, but they respond quickly based their inherent vast genetic diversity. To this extent, Thompson *et al* (2009 p16) argue that “if *adaptation to environmental changes of species with long generation times were dependent on generation time, there would be no trees left on Earth*”.

Climate change is postulated to be one of the driving forces behind some major pest infestations (Wainhouse and Inward, 2016; Hushaw, 2015; FAO, 2000, Beukena *et al.*, 2007). In plant communities, pest infestations may result in rapid population decline or collapse if genetic changes are engineered by natural selection on the existing genetic diversity of *in situ* gene pools. This may be reinforced by a prolonged process involving the development of genotypes more gradually in the modes forced by natural selection over many generations of successive breeding and reproduction (Thompson *et al.,* 2009).

Plant species that survive environmental changes or disturbance related to climate change interbreed and propagate (Thompson *et al.*, 2009). As this happens, the gene frequencies of the surviving species will dominate. The changes in gene frequencies are modified over time to create populations that adapt well to the changing environment. Conversely, species with naturally low genetic diversity may face challenges in adapting to sudden changes in environmental conditions. For example, populations of the red pine tree species in North America are extremely vulnerable to *Armillaria* spp. and *Sclerroderris lagerbergii* which have the potential to eliminate entire populations due to the species' low levels of genetic diversity (DeVerno and Mosseler, 1997; Mosseler *et al.,* 1991, 1992,). This implies that diversity at all levels is dependent on the genetic characteristics of individual populations since genetic diversity has both direct and indirect influence on diversity at species level while species diversity also directly and indirectly influences ecosystem diversity.

Thompson *et al.*, (2009) noted the need for complementarity between genetic diversity and species diversity. Species' resistance and resilience to climatic vagaries and related perturbations is reliant on genetic modification to adapt to the changing conditions. Thus, the agents of genetic modification such as insects, bats, birds and mammals play a significant role in influencing the magnitude of impact of climate change on plant species diversity. Without these agents, tree species may be restricted in their ability to adapt to change. For instance, specific gene flow volume in a population may be required to reduce the negative impacts of inbreeding and inbreeding depression of species in highly fragmented landscapes. Cwynar and MacDonald, (1987) observed that the threat of climate change on plant species can be reduced by small and isolated populations at the margins of a geographic range as they, in some instances, serve as well adapted seed sources for population migration under environmental change. Such populations are assumed to have experienced enormous environmental challenges leading to physiological stresses as they survived beyond their eco-physiological tolerances. Garcia-Ramos and Kirkpatrick (1997) postulated that such isolated populations might have experienced genetic isolation and became adapted through natural selection. In addition, Thompson *et al.*, (2009) view these species as containing special adaptations that augment their value as special genetic resources for adaptation and resilience to climate change and related environmental perturbations.

2.9.4 Factors affecting vulnerability of tree species diversity to climate change

The IPCC (2007b) postulated that climate change is associated with significant changes in climatic variables and other atmospheric variables which are predicted to stimulate biodiversity changes across the globe. Changes in rainfall, temperature, fire patterns and carbon dioxide concentration constitute significant changes in the environmental conditions in which a variety of species survive. A plethora of vegetative species have already responded to the changing environmental conditions by shifting their ranges to follow more suitable conditions (Chen *et al.*, 2012). However, a considerable number of species are unable to track favourable climatic conditions or adapt to its vagaries *in-situ* resulting in population declines and in some cases extinction of various species and taxa (Bellard *et al.*, 2012). The effect of climate change on species and taxa is seldom unvarying. This implies that there are variations between species and taxonomic diversity across ecosystems. Chen *et al.*, (2012) are of the view that certain species and taxa are more prone than others as a result of differences in exposure to climatic vagaries and biological variations between species. Gill *et al.* (2013) put the factors of vulnerability to climate change into 3 categories namely: Exposure, sensitivity and ability to adapt.

2.9.4.1 Exposure of vegetative species to climate change

According to Gill *et al.*, (2013), the first necessary step in assessing impacts of climate change on biodiversity is to assess whether climate change is occurring at a specific location that would result in species being exposed to direct and indirect consequences of climate change. If an ecosystem or plant community is exposed, for example, to increasing temperatures, species may variably respond through mortality, changes in genetic frequencies or dispersal. Gill *et al.*, (2013) predicted a global increase in exposure of tree species to high temperatures especially in Northern America, Northern Eurasia, the Tibetan Plateau, Northwest Africa and Central southern Africa. IPCC (2007a) predicted that in the southern African region, temperatures have increase by at least 0.8^0C over a 100-year period. This has exposed vegetative species to climate change that is affecting diversity at all levels.

Significant frost activity has characterised climate change in some regions, particularly the temperate regions. Exposure of some tree species to frequent and severe frost action in the temperate regions causes frost damage to some species and the effect may influence changes in diversity (Gill *et al.*, 2013)

There is general consensus amongst the scientific community that climate change has resulted in the increase in the frequency and intensity of forest fires that influence the composition of ecosystems. Thus, exposure of trees and other vegetative species to fires will make the species more vulnerable to the effects of climate change. Gill *et al.*, (2013) identified the Mediterranean biomes, montane grasslands and shrubland, desert and xeric shrubland and temperate coniferous forests as highly vulnerable to frequent and intense fires. Furthermore, exposure of tree species to droughts has resulted in the modification of ecosystems within which they survive. It has been proven that the current frequent and severe droughts in southern Africa, southern Europe, the Middle East and other parts of the globe are associated with climate change (IPCC, 2007a). Vegetative species that occur in drought prone areas are some of the most vulnerable species to climate change. In addition, there is a deluge of climate change related pests and diseases that affect natural vegetation (Wainhouse and Inward, 2016). It has been noted that there is an increase in the frequency and severity of emerging diseases and pests in regions where temperatures have increased and rainfall declined (Gill *et al.*, 2013). Trees that are exposed to pests and diseases associated with climate change are more likely to be affected with regards to species diversity changes.

Overall, exposure to environmental perturbations associated with climate change is one of the main factors that determine vulnerability of biodiversity to climate change. If plant communities are located in areas experiencing extreme conditions of climate change, they are likely to be the most affected in terms of, for example, species losses that will affect composition. Studies in Masvingo province (Simba *et al.*, 2012; Unganai, 2009) have shown that climate change is occurring and there is a multiplicity of environmental changes associated with it are taking place.

2.9.4.2 Climate change adaptive capacity of vegetative species

Vegetative species adaptive capacity relates to the capacity of the vegetative species to change adaptive qualities to suit new environmental conditions within its existing location or their capacity to track suitable conditions (Gill *et al.*, 2013). In that vein, tree species with low capacity to reproduce are slower to adapt than their competitors. What it means is that the slow to adapt species will have low abundance whilst those that can reproduce fast will dominate the ecosystem thus causing changes in species evenness. Aitken *et al.*, (2008) postulated that trees with irregular reproduction such as conifer and dipterocarp species and species that do not grow fast over years face challenges in adapting to changing environmental conditions and change their geographical spread in response to climate change. This is mainly because low reproduction provides slim chances for genetic change and reduces frequency of dispersal events.

Furthermore, species diversity is affected when some species fail to adapt due to low genetic diversity. Populations with low genetic diversity have low evolutionary potential to react to environmental changes. The projected climatic changes are likely to exceed the capacity of several species to migrate and track the suitable conditions. Thus, species with low levels of genetic diversity are less likely to cope with extreme conditions under projected exposures under climate change (Altizer *et al.,* 2003). Related to this, species with low capacity to disperse their seeds for long distances do not have the capacity to occur in new habitats that are friendlier. On the other hand, those with long range dispersal mechanisms are able to find new habitats. Gill *et al.,* 2013 point out that trees that use ants for seed dispersal, for example, may have a dispersal distance of 1 to 2 metres. Areas that mainly experience short range dispersal are found in dry regions and other locations with Mediterranean climates in Australia and South Africa (Gill *et al.,* 2013).

The structure of the ecosystem may significantly contribute to the adaptive capacity of individual populations within the ecosystems. Fragmented ecosystems or habitats, for example, reduce the adaptive capacity of species. Fragmented habitats inhibit dispersal processes to favourable environments (Mantyka-Pringle *et al.,* 2011). Gene flow between sub-populations is also inhibited under fragmented ecosystem conditions. The situation worsens if climate change further reduces the area of habitable niches available (Mantyka-Pringle *et al.,* 2011).

Besides fragmentation, some species occur in high altitude ecosystems where they are unable to disperse but succumb to climate change and related environmental perturbations. Species premised at the bounds of the existing altitudinal space usually fail to track suitable conditions and may be outcompeted by species arriving from lower altitudes. Thus, their adaptive capacity is low and this may influence the nature of plant diversity at high altitudes under a changing environment due to climate change. For example, Beckage *et al.,* (2008) indicated that the forest biomes in Vermont, USA have been observed to shift with altitude in the aftermath of changes in environmental conditions that also increased canopy mortality and increased invasion by species from lower altitudes. Changes of the same magnitude and nature have been witnessed in Spain (Penuelas and Boada, 2003) and in *Nothofagus* forest in Australia (Read and Hill, 1985). Mountain top species are spatially limited and have nowhere to go but to go extinct.

Lastly, latitudinal factors may influence adaptation capacity of vegetation species. Trees 'trapped' at certain latitudes may fail to disperse and track favourable climatic conditions and succumb to the changing environmental conditions. New species migrating from other latitudes may occupy and outcompete the native species. The increasing global temperatures are predicted to be the driving force behind tree species migrations towards the poles. In addition, Iverson *et al.,* 2004 observed that there are shifts in species ranges in the north of USA.

2.10 Issues of scale and climate change impact

Thompson *et al.,* (2009) discussed the influence of scale on the impact of climate change and other disturbances on ecosystem resilience to change and showed that plant communities are subject to alterations that occur across different temporal and spatial scales. Thus, the level of impact of climate change, for example, on vegetative species diversity can be determined by scale. Ecosystems may change successively as a result of small-scale chronic perturbations or they may change significantly at large-scales due to severe disturbances (Thompson *et al.,* 2009). Scaling is an important factor in determining the impact of climate change on the diversity of plant species. However, scale and resilience to change are often investigated for different purposes. Holling (1973) reiterated that resilience studies usually emphasise on mechanisms and causes of changes in ecosystem states while scaling studies often examine ecological phenomena assuming steady-state ecosystems. However, resilience is dependent on scale. Plant communities as well as their diversity are equally temporally and spatially resilient when ecological interactions influence reduction on the impact of climate change or any other environmental disturbance over time. Resilience to changes in diversity are achieved through species functional redundancy, or by offsetting differences among species.

In plant communities, biological diversity at species level has potential capacity to enhance ecosystem resilience to large scale environmental change (Thompson *et al.,* 2009). At the regional scale, species provide redundancy at large scales that may lead to increase in resilience if the capacity to migrate across the landscape persists. However, Thompson *et al.,* (2009) noted paucity in scientific literature on the concept. It is in line with such lack of literature that this study seeks to interrogate the resilience of vegetative species diversity to climate change at provincial level.

Determining biodiversity changes or its resilience to change requires a temporal component that is related to disturbance frequency. For plant communities, there is need to consider resilience over many decades to centuries (Thompson *et al.*, 2009). In this study, vegetative species changes are considered over a forty-year period. Hopper and Gioia (2004) postulated that some present terrestrial ecosystems have persisted largely unchanged for thousands of years but environmental changes in the form of climatic elements and other perturbations of enormous magnitude eventually modify the diversity of plant communities or ecosystems.

While climate change may appear to be a long term factor of biodiversity changes, specifically vegetative species diversity changes, it causes the proliferation of short term large scale disturbances that may abruptly and significantly affect species diversity. Some plant communities have the propensity for resilience through following a successional pathway that relays the ecosystem to its pre-disturbance structural and functional state. However, Thompson *et al.*, (2009) noted that this is particularly the case for forests and other plant communities dominated by small-scaled perturbations. A disturbance may be sufficiently severe to reorganise an ecosystem into a state, which in the short term (i.e., decades), may have a different resistance, but in the long term (i.e., centuries) may be equally as resilient as the original state. Furthermore, in the very long-term, the altered state of the ecosystem may simply be part of a long-term dynamical process.

Ecosystems, forests or plant communities comprise collections of individual species. The ranges for species across the regions reflect their physiological and ecological niches. In the case of ecological niches, the individual species have a competitive advantage (Hutchinson 1958). Species with wide-ranging physiological niche requirements are more resilient to climate change. Similarly, species with a slender ecological niche could be more resilient than they appear, if changed conditions provide them with an advantage at the expense of competitors. In both situations, it applies only to species that are genetically suitable and those that are able to migrate. If the population size, genetic diversity and ability to migrate is affected by any other disturbances, the possibility of successful adaptation to climate change diminishes (Thompson *et al.*, 2009).

2.11 Remote sensing and biodiversity assessment

The conservation of biodiversity has become a matter of concern across the globe (Noss, 1991). However, the complexity of biological diversity and the size of ecosystems around the globe complicate inventories for monitoring and management purposes. While traditional ways of biodiversity monitoring have played a crucial role, the methods do not provide enough information on biodiversity (Pettorelli *et al*., 2005; Barreto *et al.,* 2006). This has largely contributed to the paucity in scientific understanding of biodiversity and therefore designing of inappropriate management tools and policies. Consequently, most of the 20 Aichi biodiversity indicator targets are unlikely to be met by 2020 (Tittensor *et al.*, 2014). The development of trait databases on thousands of vascular plant species remain under-sampled (Kattge *et al.,* 2016; Diaz *et al.,* 2016). However, Remote Sensing (RS) holds much promise for mapping and monitoring of biodiversity and may play a significant role in reducing the complexity if effectively and appropriately used (Pettorelli *et al*., 2005; Ustin, 2016).

RS involves observing the Earth's surface without being directly in contact with it (Gillespie, 2001; Gould, 2000). Information can be obtained about the planet and human activities from a distance revealing features, patterns and relationships that may not be possible or affordable to assess from ground level. Currently, there is a deluge of remote sensing satellites and aircraft instruments with observational proficiency in terms of temporal, spatial, and spectral resolution (Ustin, 2016). Likewise, significant advancement in image processing algorithms has amplified the prospects of characterising biodiversity at various scales. Previous studies (Jorgenson and Nohr, 1996; Lee *et al.,* 2002; Turner *et al.*, 2003; Wang *et al.,* 2010; John *et al*, 2008; Skidmore *et al*, 2015; Petrou *et al.,* 2015) have contributed to the understanding of remote sensing use in biodiversity monitoring. The availability of historical data in the form of satellite images provides an opportunity for assessing vegetation species diversity changes over time. It also provides an opportunity for assessing how climate change is influencing biodiversity changes over time.

RS and related technologies, as well as the growing databases improve biodiversity management proficiency and effectiveness across the world (Turner *et al.,* 2003; McCormick. 2002; Stritfholt *et al.,* 2006). The use of Remote Sensing (RS) in biodiversity management provides bases for projecting changes in multiple facets of biodiversity over time, predicting spatial distribution of species, classification of species richness, monitoring factors that affect future biodiversity distribution across the globe and change detection.

Remotely sensed data has revolutionised the projection of biological diversity (John *et al.,* 2008). Several studies have demonstrated an increase in precision and confidence in using remote sensing approaches in understanding the variety of species and their interactions within the ecosystems (Seto *et al.,* 2004; Waring *et al.,* 2006; Gavin and Hu, 2006; Skidmore *et al.,* 2003; Pettorelli, 2005). Seto *et al.,* (2004) studied the relationship between Landsat derived NDVI and bird species diversity in space. In the United States, Waring *et al.,* (2006) discovered a practical linkage between MODIS enhanced vegetation index (EVI) and tree species distribution. They observed that several terms of EVI illuminate up to 60% of tree species diversity. Skidmore *et al.,* 2015 show unimodal relationships between species richness and NDVI at regional scale. Skidmore *et al.,* (2003), also demonstrated that diversity is a function of productivity, consolidating the productivity hypothesis which states that when resources are abundant and consistent, species number per unit area will increase. It is, thus expected that a reduction in rainfall implies a reduction in resources, affecting productivity and consequently diversity.

NDVI has been shown to be related to plant as well as animal diversity (Walker *et al* 1992). A study in California (Walker *et al.* 1992) found a positive relationship between plant species richness to NDVI while in the Sahel region, Jorgensen and Nohr (1996) related bird diversity to landscape diversity and biomass availability using RS products as proxy indicators. Box *et al.,* 1989 and Prince 1991 observed that NDVI is correlated with Net Primary Production (NPP) at broad spatial scales. The observation of direct relationships from NDVI to NPP and NPP to species richness encouraged Skidmore *et al.,* 2003 to investigate whether a relationship could be established between NDVI and species richness.

Some species diversity studies used NDVI as a proxy for productivity as the independent variable (Oindo and Skidmore, 2002). However, Enhanced Vegetation Index (EVI) has been regarded as better surrogate of productivity and diversity due to its insensitivity to soil and atmospheric effects. In addition, EVI adjusts the red wavelength as a function of the blue wavelength to minimise brightness related to soil effect (Huete *et al.,* 1997, 2002). John *et al,* (2008) used MODIS 16 day EVI to predict plant species diversity in Inner Mongolia, China. Using MODIS derived metrics, John *et al.,* (2008) found positive, linear relationship between remotely sensed vegetation indices and diversity variables, specifically species richness. The relationships improved significantly when species richness was divided by life form.

Several studies have assessed various diversity aspects from different spectral, spatial and temporal scales demonstrating the many ways in which RS can address biodiversity concerns. For example, Cavender-Bares *et al.* (2016) detected phylogenetic variation in oaks using 400-2500 nm leaf level spectroscopy while Santos *et al.* (2016) analysed EVI Landsat data to identify trends in oak productivity in relation to climate. In another study, McManus *et al* (2016) demonstrated the capability of RS in distinguishing phylogenetic relationships in tropical forest species. Graves *et al*. (2016) used imaging spectroscopy for species classification and addressed accuracy complications of imbalanced training data. Furthermore, Chadwick and Asner (2016) mapped leaf mass area (LMA), foliar nitrogen, phosphorous, magnesium, potassium and calcium using high spatial and spectral resolution Carnegie Airborne Observatory data while Revermann *et al*. (2016) used MODIS and Shuttle Radar Topographic Mission (SRTM) data to map alpha diversity. In a different study, Wang *et al*. (2016b) used a field spectrometer to assess NDVI-species richness relationships. Mockel *et al*. (2016) predicted species richness and Simpson's diversity using spectral responses from an imaging spectrometer (414–2500 nm).

Wang *et al*. (2016a) also used imaging spectrometry to assess grassland productivity based on species richness and the Shannon Index. Garroutte *et al*. (2016) evaluated grassland quality using seasonal MODIS EVI and NDVI. Zhao *et al.* (2016) demonstrated the potential of RS in mapping foliar traits associated with ecosystem functionality. McManus *et al*. (2016) observed a relationship between foliar reflectance spectra and the phylogenetic composition of in tropical forests. Coops *et al.* (2016) projected forest species migration in the Pacific Northwest of North America under climate change, and Zhang *et al*., (2016) characterised terrestrial biodiversity using Photosynthetically Active Radiation (fPAR). Imaging spectroscopy data was also used by Barbosa *et al*., (2016) to identify sub-canopy invasive species *Psidium cattleianum* in Hawaiian forests.

RS offers the opportunity for large area characterisations of biodiversity in a systematic, repeatable and spatially exhaustive manner (Turner *et al.*, 2003). RS has become a cost effective source of information on biodiversity including wide spatial coverage of environmental information in a constant and timely manner. Constant monitoring of biodiversity provides policy and research with necessary information for action.

RS directly uses space borne sensors to identify either species or land cover types and directly map the distribution of species assemblages (Kerr *et al*., 2001; Turner *et al.,* 2003; Saatchi *et al*., 2008). Indirectly, RS approaches facilitate assessments of environmental parameters like land cover, geology, elevation, landform and others, which affect biodiversity distribution. However, RS requires ground verification through fieldwork to validate desktop work. Fieldwork and interpretation of RS imagery form a reliable and cost-effective analytical framework for accurately assessing biological diversity.

Recent advances in sensor design have made it possible for RS to study individual species and also focusing on broad patterns in variables of biodiversity (Kerr *et al*., 2001; Turner *et al.,* 2003; Saatchi *et al*., 2008; Rocchini *et al*., 2007). Mapping of forest characteristics, assessing relationships between species, updating forest intactness, mapping invasive species, assessing biodiversity richness and spatial distribution of species across the globe, occurrence of fires and fragmentation and destruction of natural habitats can now be done through of RS. For example, sensor such as Landsat, Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS) and IKONOS satellite products are being successfully used to study phenological changes in vegetation, land cover classification and climate change processes that have impact on biodiversity (White and Nemani, 2006; Turner *et al.,* 2003).

Application of RS on land cover types depends on spectrum, visible near-infrared and middle-infrared region as reflectance differs from each surface such as soil, leaves, wood, ash, water and snow. In vegetation, the canopy structure affects shading which in turn strongly affect reflectance from that canopy back to the sensor (Riitters *et al*., 2004). For example, tall forests tend to appear darker than shorter forests because of greater canopy shading with height. The combination of these reflectance properties allows one to make differentiation between many vegetation types with the use of satellite imagery. This is so because vegetation types are often good indicators of land cover or habitat type. In RS, RADAR and LIDAR active sensors are useful for mapping forest characteristics including age, density and biomass (Saatchi *et al*. 2008; Kerr and Ostrovsky. 2003). RS also contribute to proper assessment of forest quality which is essential for biodiversity management. Remotely sensed data has been used, for example, to assess forest intactness and large forest blocks, forest fragmentation area, location of old growth area, location of plantations, changes in forest pests and diseases, fire occurrences and trends in invasive species (Buchanan *et al*., 2005; Mooney and Cleland .2001; Saatchi *et al*. 2008; Riitters *et al*., 2004; Bonneau *et al*., 1999).

Forest intactness and large forest blocks are essential to maintain forest quality. As the demand for forest products increases, there is a danger of losing some tree species if there is no remedy. RS has been used in previous studies to monitor forest intactness (Stritfholt *et al*., 2006). An ecosystem with high level of intactness maintain its biodiversity and ecosystem functionality. The Global Forest Watch (GFW) has used moderate resolution satellite to map and update forest intactness products for Brazil and Canada (Barreto *et al*., 2006; Peters *et al*., 1997).

Forest fragmentation and destruction of natural habitats is reported as the most significant driver in the global decline in biodiversity. Riitters *et al.*, (2004) created digital forest fragmented maps from global land cover characteristics (GLCC) land cover maps where each pixel value represents a forest fragmentation category for the surrounding 81 km^2 landscape. Mapping forest fragmentations has been demonstrated using Moderate- Resolution imagery and ancillary data for entire countries such as United States which could be applied to other nations regardless of their size (Stritfholt *et al*. 2006; Riitters *et al*. 2004).

Fire occurrences across the world's landscape is considered as the most natural disturbance agent in forested ecoregions. Monitoring of forest fires is extremely important in forest management, and RS is an effective means for monitoring fires in near real-time (Barreto *et al*. 2006). AVHRR and SPOT satellites have been used to map burnt areas. For example, in equatorial Africa and southern Africa, MODIS and AVHRR products have been used to monitor fires, providing information on ecological processes such as carbon storage and nutrient budget (Turner *et al.,* 2003; Riitters *et al*. 2004).

Some studies make closer examination of fire occurrence with the use of Landsat TM which reveals the configuration and extent of various severities (areas of high severity (magenta) to areas untouched by fire (Green). This helps understand the full impact of fire on biodiversity (Steyaert *et al*. 1997). In boreal forest, Landsat TM image has been widely used to show recent fire event. From biodiversity perspective, mapping of areas where forest landscapes are becoming more susceptible /prone to fires helps or provide spatially explicit guidance as to where regional biodiversity will be at risk especially if it is outside the range of natural variability for a given region.

Invasive species are a threat to global biodiversity and ecosystems function as well as incurring economic costs (Mooney and Cleland, 2001). Invasive alien plants have been studied using RS, to monitor their trends, distribution and identification of areas vulnerable to invasion. RS has become an indispensable tool in environmental studies, effectively used to map species dominating forest canopies, which include Surinam Cherry, Tamarisk, Maritine pine, Chinese tallow and trumpet tree (McCormick, 2002). Bonneau *et al.* (1999) were able to classify and track hemlock forests infested by the hemlock woolly adelgid, exotic insect pests using RS. Bryceson (1991) on the other hand used RS to track the Australian plague locus (*chorloicetes termini flora*) using Landsat TM imagery.

RS plays a crucial role in assessing phenological change in vegetation, particularly in dry and sub-humid ecosystems, where temporal resolution of satellite imagery is used. Phenological indicators, like the start of growing season, end of growing season, length of growing season, date of maximum plant maturity can be determined with the use of NDVI. Periodic temporal changes in vegetation phenology can be used to classify certain ecosystem types with known phenological patterns (White and Nemani, 2006). Shifting of phenological patterns over time provides evidence of climate change.

Chapter 3 : MATERIALS AND METHODS

3.1 Introduction

This chapter presents the various methods that were used in the collection, analysis, presentation and interpretation of data in this study. The methods are discussed in line with the aim, specific objectives, research questions and conceptual framework presented in previous chapters. Key aspects discussed include the research paradigm, research design, sampling methods, reconnaissance surveys, field data collection methods and procedures, document analysis. These are discussed in the light of the validity and reliability of methods used.

As the study assesses the response of vegetative species diversity to climate change under semi-arid conditions of Masvingo province in Zimbabwe, the following specific objectives were spelt out: (a) determine the climatic trends in Masvingo province over a 40 year period; (b) examine the relationship between climatic elements and vegetative species diversity (c) assess the relationship between vegetative species diversity and NDVI calculated from remotely sensed biophysical data, and (d) evaluate changes in vegetative species diversity from vegetation indices maps over the 40 year period. To address the stated aim and specific objectives, a multiplicity of research methods were adopted. The methods were deemed adequate in addressing the wider spectrum of key variables to address the posed research questions.

3.2 Strategy of inquiry

In this study, a mixed methods design was adopted as the strategy of inquiry. The design uses both quantitative and qualitative methods (Gray, 2011). The quantitative approach is rooted in the positivist paradigm (Collins, 2010) while the qualitative approach is grounded in the phenomenological philosophy (Corbetta, 2003). Morgan (2008) postulates that the mixed methods design emanates from the pragmatic school of thought and is being widely used by researchers from various disciplines. Spradley (1980), Bryman (1988) and Patton (1990) have contributed significantly to the development of this paradigm. The approach is also rooted in the argument that knowledge is generated from activities, circumstances and consequences and not antecedent conditions as in the positivist philosophy (Sango, 2013). The choice of the mixed methods design was based on the sense that it uses the strengths and similarities of both qualitative and quantitative approaches. It absolves the weaknesses of each of the research paradigms by capitalising on the strengths of both. For example in the positivist paradigm, the assumption that all changes can be perceived as a result of the relationship between two variables (e.g. climate and species diversity) could not be accurate as correlation is not always causality. This gap can be filled in by a phenomenological paradigm which tries to understand the views and reactions of the people who have been interacting with the environment over a long period of time concerning the response of vegetative species diversity to climate change under semi-arid conditions.

Punch (2011) reiterates that the mixed method design is highly pragmatic and convenient as it allows the researcher to use quantitative and qualitative techniques either interdependently or independently. Thus, it is vastly flexible and can be used in diverse research projects. While quantitative methods focus on the collection of facts, qualitative methods place prominence on the meanings derived from the facts. Figure 3.1 shows the methodological approach used in this study.

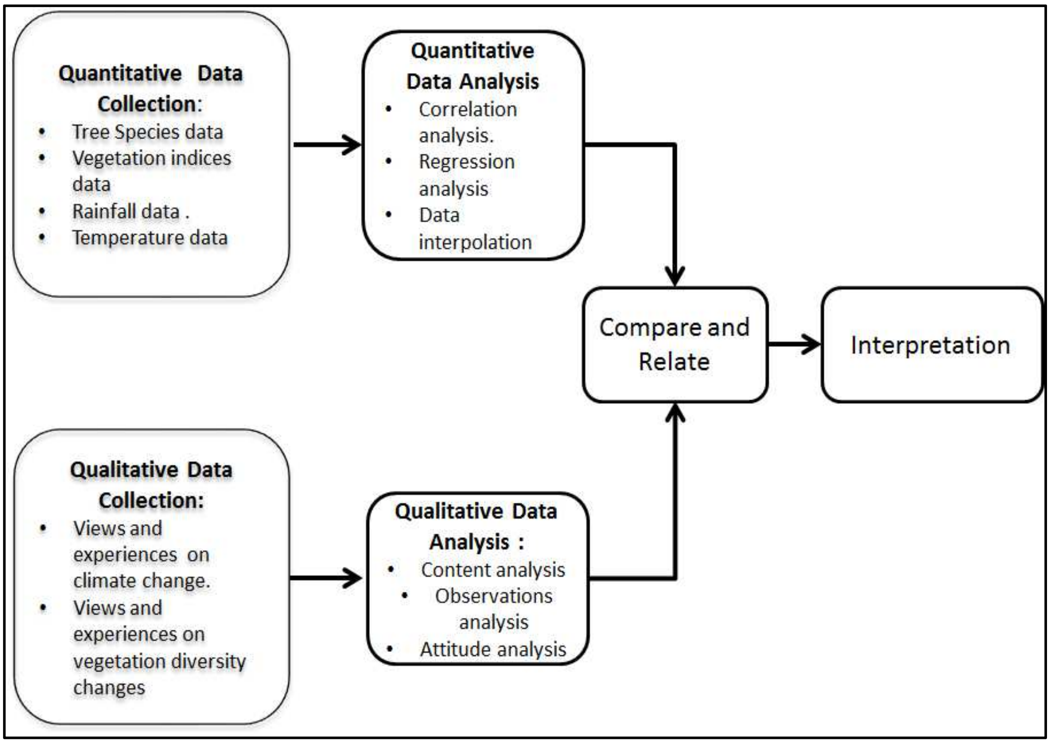


Figure 3.1. The mixed methods approach as applied in this study
Source: Developed by Author

Plano (2010) avers that the choice of the mixed methods approach is dependent on a variety of reasons. These include, *inter-alia;* to analyse problems from different standpoints to develop and understand the meaning of a singular perspective, to make use of both quantitative and qualitative data to better understand a problem; to develop a complementary picture; to compare, validate, or triangulate results; to provide illustrations of context for trends; or to examine processes/experiences along with outcomes. In this study, the mixed methods approach has been selected to merge quantitative and qualitative data to develop a more complete understanding of the impact of climate change on natural vegetative species diversity. In addition, it is a way of validating the results emanating from image analysis.

Thus, positivist and phenomenological approaches were combined under this study. As a research paradigm, positivism is associated with scientific theories and depends on quantifiable observations that lead to statistical analysis. It has an "atomistic, ontological view of the world as comprising discrete, observable elements and events that interact in an observable, determined and regular manner", (Collins, 2010). Positivists view success of natural science recently as stemming from scientists' refusal to go beyond what can be supported by empirical evidence, particularly evidence emanating from careful observation of phenomena.

The phenomenological approach seeks to understand, analyse and describe phenomena without emphasis on quantitative measurements and statistics (Dawson, 2007). It focuses on qualitative interpretation of people's perceptions and meanings attached to phenomena (Lincoln and Guba, 2000). Contrary to positivism, the phenomenological approach is more subjective than objective. It provides space for interpretation of phenomena and associated changes such as those observed in the assessment of climate change impacts on vegetative species diversity as opposed to strict quantitative measurements. Leedy (1989) claims that the qualitative research methodology is considered "warm" to the central problem of research as it investigates issues identified earlier in addition to interpersonal relationships, meanings construction, experiences and associated thoughts or feelings. With this, the researcher attempted to attain rich, deep, real and valid data on climate change experiences and the associated responses of vegetative species diversity in Masvingo province.

3.3 Vegetative species documentation and diversity assessment

Individual types of vegetative species were documented and followed by diversity assessments for the whole province. Documentation was done on selected sampling plots, which were deemed representative, initially in August 2013 followed by subsequent seasonal documentations within the same plots to assess changes. Diversity assessments were done using the Shannon weaver and Simpson's diversity indices.

3.3.1 Plot size determination

The size of sampling plots can influence quality of data collected through affecting representativeness. It determines sampling density, time and resources used in a study. In this study, the species area method was used to determine the size of the sampling plots. This method involves plotting the number of species (Species richness) identified in plots of successively larger size, so that the area enclosed by each one includes the area enclosed by the smaller one. Thus 100 m^2, 400 m^2, 900 m^2, 1600 m^2 and 3600 m^2 plots were successively constructed to determine the optimum plot size as illustrated in Figure 3.2. Species richness for each plot was recorded. In the 100 m^2, 400 m^2, 900 m^2, 1600 m^2 and 3600 m^2 plots, 5, 7, 12, 12, 12 species were observed respectively.

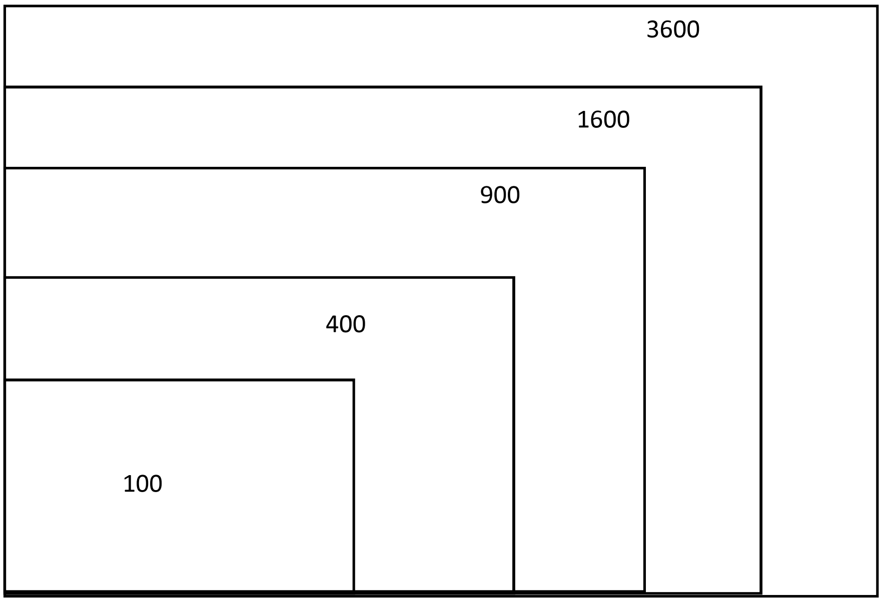


Figure 3.2. Plots used in determining the optimum plot size in the study
Source: Developed by Author

The data was plotted in a graph as shown in Figure 3.3 to determine the optimum plot size. The optimum plot size is the one in which the number of species identified will not change with an increase in the size of the plot size. As illustrated in Figure 3.3, the 900m2 plot was identified as the optimum plot size. This falls within the recommended range of 400-2500 m^2 as postulated by Sutherland, (1996).

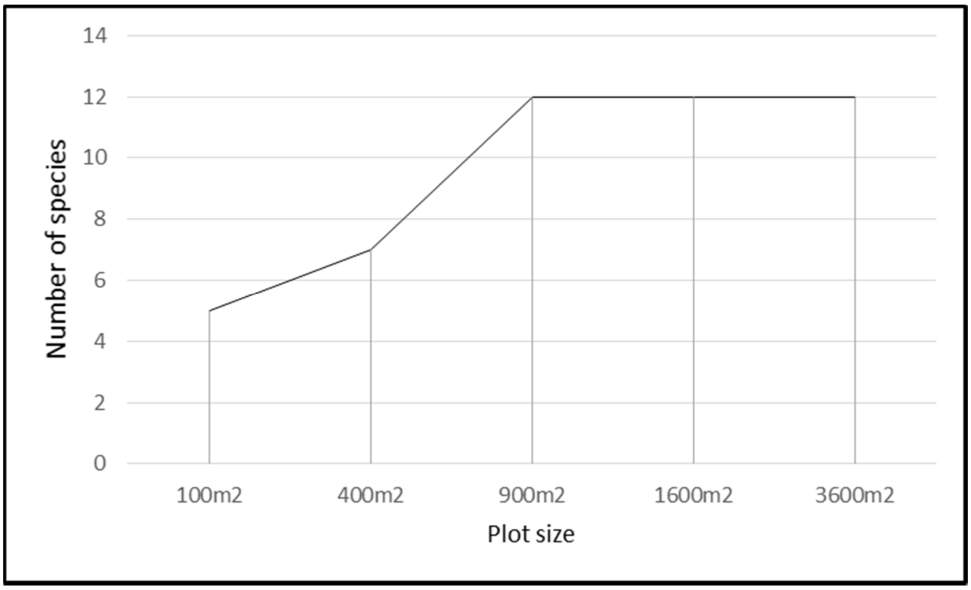


Figure 3.3. Species area curve used in determining the optimum plot size.
Source: Developed by Author

3.3.2 Sampling and data collection

A GIS based nested non-aligned block sampling method was used to sample the study plots from which vegetative species data were collected. The method uses a grid as a basic template, where sampling locations are randomly nested. The grid is a row and/or column that divides space into a unit or units of equal size. This method permits multi-level assessment of variables at varied scales (Chapungu and Yekeye, 2013; Urban and Liu, 2002). It takes into consideration regions of obvious variations, reducing sampling bias as samples will be taken from each area of geographical difference. The sampling was done on the map of Masvingo province using the Integrated Land and Water Information System (ILWIS) software. The process involved 3 main steps.

Step 1: Grids of the same size were overlaid on the map of Masvingo province (Figure 3.4 a). These grids were meant to divide the study area in a way that would allow samples to be obtained from all areas of geographic differences. All grids covering more than 40% of the province were selected. Each grid represents an area from which samples were taken. This makes the samples more representative as they cover all geographic areas throughout the study area. A total of 22 grids were selected.

Step 2: Grids selected in step 1 were further subdivided into smaller grids of same size (Figure 3.4 b) from which 3 were randomly selected using the random point generator in ArcView GIS (ESRI, 1992-1998). Thus, the number of selected grids increased to 66.

Step 3: Grids in step 2 were further subdivided to come up with smaller grids of same size (Figure 3.4 c). Three smaller grids or sub cells were randomly selected from each larger grid established in step 2. Thus, the number of selected grids increased to 198. These were the sampling points from which data was collected. From these selected grids, plots of 30 m x 30 m were established. Figure 3.4 is an illustration of the nested non-aligned block sampling design used in the study.

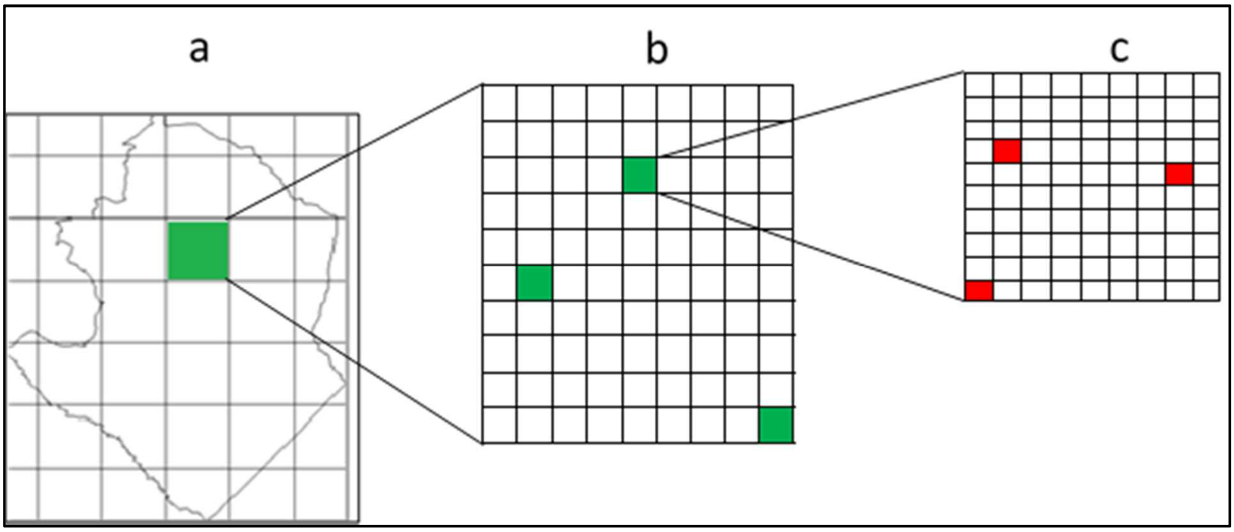


Figure 3.4. The non-aligned block sampling design: a) The study area divided into large grids of same size (b) The grids further subdivided into smaller grids of same size from which 3 are randomly selected and (c) Final sampling points after further subdivision and random selection of 3 grids.
Source: Developed by Author

However, inaccessibility of some randomly selected points was an impediment to collection of data from all the 198 sampling sites. In some cases, the points were located at mountain tops with forest thickets that were difficult to work in. In others, the points fell in the middle of Lake Mutirikwi while in a few isolated cases access was denied at private properties. Figure 3.5 shows the final sampling points in the study area and the points that were inaccessible due to various reasons. It is noted that only 4.04 percent of the sampling points were inaccessible and the final sample constituted of 189 points (See appendix II for the list of points and their coordinates).

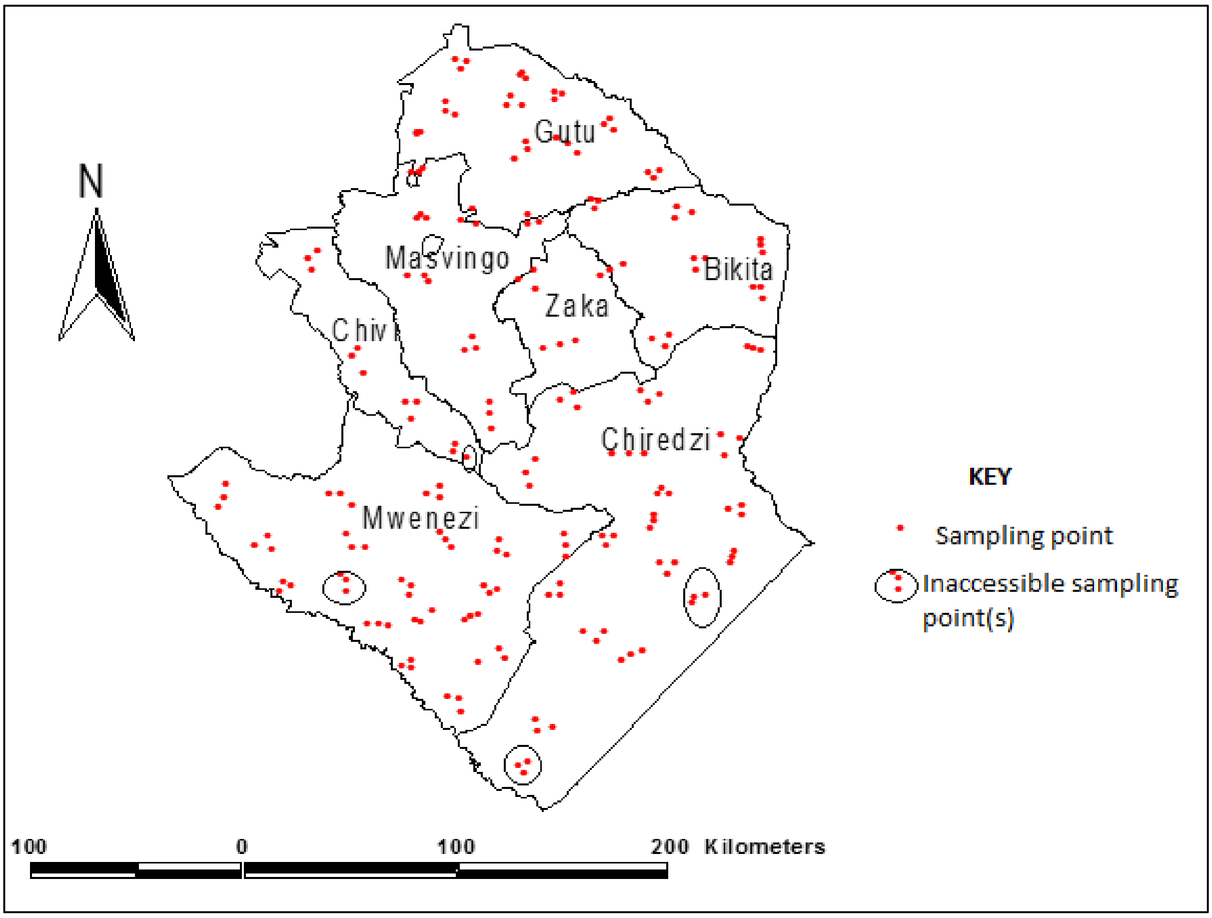


Figure 3.5. Final sampling points across the study area
Source: Developed by Author

The coordinates of the centres of the selected grids were fed into a Hand-held Global Positioning System (GPS) receivers which were then used to navigate to the point locations at approximately 10 meters error. Species counting was conducted within the study units (30 m x 30 m plots). To avoid double counting and skipping of some species, the plots were subdivided using a rope into smaller units that were easy when counting species. Furthermore, within the sampling plots, the Point Centre Quarter Method (PCQM) (Mitchell, 2007) was used to collect various data used in assessing status of vegetative species diversity. The technique involved the observer moving along a transect line in a predetermined direction within the plot, recording data at predetermined intervals. Figure 3.6 shows the plot and transect lines constructed at regular intervals of 6 meters from which measurements were done.

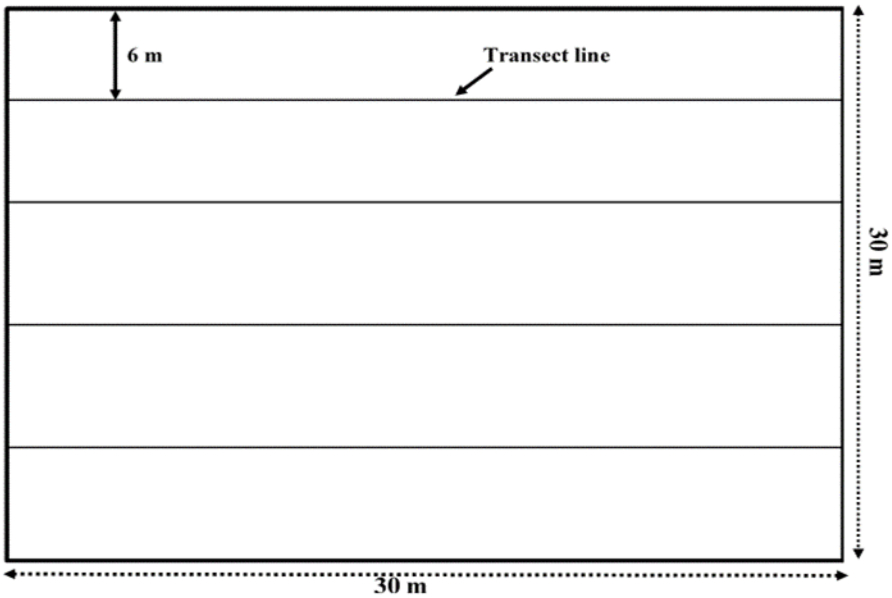


Figure 3.6. 30 x 30 m plots and transects used during data collection
Source: Developed by Author

All vegetative species within the confines of the established plots and quadrats were assessed and quantified to determine diversity of species. The rooted frequency approach (Chapungu and Yekeye, 2013; Ludwig and Reynolds, 1988), where only trees, herbs and grasses with roots found within the confines of the plots and quadrats were counted, was used. 30 m transect lines in each selected sampling plot were followed and measurements done at 6 m intervals. At each sampling point the tree nearest to the transect line was recorded together with the distance as illustrated in Figure 3.7.

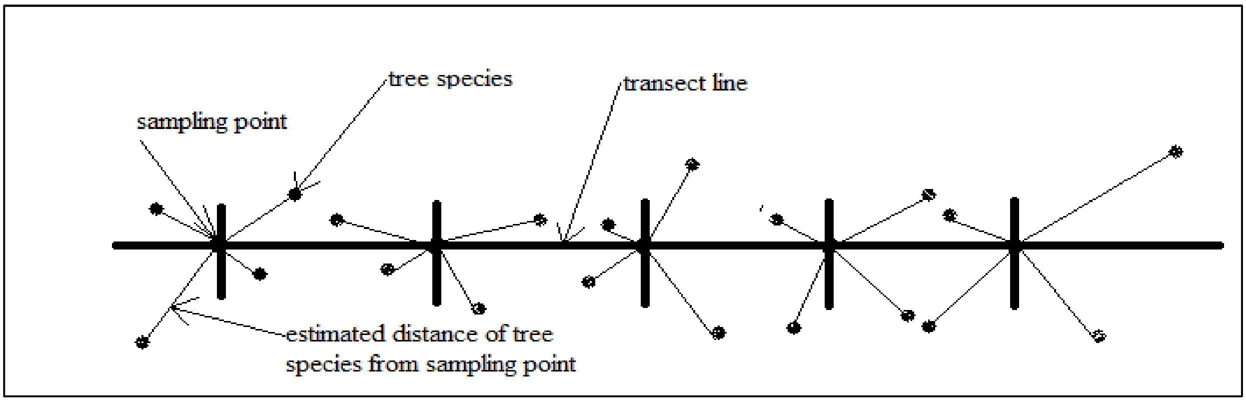


Figure 3.7. Transact line on which sample points were located and from which measurements were done.
Source: Developed by Author

Species identification and distinction within the plots were done by a plant botanist from the Zimbabwe National Herbarium. The purpose was to guard against attributing particular species to the inaccurate species genera, double counting and skipping of some species. All the species data collected within plots were recorded on data sheets. This data was collected from the same plots four times over a year to cover all seasons (summer –November to March, Post Summer- April to May, winter- June to August and Post winter- September to October) to monitor seasonal changes.

3.3.3 Sampling of graminae and other small species

In this study all vegetation strata were considered. Thus, the assessment criteria for graminae species was different from that of tree species. Within the established plots, a radial arm was designed to facilitate the capture of variations in small, particularly grass, species within the 900 m^2 plot. Using the radial arm as the sampling framework, data on small vegetative species were collected from four quadrats: one from the centre, one from the north east, one from the south east and the other from the north-west. The angle between arms was 120^0 while the length of the arms was 12.2 m. To construct the radial arm, a campus was used to establish the azimuth of the arms. At the end of each arm and at the centre, a 1 m^2 quadrat was designed as shown in Figure 3.8.

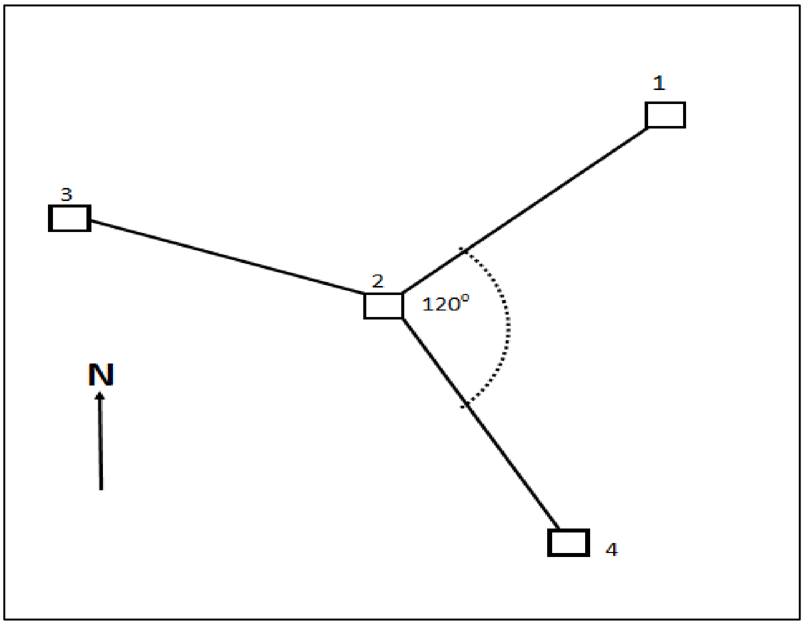


Figure 3.8. The radial arm used to sample small vegetative species.
Source: produced by Author

Small vegetation species within the 1 m x 1 m quadrats were assessed to determine species richness and evenness. The grasses and other small species were identified and the percentage cover determined with the help of a plant botanist from the national herbarium of Zimbabwe.

3.4 Satellite image downloading and processing

The images were acquired from online Landsat archive via GloVis web-link (http://glovis.usgs.gov/). The year for the first imagery was determined by the availability of imagery with bands necessary to calculate NDVI. The selection of years was also determined by the availability of free imagery from the GloVis web link. The study however ensured that the selected images are distributed across specific decades e.g. between 1970 and 1980, 1980 and 1990, 1990 and 2000, 2000 and 2010, 2010 and 2020. It was also considered that there is a gap of more than 8 years between the years. The Landsat images were acquired in digital number (DN) format and calibrated to spectral radiance units (W m–2 sr–1 µm–1). The algorithm developed by Chander *et al*. (2009) specifically for calibrating Landsat images and the calibration coefficients were provided together with the respective Landsat image files as metadata files as shown in Equation 4.1:

$$L_{\lambda} = \left(\frac{Lmax_{\lambda} - Lmin_{\lambda}}{Qcalmax - Qcalmin}\right)(Qcal - Qcalmin) + Lmin_{\lambda} \qquad [4.1]$$

Where L_{λ} is the quantized calibrated pixel value. Q_{cal} is the calibrated and quantized scaled radiance in units of digital numbers, $Lmin_{\lambda}$ is the spectral radiance at *QCAL* = 0, $Lmax_{\lambda}$ is the spectral radiance at *QCAL* = *QCALMAX*, and *QCALMAX* is the range of the rescaled radiance in digital numbers. The conversion from DN to spectral radiance was done by implementing the Chander *et al*. (2009) algorithm using the Environment for Visualizing Images (ENVI) software.

Landsat 8 Thematic Mapper (TM) imagery with spatial resolution of 30 m was for analysis of NDVI. NDVI is an arithmetical indicator mostly used as a surrogate of plant biomass from remotely sensed data (Rulinda *et al.,* 2010; Kromkamp and Morris, 2006; Tucker, 1979). This index uses the visible red band (0.4–0.7 µm) and near-infrared (NIR) bands (0.75–1.1 µm) of the electromagnetic spectrum (Rulinda *et al.,* 2010; Tucker, 1979) to analyse remotely sensed data.

The relationship between NDVI and species richness was examined to confirm the utility of remote sensing in predicting vegetative diversity. NDVI was calculated using the formula shown in Equation 4.2 (Gao, 1996):

$$\text{NDVI} = \frac{NIR - R}{NIR + R} \qquad [4.2]$$

Where NIR and R are the reflectances of the near-infrared (NIR, 0.78–0.89 m) and red band (0.6-0.7) regions, respectively.

The greater the difference between the NIR and the Red reflectance the higher the biomass. In this study, the hypothesis is that the higher the biomass the greater the diversity of species. The NDVI values range from −1 through 0 to 1, where negative values are a sign that there is water, zero symbolises bare soil while positive values signal healthy vegetation. NDVI was used over other indices because it has low sensitivity to soil differences, it is a function of a ratio, therefore, it is less sensitive to solar elevation, and it is very sensitive to the amount of green vegetation. Tables 3.1 and 3.2 show the paths, row, seasons and dates of the images acquired for NDVI analysis for wet and dry seasons.

Table 3.1. Images downloaded for analysis of dry season NDVI

Tile	Path	Row	Date (Dry season)			
			1986	1998	2006	2014
1	169	73	24/08/86	26/09/1998	30/07/06	6/9/2014
2	170	74	31/08/86	3/10/1998	21/07/06	29/09/14
3	169	74	24/08/86	26/09/1998	30/07/06	6/9/2014
4	170	75	31/08/86	19/10/1998	21/07/06	28/08/14
5	169	75	24/08/86	10/9/1998	30/07/06	6/9/2014
6	168	75	27/08/84	3/9/1998	7/7/2006	15/09/14
7	168	74	27/08/84	3/9/1998	23/07/06	15/09/14

Table 3.2. Images downloaded for the analysis of wet season NDVI

Tile	Path	Row	wet season				
			1972	1987	1998	2006	2014
1	169	73	8/12/1972	31/01/87	13/11/98	21/12/06	27/12/14
2	170	74	3/11/1972	6/1/1987	22/12/98	28/12/06	12/12/2014
3	169	74	8/12/1972	31/01/1987	15/12/98	21/12/06	11/12/2014
4	170	75	3/11/1972	6/1/1987	22/12/98	28/12/06	3/1/2015
5	169	75	8/12/1972	31/01/87	15/12/98	21/12/06	28/01/15
6	168	75	7/12/1972	8/1/1987	8/12/1998	14/12/06	4/12/2014
7	168	74	7/12/1972	8/1/1987	8/12/1998	14/12/06	4/12/2014

3.5 Rainfall and Temperature data

Rainfall and temperature data were obtained from weather stations within and near Masvingo province (Figure 3.9) which are run by the Meteorological Services Department (MSD) of Zimbabwe. Specifically, data for Zaka, Masvingo Airport, Chisumbanje, Buffalo Range and Makoholi weather stations were used.

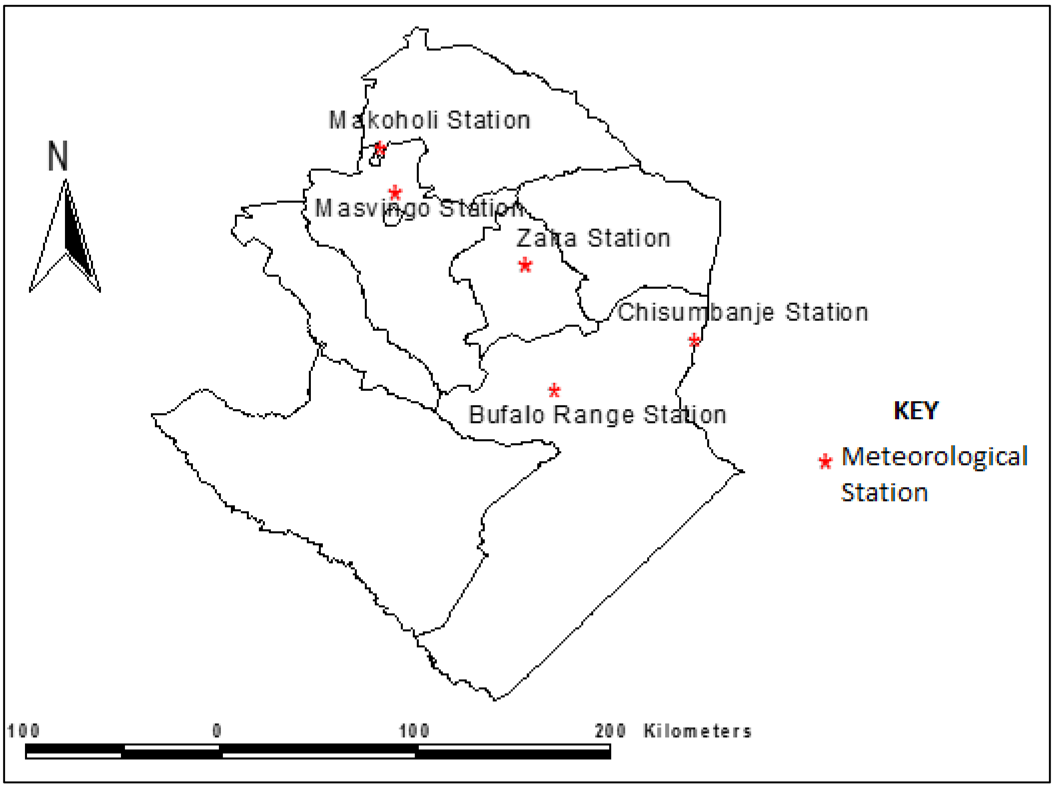


Figure 3.9. Distribution of meteorological stations from which data was obtained.
Source: Produced by Author

The dataset obtained from the MSDZ was incomplete. The last records from the data were in 2010 yet the research needed data for a period spanning to 2014. Other data was then obtained from the National Climate Data Centre (NCDC) which is managed under National Oceanic and Atmospheric Administration (NOOA) programs for preserving, monitoring and provision of climate and historic weather data (www.ncdc.noaa.gov). The NCDC had records spanning throughout the period under assessment but not for all other districts except Masvingo. To use both sets there was need for validation to assess whether the two systems recorded similar data from the same station. This was done through regression analysis of available data from the two data sources.

Rainfall data validation was performed through regression of data from the meteorological department of Zimbabwe and that obtained from the National Climate data Centre. This was done in order to use both sets of data since no one source had a complete set of bioclimatic data. Spearman rank correlation coefficient analysis revealed a strong positive ($r = 0.95$) relationship between the two data sets with 0.91 as the coefficient of determination. Figure 3.10 shows the regression results of MSDZ data by NCDC data.

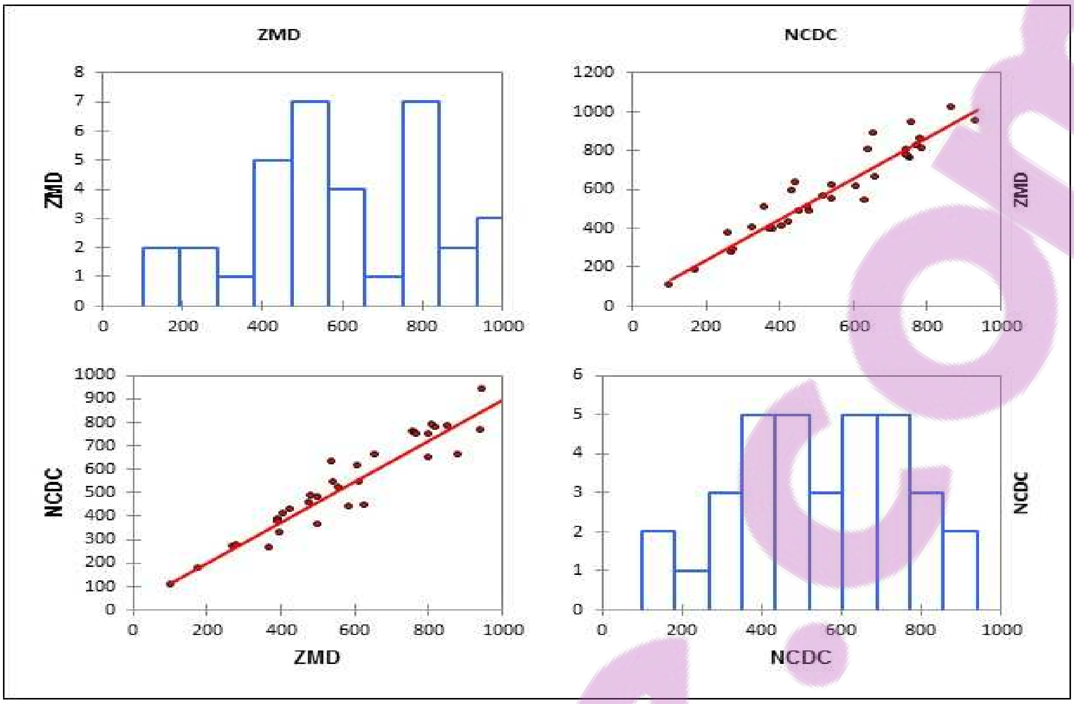


Figure 3.10. Relationship between NCDC and ZMD meteorological records

Given the strong positive relationship between the two data sets, the data from the two sources were combined and used for the analysis of climate change in the study.

3.6 Questionnaire surveys

Questionnaire surveys were administered in local communities at household level where the natural vegetative species exist. It is generally understood that local communities are aware of the changes that have taken place in their localities over time. Thus, a survey questionnaires was used to gather information on the impact of climate change on vegetative species diversity. This information complemented data obtained through direct observation and remote sensing. Adoption of questionnaire surveys as a tool for data collection was based on its robustness in collecting both quantitative and qualitative data from subjects that have experienced changes over time. Stimpson (1996) opined that questionnaire surveys provide snapshots of existing conditions at specific localities. Mapira (2015) aver that they remain one of the cheapest methods to collect data that can be useful across various disciplines. Furthermore, they are a tool that are cost effective and can be used in large sample sizes based on a structured design where the researcher poses specific questions relevant to the study (Lincoln & Guba, 2000; Ian, 1996).

Questionnaire surveys contain close-ended and open-ended questions. Close ended questions require objective answers selected from a provided list while open ended questions allow respondents to express their views with high flexibility. The surveys used in this study contained both types of questions and managed to capture quantitative data as postulated by Bailey (2007) who observed the aptitude of questionnaires to generate data acquiescent to transformation into quantitative data that can be analysed using statistical procedures. Thus, answers to particular questions can be organised such that parametric and non-parametric tests can be computed.

The sampling criteria followed in the administration of questionnaires was more or less similar to the one adopted for vegetative species assessment. In this case, a household in the final selected plot location was randomly selected to participate in the questionnaire surveys. A total of 198 samples were planned but due to inaccessibility of some plots, a total sample of 189 questionnaires was distributed. The response rate for these surveys was 95.24%. The observed reasons attributed to lack of 100 percent response rate include, *inter alia,* busy schedules, hesitancy to provide wrong information and general truancy.

3.7 Key Informant Interviews

Key informant interviews were conducted to infer data from important institutions and individuals involved in the management of natural vegetative species diversity and climate change related impacts. Thus, the ministry of Environment, Water and Climate was regarded as an important stakeholder in climate change and biodiversity issues. In addition, the Climate change office of Zimbabwe and the Meteorological Services Department (MSD) were regarded important as well with regards to climatic patterns in the region. Furthermore, the Forestry Commission of Zimbabwe and the Environmental Management Agency (EMA) were regarded as important to provide insight on vegetative species diversity dynamics over time. At community level, traditional leaders were regarded as key informants due to their influence as the custodians of natural resources. Members from the above stated institutions and 7 traditional leaders, one from each district, were interviewed as key informants.

Sango (2013) put forward that interviews entail gathering of verbal data from individuals directly or indirectly affected by a phenomenon under investigation. The process involves asking questions whose responses provide answers to the research questions of the ongoing study. Of the different types of interviews available, this study used the semi-structured type in which data collection process was flexible but at the same time maintaining some structure over the concepts being discussed. An interview guide, which is basically a set of pre-conceived questions, was used to guide the interview process. The process enabled the interviewer to have a dialogue with the interviewees as postulated by Fontana and Frey, (1994). Using the semi-structured interviews, the views of the key informants were fully characterised based on their knowledge, expertise and experience with regards to the impacts of climate change on natural vegetative species diversity.

3.8 Data analysis methods

The data collected through various collection methods were analysed using different methods and procedures based on the type of data and the objective being addressed. Both exploratory and confirmatory data analysis approaches were used.

3.8.1 Normality tests

Rainfall and temperature data, which constituted the time series data, as well as vegetative species data were tested using the Kolmogorov-Smirnov test to ascertain whether they deviate from normal distribution or not. This helped in determining whether the data satisfy assumptions of parametric or non-parametric statistical analysis methods (Chikodzi and Mutowo, 2014). Parametric tests are applicable when the data assumes a normal distribution; otherwise it is ordinarily sensible to use non-parametric tests (Lettenmaier, 1976; Hirsch *et al.,* 1993). In this study therefore, non-parametric statistical analysis methods were used.

3.8.2 Auto-correlation and Pre-whitening

Prior to trend analysis using the non-parametric Mann-Kendal test, meteorological and vegetative species data was initially tested for autocorrelation to determine the need for pre-whitening. Auto-correlation is the correlation of a time series with its past and future values (Hamed and Rao, 1998). Its detection would require the data to be pre-whitened. Hamed and Rao (1998) noted that geophysical time series are frequently auto-correlated because of inertia or carryover processes in the physical system. This complicates the application of statistical tests by reducing the number of independent observations thereby increasing the chances of detecting significant trends even if they are absent and vice versa.

Pre-whitening is the process of removing undesirable autocorrelations from time series data prior to analysis. Thus, the data was pre-whitened in Paleontological statistics (PAST 3.0) software using the Autoregressive Integrated Moving Average (ARIMA) model (Hamed and Rao, 1998). The ARIMA model performs time series forecasting and smoothening and project the future values of a series based entirely on its inertia. It takes into account trends, seasonality, cycles, errors and non-stationary aspects of a data set when making forecasts. It reduces residuals to white noise in the time series hence removing the possibility of finding a significant trend in the Mann-Kendall test when actually there is no trend (Von Storch, 1995).

3.8.3 Trend testing

The study tested if there was a significant change in precipitation, temperature and species diversity over a 40 year period (1974-2014) using the Mann-Kendall (MK) trend test which was proposed by Mann, (1945) and further developed by Kendall (1975). The MK test is a non-parametric method commonly employed to detect monotonic trends in series of environmental, climate or hydrological data (Pohlert, 2016). The test is simple, robust, can cope with missing values, and seasonality and values below detection limit (Hirsch *et al.*, 1993; Dietz and Kileen, 1981). An add-in of Microsoft excel, XLSTAT 2015 was used to carry out this test due to its ability to take into account and removing the effect of autocorrelations.

Using the Mann Kendall test, the null hypothesis, H_0, is that there is no trend in the series. Thus, the data come from a population with independent realizations and are identically distributed. The alternative hypothesis, H_1, is that there is a trend in the series. Thus, the data follow a monotonic trend. The Mann-Kendall test statistic is calculated using Equation 4.3:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\ (Xj - Xk) \quad [4.3]$$

where S is the Kendall score. Sgn (x) = {1 if x>0, 0 if x = 0, -1 if x <0} (Mann, 1945)

3.8.4 Interpolation

Species data collected from the sampling plots and meteorological data from the 5 weather stations were first interpolated using the Thiessen polygons approach in a GIS to ensure that all areas are represented by species, temperature and rainfall data. The Thiessen Polygon approach is one of the most common methods used in hydrometeorology for determining average precipitation over an area when there is more than one measurement. The area of the province was divided into several polygons, each around a measurement point. Weighted average of the measurements was taken based on the size of each one's polygon. The weighted average was calculated using Equation 4.4:

$$\bar{P} = \frac{P1A1+P2A2+P3A3........PnAn}{A1+A2+A3.........An} = \frac{\sum_{i=1}^{n} P1A1}{\sum_{i=1}^{n} A1} \quad [4.4]$$

where $\bar{P}$ is the weighted average, P's are measurements, and A's are areas of each polygon.

The interpolated data was then used for regression analysis of vegetative species and meteorological data to establish the relationship between climatic elements and species diversity.

3.8.5 Calculating Species diversity

Species diversity indices were calculated to assess vegetative species diversity throughout the province. Species diversity indices are used to represent the diversity of species within a community. A diversity index is a mathematical measure of species diversity in a specific community. There are two main categories of indices i.e. the dominance and the information statistic index. From each category we selected one species index. Thus the Shannon weaver index (H) and the Simpson's reciprocal index (Simpson 1/D) were used.

3.8.5.1 Shannon Weaver Index

Data on species abundance collected in the field was used to calculate vegetation species diversity using the Shannon Weaver index (H) (Shannon and Weaver, 1949), which combines aspects of richness and evenness. It is an information statistics index which measure the average degree of uncertainty in predicting to what species chosen at random from a collection of *S* species and *N* individuals will belong (Ludwig and Reynolds, 1988). This index was calculated using Equation 4.5:

$$H = -\sum_{i=1}^{s} Pi \ln P \quad [4.5]$$

where Pi is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln is the natural log, Σ is the sum of the calculations, and s is the number of species.

3.8.5.2. Simpson reciprocal 1/D index

Simpson's Diversity Index is a measure of diversity which takes into account both richness and evenness. The term 'Simpson's Diversity Index' can actually refer to any one of the 3 closely related indices i.e. the Simpson index D, Simpson index 1-D and Simpson index 1/D. In this study Simpson Index 1/D was used because it overcomes the problem of counter intuitive nature of the other two indices. The lowest value of this index is 1. This figure implies that the community assessed contains only one species. The higher the value of the index, the greater the diversity of species within the community. The maximum value is the number of species in the sample. For example if there are seven species in the sample, then the maximum possible value is 7. Formula 4.6 was used to calculate diversity:

$$Simpson's\ index\ 1/D = 1/\frac{1}{\sum_{i=1}^{s} Pi2} \qquad [4.6]$$

Where P is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), Σ is still the sum of the calculations, and s is the number of species.

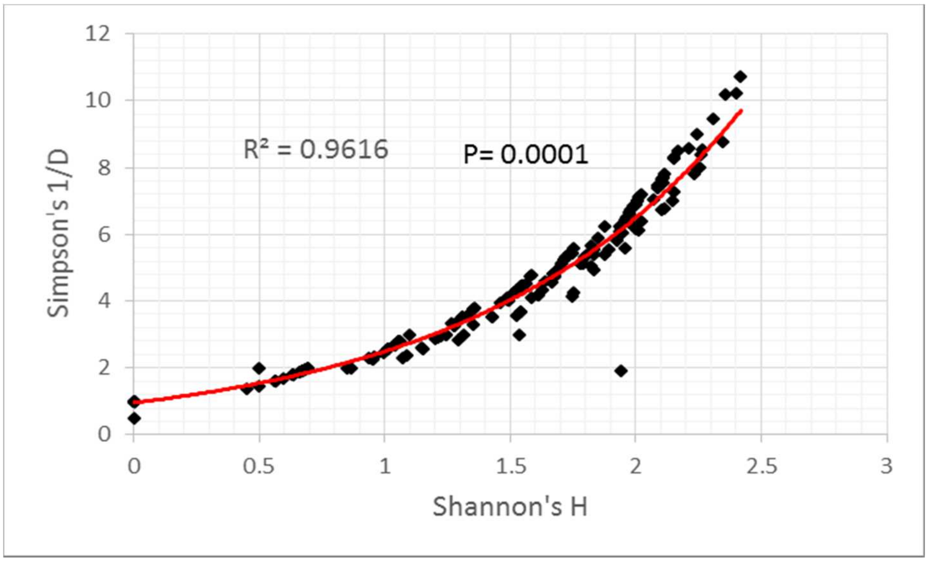


Figure 3.11. Relationship between Shannon’s H and Simpson’s 1/D

To guard against redundancy, the study checked if the use of both diversity indices would not produce the same results. This was done through regression analysis of the two diversity indices. Figure 3.11 shows the results of the analysis. As indicated in Figure 3.11, there is a significant (p=0.0001; α= 0.05) relationship between Shannon weaver index and Simpson’s reciprocal index calculated from vegetation species data from the study sites. It is shown that, for about 96 percent of the times, we are able to predict Shannon's Weaver index from Simpson's 1/D. Therefore, there is no need in this study to use both diversity indices as they produce similar results. The Shannon Weaver index was preferred as it is regarded as the most robust method of calculating biodiversity.

3.8.6 Assessing the relationship between species diversity and climate variables.

The study sought to understand the relationship between vegetative species diversity and climatic elements under the semi-arid conditions of Masvingo province. This would make it possible to construe the effect of changes in climatic variables on species diversity. Temperature related variables such as temperature of the coldest month, temperature of the warmest month, monthly mean maximum temperatures, and monthly mean temperatures were regressed against vegetative species diversity calculated using the Shannon Weaver Index (SWI). Precipitation related variables such as the monthly mean precipitation, precipitation of the warmest quarter, seasonal total precipitation and total annual precipitation were also regressed against the SWI. Vegetative species comprised trees, shrubs and subshrubs. Graminoids were considered separately to guard against computational problems posed when calculating the SWI (H).

3.9 Conclusion

This chapter has illustrated and explained the methods that appropriately address the objectives of the research. Strengths drawn from the mixed methods approach cannot be over-emphasised. The first objective of assessing the trend in climate over a 40year period (1974-2014) has been addressed by collection of rainfall and temperature time series data. The data was analysed using the Mann Kendall trend tests to examine whether the trends are statistically significant. Information about changes in temperature and precipitation characteristics over the period under review was obtained through questionnaire surveys and interviews. The second objective of assessing the relationship between climatic elements and vegetative species diversity was achieved through collection of vegetative species data in sample sites across the province and meteorological data obtained from relevant department and website. Species diversity indices were calculated. After interpolation of all variable data, regression analysis was performed to determine the relationships. The third objective of examining the relationship between remotely sensed data and vegetative species diversity was addressed by the analysis of Landsat imagery to obtain data through NDVI analysis. NDVI provided satellite based data which was regressed with vegetative species diversity indices data. The fourth objective of evaluating changes in vegetative species diversity as influenced by climate change between during the period under review was achieved through analysis of imagery and NDVI maps over the same period and inferring from communities and stakeholders who have been co-existing with the concerned ecosystems.

Chapter 4 : RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents results and discusses findings of the assessment of response of vegetative species diversity to climate change under semi-arid conditions with reference to Masvingo province in Zimbabwe. The results are a product of various data collection and analysis methods which include; field measurements and observations of vegetative species, downloading, processing and analysis of Landsat imagery, interpolation and statistical analysis of climate data obtained from the National Climate Data Centre (NCDC) and Zimbabwe Meteorological Department (ZMD), statistical analysis of georeferenced plant species data obtained from Zimbabwe National Herbarium and Botanic Gardens and questionnaire surveys distributed to local people to obtain information about their perceptions of climate change and its impacts on vegetative species diversity. Both qualitative and quantitative data were collected given the mixed research method design that was adopted.

The results and discussions are presented following the order of the specific objectives and research questions presented in chapter one. In this regard, the chapter first presents the climate trend covering a period of forty years (1974 – 2014). Presentation and discussion of the climatic trends, focusing on rainfall and temperature related variables serves to examine the existence of the climate change phenomenon in the province. This would justify the need to study its impacts on vegetative species diversity. While some studies (Chapungu and Nhamo, 2016; Chikodzi and Mutowo, 2014; Simba *et al.*, 2012) have already hinted on the existence of climate change in some parts of the province, this study further examines the phenomenon at provincial level using several bioclimatic variables different from those used by other authors to confirm the occurrence of climate change.

In summation, the results show statistically significant climate change in Masvingo province over the forty years period under review. The monthly mean, monthly mean maximum and monthly mean minimum temperatures recorded between 1974 and 2014 indicate a warming trend through time. The annual total rainfall records over the same period show a decreasing trend and an increase in inter-annual variability. Views from local communities confirm statistical observations that the climate in the province is changing over time. Given the influence of temperature and rainfall on plant species growth, the changing climatic conditions have triggered phenological, compositional and physical characteristics changes in vegetation communities in the province. These results sanction the feasibility of assessing changes in vegetative species diversity as a consequence of statistically and qualitatively proven changing climate.

Secondly, the chapter presents and discusses results on the relationship between vegetative species diversity and climatic elements. The purpose is to determine whether various rainfall and temperature related variables affect vegetative species diversity or not. Spatial rainfall and temperature data was regressed against spatial vegetative species diversity data. Results show significant correlations between climatic and vegetation diversity indices. Thus, climate variables data may be used in predicting vegetative species diversity.

Third, the chapter presents and discusses results on the relationship between vegetative species diversity and remotely sensed vegetation indices, specifically NDVI with the aim of considering RS in biodiversity assessment. Results indicate a positive correlation between vegetative species diversity and NDVI. This enables assessment of vegetative species diversity changes over time (since 1974) through analysis of satellite data.

Lastly, the chapter presents results on the evaluation of changes in vegetative species diversity between 1974 and 2014 due to influence of changes in climatic conditions over the same period. NDVI maps are used to show the changes in species diversity over time. Significant changes are observed on NDVI maps over the period under review.

4.2 Climate change trends in Masvingo province from 1974 to 2014.

An analysis of time series temperature and rainfall data recorded over a period of 40 years was performed to determine how climate change has impacted on species diversity in a semi-arid environment. Temperature and rainfall are the most important climatic elements used as proxies for climate change detection (Warburton and Schulze, 2005; Kruger and Shongwe, 2005; Warburton *et al.*, 2005; New *et al.*, 2011). These elements were used in this study to determine the existence or non-existence of the climate change phenomenon in Masvingo province. The objective was to statistically and qualitatively show that climate change has occurred over the period under review. This enables assessing the impacts on vegetative species diversity.

A total of 8 bioclimatic variables were analysed (Table 4.1), which also include, the trend equation, the p value and a description of the trends.

Table 4.1. Bioclimatic variables explaining climate change in Masvingo province.

Climate Change Variable	Trend Equation	*p*-Value	Description of trend
Monthly mean max temperature	y= 0.0327x-38.399	0.001	Significant change/ increasing trend
Monthly mean temperature	y=0.0187x-17.651	0.002	Significant change/ increasing trend
Max temperature of warmest month	y=0.863x-89.854	0.011	Significant change/ increasing trend
Min temperature of the coldest month	y=-0.0445x+89.269	0.043	Significant change/Declining trend
Total annual precipitation	y=-4.7883x+10116	0.049	Significant change/Declining trend
Monthly mean precipitation	y=0.4203x+88534	0.046	Significant change/Declining trend
Precipitation of the warmest quarter	y=3.4206x+7137.3	0.048	Significant change/Declining trend
Seasonal maximum precipitation	y=4.4614+60021	0.323[a]	Not significant/ Declining trend

[a] *Trend not significant at α=0.05*

Seven out of the 8 (82.5%) assessed variables show a significant trend in climatic variables that explain that climate is changing (Table 4.1). Temperature related variables are showing a generally increasing trend indicating that the atmosphere is getting warmer with time. On the other hand precipitation related variables are showing a declining trend implying a decline in the amount of rainfall received in the province over time.

4.2.1 Temperature

Temperature data over the 40 years period was analysed to determine the statistical significance of different temperature related variables. Bioclimatic variables considered under temperature include the monthly mean maximum temperatures, monthly mean temperatures, maximum temperatures of the warmest month and minimum temperatures of the coldest month. These variables are considered important as they determine major climatic shifts over a long period of time. Gwitira *et al.*, (2013) have shown that these variables are important especially when determining effects of climate change on plant species diversity.

4.2.1.1 Monthly mean maximum temperatures.

Results from the Mann-Kendall trend tests show statistically significant (p= 0.001, α = 0.05) changes in monthly mean maximum temperatures in Masvingo province. The trend is shown in Figure 4.1. The linear model presented shows an increase in mean maximum temperatures from 1974 to 2014.

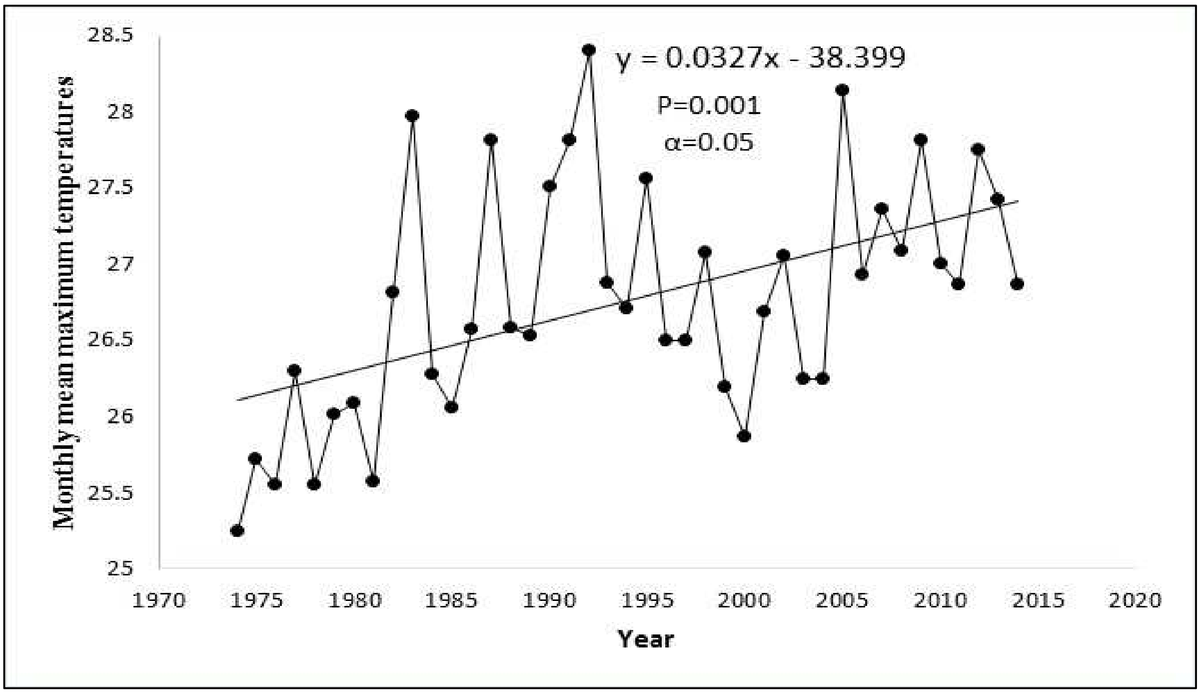


Figure 4.1. Monthly mean maximum temperatures from 1974 to 2014

The null hypothesis proposed in order to test the trend is that there is no trend in the monthly mean maximum temperature data while the alternative hypothesis suggests that there is a trend in the data. Formerly stated:

H_0: There is no trend in monthly mean maximum temperatures from 1974 to 2014.

H_1: There is a trend in the monthly mean maximum temperatures from 1974 to 2014.

Where H0 is the null hypothesis and H1 is the alternative hypothesis.

As the *p*-value (0.001) is lower than the significance level alpha (0.05), the null hypothesis that there is no trend was rejected. The exact approximation method to the distribution of the average Kendall tau shows that the risk of rejecting the null hypothesis while it is true is 0.14%. Further trend analysis reveals that, over the period 1974 – 2014, the monthly mean maximum temperatures increased by 0.330C per decade over the period.

4.2.1.2 Monthly mean temperatures

Mann-Kendall trend tests reveal a significant (P=0.002 α=0.05) trend in monthly mean temperatures between 1974 and 2014. The trend is shown in Figure 4.2. The linear model for the trend shows that the monthly mean temperatures increased over the period.

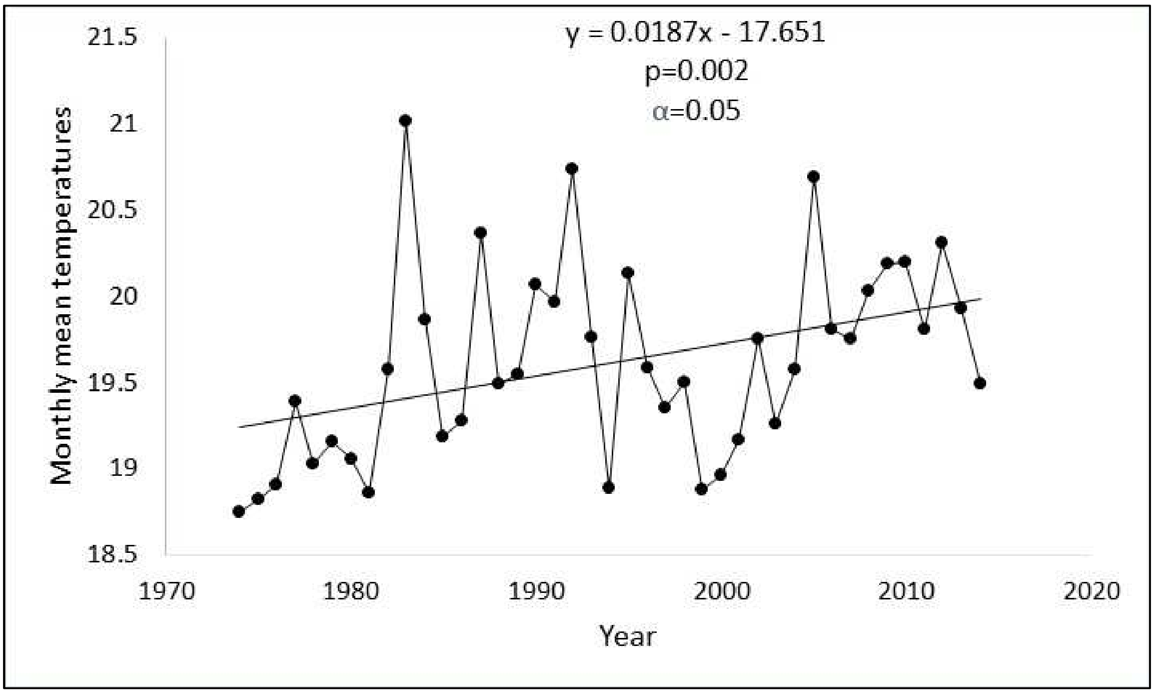


Figure 4.2. Monthly mean temperatures from 1974 to 2014.

The null hypothesis was that there is no trend in monthly mean temperatures whilst the alternative hypothesis was that there is a trend in the temperatures. Formerly stated:

H_0: There is no trend in monthly mean temperatures from 1974 to 2014.

H_1: There is a trend in the monthly mean temperatures from 1974 to 2014.

Where H0 is the null hypothesis and H1 is the alternative hypothesis.

The P-value (p=0.002) of the trend data is lower than the significance level alpha (0.05). This means that the null hypothesis that there is no trend in monthly mean temperatures between 1974 and 2014 should be rejected. The normal approximation to the distribution of the average Kendall tau shows that the risk of rejecting the null hypothesis while it is true is 0.17%. Further trend analysis reveals that, over the period 1974 – 2014, the monthly mean temperatures increased by 0.27^{0}C per decade over the period.

4.2.1.3 Maximum temperature of the warmest month

Figure 4.3 shows the trend for maximum temperature of the warmest month. The warmest month considered under this study is October. Selection of the month was based on a preliminary analysis of temperature characteristics of all months over a thirty year period 1974-2004.

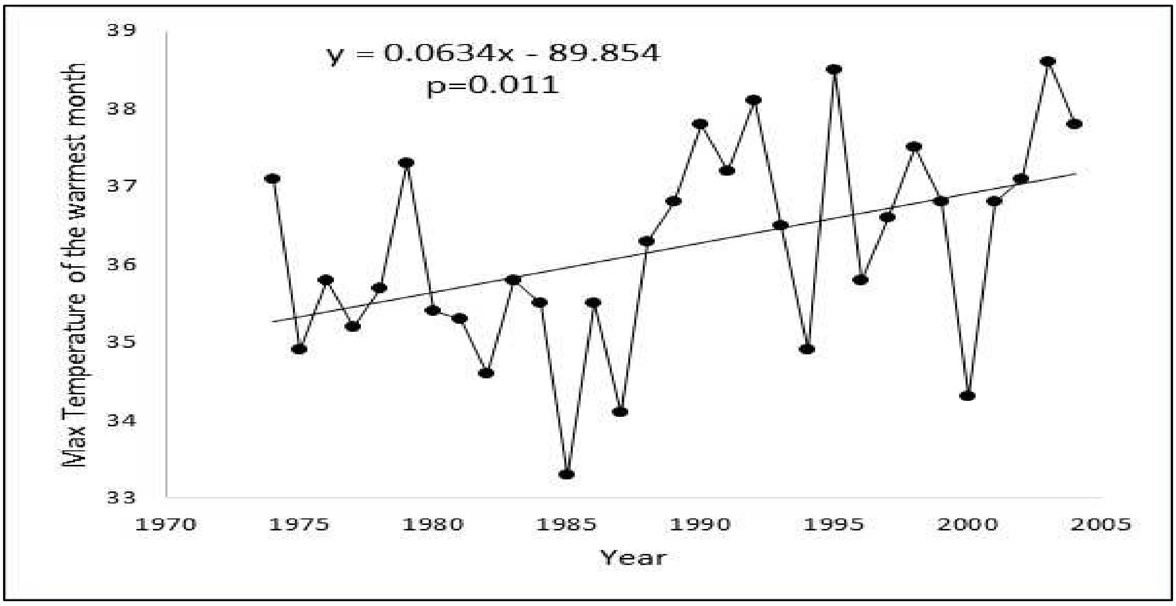


Figure 4.3. Trend for maximum temperature of the warmest month over a 30 year period

The Mann-Kendall trend tests reveal a significant (p=0.011; α=0.05) trend in maximum temperatures of the warmest month. The null hypothesis was that there is no trend in the maximum temperatures of the warmest month over the 30 year period. The alternative hypothesis was that there is a trend in these temperatures. As the computed p- value is lower than the significant level alpha 0.05, the null hypothesis is rejected. The risk to reject the null hypothesis while it is true is 1.07%.

4.2.1.4 Minimum temperatures of the coldest month

The study considered changes in the minimum temperatures of the coldest month as an appropriate proxy indicator for climate change. Gwitira *et al.,* (2013) shows this indicator as a good predictor of plant species richness under a changed climate. Figure 4.4 shows the trend for minimum temperatures of the coldest month. The coldest month was determined through analysis of minimum temperatures of all months over a 30 year period.

As shown in Figure 4.4, minimum temperatures of the coldest month in the province are decreasing significantly (p=0.043; α= 0.05) with time. The null hypothesis is that there is no trend in the minimum temperatures of the coldest month whilst the alternative hypothesis posited that there is a trend. Given that the computed p- value (0.043) is lower than the significance level alpha 0.05, the null hypothesis is rejected. An approximation to the distribution of the average Kendall tau shows that the risk of rejecting the null hypothesis while it is true is 4.33%.

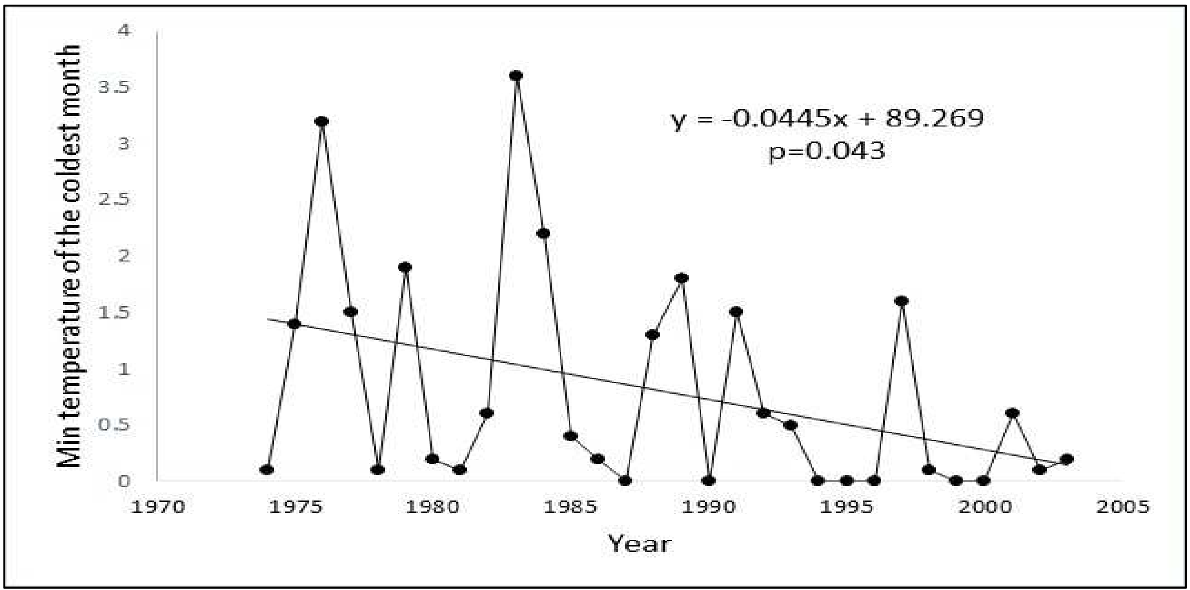


Figure 4.4. Trend of minimum temperatures of the coldest month (June) over a 30 year period.

4.2.1.5 Perceptions on temperature changes between 1974 and 2014.

A qualitative analysis of temperature changes in Masvingo was performed to confirm the validity of quantitative claims presented in this chapter. This was based on views that were gathered through qualitative instruments like questionnaires and key informant interviews. Figure 4.5 presents the views of local people across the province and the percentage of respondents for each view. As shown in Figure 4.5, most of the respondents indicated that the temperature related variables in the province are changing over time. They either agree or strongly agree to the fact that the temperatures are increasing through observed changes in temperature related bioclimatic variables such as monthly mean maximum temperatures,

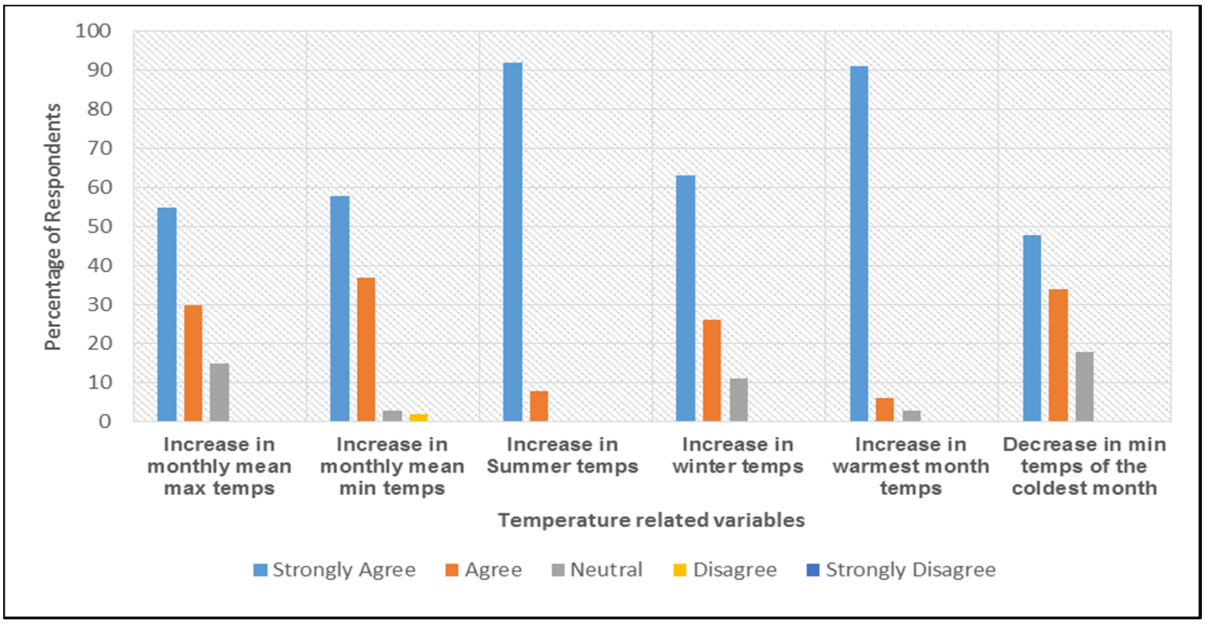


Figure 4.5. Perceptions of local people on long term temperature changes.

monthly mean minimum temperatures, winter temperatures, summer temperatures, minimum temperatures of the coldest month and maximum temperatures of the warmest month.

It is observed that out of a total of 189 people interviewed, 55% of the respondents strongly agree that the monthly mean maximum temperatures within the province have increased. About 30% generally agree to this view whilst 15% was neutral. None of the respondents indicated that the monthly mean maximum temperatures are not increasing with time. These views confirm the statistical trend test results that show a significant change in the trend of monthly mean maximum temperatures in the province.

Whilst only 2 percent of the respondents do not agree with the view that monthly mean minimum temperatures are increasing over time, most of the respondents (approximately 95%) perceive monthly mean minimum temperatures to have increased between 1974 and 2014. Approximately 58% of the respondents strongly agree that monthly mean minimum temperatures have increased over the period whist 37% are in agreement with this view. Only 3% of the respondents indicated that they are not sure as they remained neutral.

Furthermore, as shown in Figure 4.5, local people confirm the increase in winter and summer temperatures in the province. About 92% of the respondents indicated that they strongly concur with the view that summer temperatures are increasing while the remaining 8% agree with this view. For winter temperatures, 63% of the respondents strongly agree that there is an increase whilst about 27 percent agree with this view from their experience and observation. 11% showed neutrality to this view. In addition, according to the observations from local people, maximum temperatures of the warmest month have increased between 1974 and 2014. Over 90 percent of the respondents strongly agree whilst 5% agree with this perception. Only less than 4% of the respondents indicated neutrality to the notion.

The study also investigated perceptions on the pattern of minimum temperatures of the coldest month over the period 1974-2014. Results show that most of the respondents either strongly agree or agree that there has been a decrease. About 48% of the respondents indicated that they strongly agree that there was a decrease in the minimum temperatures of the coldest month whilst 34% agree with this conception. However, 18% indicated that they neither agree nor refute to this claim.

In general, results have shown that none of the respondents have observed consistently unchanging patterns in temperature regimes of the province over the period under investigation. These qualitative findings confirm the quantitative results established under this study through a quantitative analysis of meteorological data obtained from ZMSD and the NCDC.

4.2.2 Precipitation

Precipitation is an important proxy indicator for climate change, widely used in several analyses of climate change (Ngongondo *et al.,* 2011; Mazvimavi 2010; Kane 2009; Sichingabula, 1998). In this study, precipitation data for the period 1974 to 2014 was analysed to determine the statistical significance in the trends of different precipitation related variables. The variables considered under precipitation include total annual precipitation, monthly mean precipitation, precipitation of the warmest quarter and seasonal total precipitation. The variables significantly depict climatic shifts over a long period of time. Gwitira *et al.,* (2013) have shown that these variables are important especially when determining effects of climate change on plant species diversity.

4.2.2.1 Total annual precipitation

Total annual precipitation is the sum of all precipitation received and recorded throughout the year under consideration. In this study, the total annual precipitation over a forty year period (1974-2014) for Masvingo province was analysed to determine the trend. Results show that there is a statistically significant (p=0.049, α=0.05) trend (Figure 4.6). The trend line equation shows that the amount of rainfall recorded throughout the year decreased with time over the period.

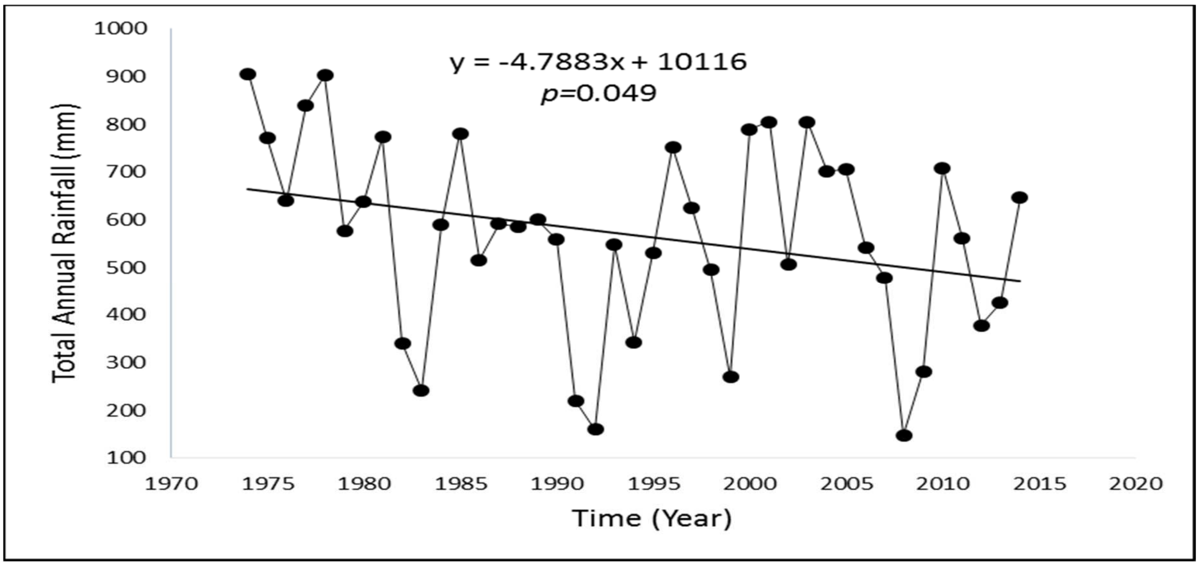


Figure 4.6. Trend for total annual rainfall from 1974 to 2014

As shown in Figure 4.6, the total annual rainfall for the province is decreasing with time. The null hypothesis is that there is no trend in the total annual precipitation between 1974 and 2014 whilst the alternative hypothesis is that there is a trend in the rainfall pattern. Formally stated:

H_0 = there is a no trend in the total annual rainfall from 1974 to 2014 in

H_1 = there is a trend in the total annual rainfall from 1974 to 2014 in

Where H_0 is the null hypothesis and H_1 is the alternative hypothesis.

Results show that the *p* value (0.049) is lower than the significance level alpha 0.05. The null hypothesis should therefore be rejected. The risk to reject the null hypothesis H_0 while it is true is 4.90%.

4.2.2.2 Monthly mean precipitation

The monthly mean precipitation from 1974 to 2014 was analysed to determine if there is a significant trend that would depict a changing climate. Results (Figure 4.7) show that there is a significant (p = 0.046, α= 0.05) trend in mean monthly precipitation over the period.

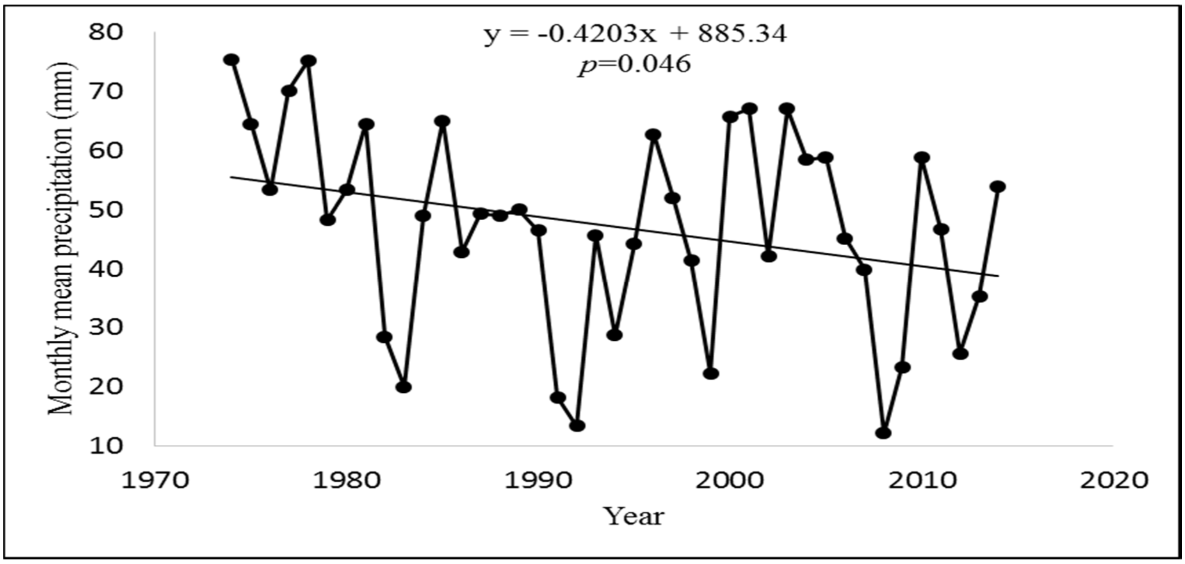


Figure 4.7. Monthly mean precipitation from 1974 to 2014.

As shown in Figure 4.7, there is a declining trend in mean monthly precipitation and the decline is significant. In the statistical analysis, the null hypothesis was that there is no trend in the time series data of mean monthly precipitation. The alternative hypothesis was that there is a trend in the time series. Formerly stated:

H_0 = There is no trend in the monthly mean precipitation for Masvingo

H_1 = There is a trend in the monthly mean precipitation for Masvingo province

Where H_0 is the null hypothesis and H_1 is the alternative hypothesis.

As the computed *p*-value is lower than the significance level alpha (α= 0.05), the null hypothesis is rejected and it is concluded that there is a significant trend in the monthly mean rainfall over time. The approximation of the distribution shows that the risk to reject the null hypothesis whilst it is true is 4.55%.

4.2.3.3 Precipitation of the warmest quarter

The warmest quarter is the three month period which receives the highest amount of radiation and consequently temperatures throughout the year. In the subtropical region in general and Zimbabwe in particular, this period falls between October and December. In this study, precipitation data for the warmest quarter from 1974 to 2014 was analysed to determine the characteristics of the rainfall received. Mann-Kendall trend tests reveal a statistically significant (p=0.048, α = 0.05) trend over the period (Figure 4.8).

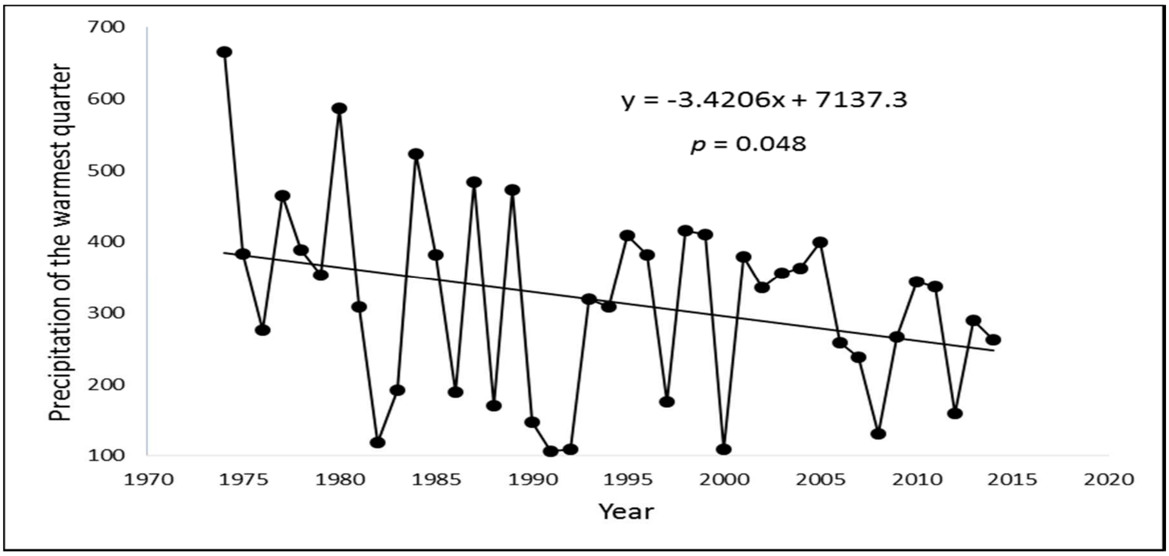


Figure 4.8. Trend of precipitation of the warmest quarter from 1974 to 2014

The trend in figure 4.8 indicates declining precipitation totals for the warmest quarter of the year over time. In the statistical tests, the null hypothesis is that there is no trend in the series whilst the alternative hypothesis states that there is a trend in the series. Formerly stated:

H_0: There is no trend in the precipitation of the warmest quarter from 1974 to 2014

H_1: There is a trend in the precipitation of the warmest quarter from 1974 to 2014

Where H_0 is the null hypothesis and H_1 is the alternative hypothesis.

Results of the Mann-Kendall trend tests using the approximation method show that the p value (0.048) is lower than the significance level (α = 0.05). The null hypothesis was therefore rejected whilst accepting the alternative hypothesis. The probability for rejecting the null hypothesis whilst it is true is 4.80%.

4.2.2.4 Seasonal total precipitation

Precipitation data for the rain season from 1974 to 2014 was analysed to determine the trend. Figure 4.9 shows the results of Mann-Kendall trend tests, which reveal that there is no significant (p=0.323; α = 0.05) trend in the series. However a gradually declining trend can be observed over time.

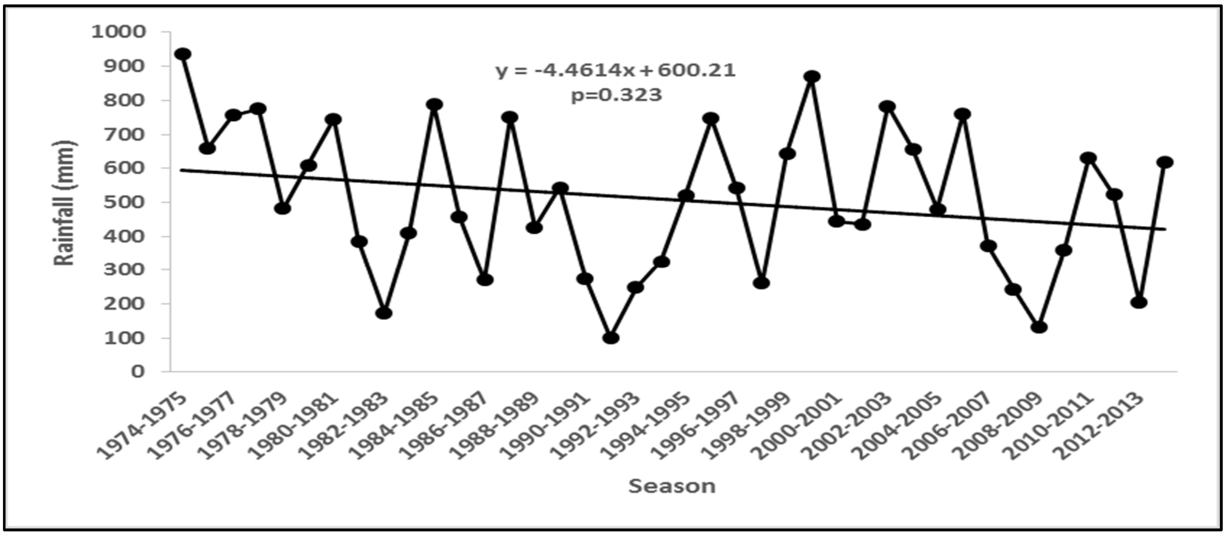


Figure 4.9. Trend in seasonal total precipitation from 1974 to 2014

In this analysis, the null hypothesis that there is no trend in the series was accepted given that the P value (0.323) is greater than the significance level (α = 0.05). However, there is a noticeable decline in the seasonal totals although the trend is not statistically significant. The decline may cause environmentally significant changes in the ecosystems. More so, it is observed in the trend that there is an increase in the inter-annual variability of precipitation with time. These results confirm findings by other authors who used seasonal total rainfall to assess climate change phenomenon in southern Africa. For example, Mazvimavi (2010) concluded that changes in seasonal rainfall are currently not statistically detectable but a declining trend can be observed. Moreover, climate change could be explained by the increasing inter-annual variability of rainfall observed in the trend.

4.2.2.5 Perceptions on precipitation changes

The study analysed views of local people with regards to their experiences with the precipitation regimes obtaining in the province. Figure 4.10 shows how the respondents rated the precipitation regimes over the four decades under analysis. The higher the score, the higher the amount of precipitation received during the specific decade.

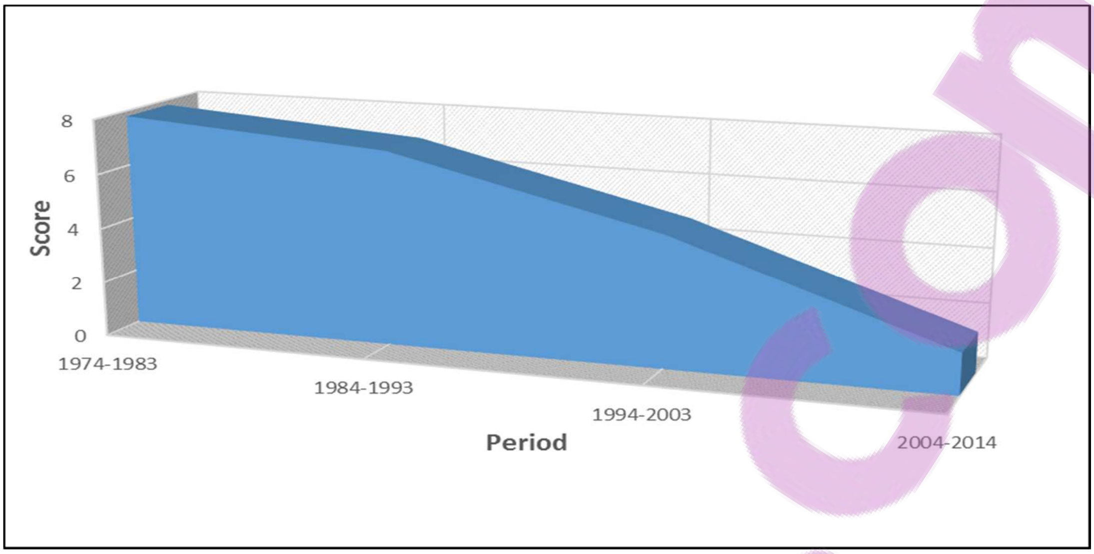


Figure 4.10. Changes in precipitation regimes over time as understood by local people

A score of 10 indicates high amount of rainfall received which was evenly distributed throughout rainy season whilst a score of 0 means very little rainfall was received and its distribution was not even. As shown in Figure 4.10, the local people perceive the precipitation amount received to be decreasing over time. During the period 1974 to 1983, the respondents indicated that the amount of rainfall was high but started declining in the preceding decade and the trend continued in the succeeding decades. The respondents viewed 2004-2014 as the driest period since 1974. These sentiments are in sync with the statistical results for various precipitation related variables which show a declining trend of precipitation over time.

Table 4.2 also shows descriptions of precipitation variables by local residents. About 73% of the respondents indicated that they strongly agree that annual rainfall totals are decreasing with time. 20% indicated that they agree to this view while 7% were not sure. As shown in table 4.2, all of the variables are shown to be decreasing with time according to most of the respondents who either strongly agree or agree. A small fraction in all cases indicated that they are not sure.

The respondents reported an increase in the severity and frequency of droughts. Furthermore, there is an increase in the intensity of floods occurring in the province as reported by 98% of the respondents who either strongly agreed or agreed with this view. In general, variable descriptions by local people have shown that climate change is occurring as indicated by the long term changes in specific precipitation related variables.

Table 4.2. Responses of local residents on precipitation related climate change indicator variables

Variable description	S .A	A.	D.K	Total (%)
Decrease in annual rainfall	73	20	7	100
Reduced length of the rainy season	95	5	0	100
Decrease in seasonal total precipitation	67	15	18	100
Decrease in precipitation of the warmest quarter	71	12	17	100
Decrease in monthly average precipitation	33	55	12	100
Increase in drought severity over time	89	11	0	100
Increase in drought frequency	93	6	1	100
Increase in inter-annual variability	67	26	7	100
Increase in flood intensity	58	40	2	100

4.3 Vegetative species diversity and climate in Masvingo Province

Table 4.3. Results of regression of vegetative species diversity by climatic variables in Masvingo

Regression Variables	Regression equation	Correlation coefficient (r)	*p* Value	R^2	Description
SWI (H) and monthly mean precipitation	$Y=-0.0007x^2 + 0.1164x-3.0143$	0.794	<0.001	0.6736	The variability of vegetation diversity is explained by monthly mean precipitation
SWI (H) and precipitation of the warmest quarter	Y=-2E-05x2 + 0.0214x-2.7324	0.734	<0.001	0.6455	The variability of vegetation diversity is explained by precipitation of the warmest month
SWI (H) and seasonal total precipitation	Y=-2E-05x2 + 0.0221x-3.1459	0.702	<0.001	0.5841	The variability of vegetation diversity is explained by seasonal total precipitation
SWI (H) and total annual precipitation	Y=-8E-06x2 + 0.0111x-1.7054	0.703	<0.001	0.6261	The variability of vegetation diversity is explained by total annual precipitation
SWI (H) and temperature of the coldest month	Y= 0.5211x-0.834	0.706	<0.001	0.4979	The variability of vegetation diversity is explained by temperature of the coldest month
SWI (H) and temperature of the warmest month	Y=0.0171x2 + 0.9883x-12.105	-0.799	<0.001	0.6706	The variability of vegetation diversity is explained by temperature of the warmest month.
SWI (H) and monthly mean maximum temperatures	Y= 0.0078x2 + 0.2377x + 0.329	-0.776	<0.001	0.6223	The variability of vegetation diversity is explained by monthly mean maximum temperatures
SWI (H) and monthly mean temperatures	Y= -0.337x2 + 13.137x-126.22	-0.126	<0.001	0.6943	The variability of vegetation diversity is explained by monthly mean temperatures

NB: SWI=Shannon Weaver Index (H).

Results of regression analysis of vegetative species diversity and climate related variables are presented in table 4.3. Vegetative species diversity is represented by the SWI. In general, the results show positive correlations between vegetative species diversity and all of the climatic variables. For precipitation related variables, the monthly mean precipitation best explains vegetative species diversity while for temperature related variables monthly mean temperatures have the best coefficient of determination.

4.3.1 Vegetative species diversity and precipitation related variables

Results of regression analysis of SWI by precipitation related climate variables (mean monthly precipitation, total annual precipitation, seasonal total precipitation and precipitation of the warmest quarter) are shown in Figure 4.11, where that the four precipitation related climate change variables positively describe the diversity of vegetative species in Masvingo Province. Results indicate that there is a positive correlation (r=0.794) between SWI (H) and mean monthly precipitation. It is observed that 67% of vegetative species diversity is significantly (p<0.001) predicted by monthly mean precipitation (figure 4.11a).

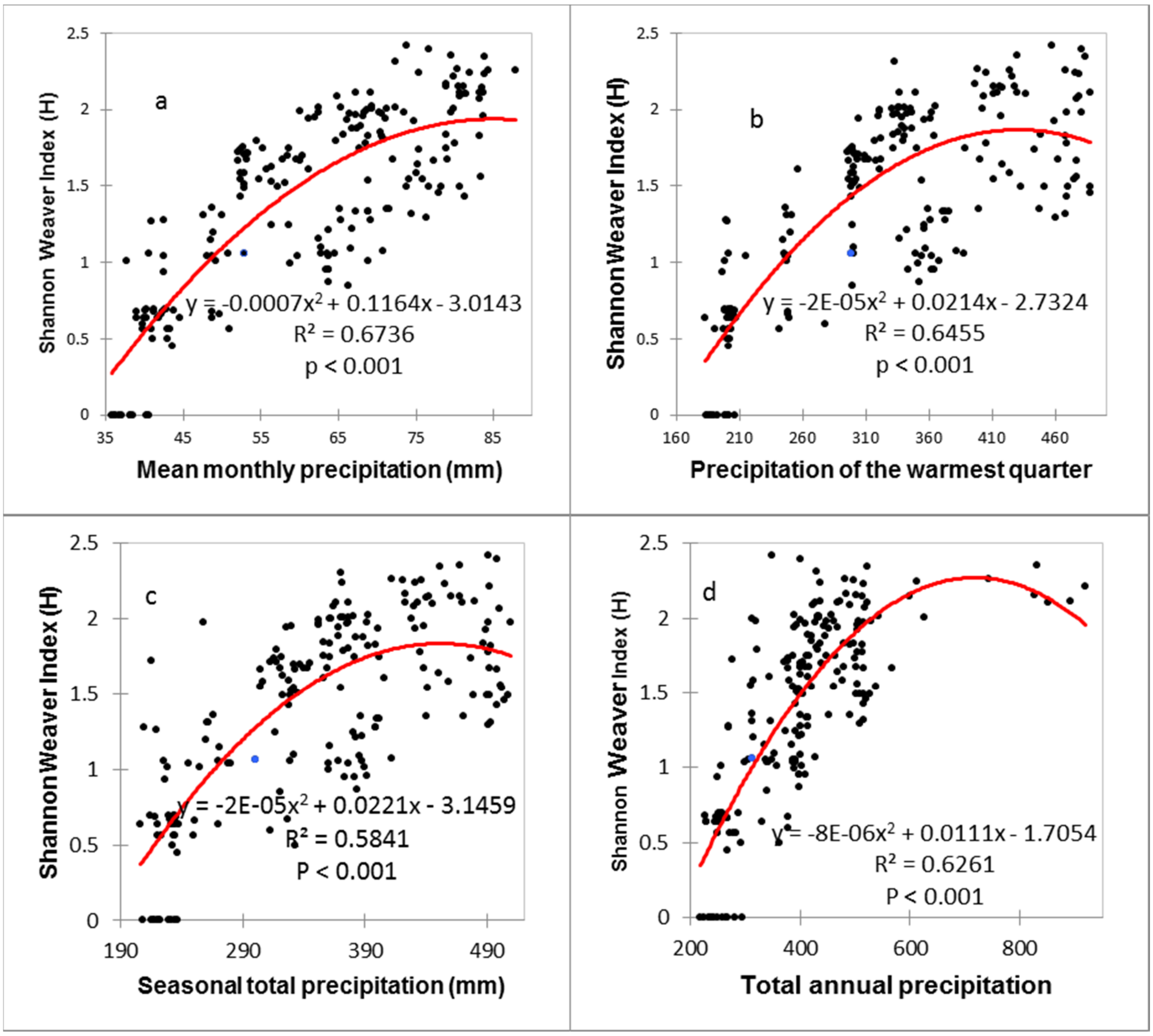


Figure 4.11. Regression of the Shannon Weaver diversity Index (H) by precipitation related variables (a) Mean monthly precipitation (b) Precipitation of the warmest quarter (c) Seasonal total precipitation and (d) Total annual precipitation.

From the regression equation of the two variables, the diversity of vegetative species increases with an increase in mean monthly precipitation. However, an increase beyond 80 mm mean rainfall does not correspond with an increase in vegetative species diversity.

Similarly, precipitation of the warmest quarter explains vegetative species diversity in Masvingo province (Figure 4.11b). There is a positive correlation (r=0.734) between H and precipitation of the warmest quarter (October to December). About 65% of the diversity of vegetation species is significantly (p<0.001) predicted by precipitation of the warmest quarter. The results show that as precipitation of the warmest quarter increases, vegetative species diversity also increases but an increase beyond 430mm is not associated with an increase in species diversity.

In addition, seasonal total precipitation plays an important role in determining the diversity of ecosystems in Masvingo Province. This is shown by the positive correlation (r=0.702) between Shannon's H and seasonal total precipitation. Figure 4.11c indicates that 58% of vegetative species diversity is significantly (p<0.001) explained by seasonal total rainfall. Regression of the two variables shows that as seasonal total precipitation increases, species diversity also increases. Similar to other precipitation related variables, a continuous increase in seasonal total rainfall does not correspond to continuous increase in vegetative species diversity. Seasonal total precipitation above 450mm does not influence changes in species diversity.

Furthermore, total annual precipitation has been shown to influence species diversity as there is a strong positive correlation (r=0.703) between the two variables. It is shown in figure 4.11d that about 63% of vegetative species diversity in Masvingo province is significantly (p< 0.001) explained by total annual precipitation in the area. Regression of the two variables shows that an increase in total annual precipitation corresponds with an increase in the diversity of vegetative species. However, an increase above 750mm does not support an increase in the diversity of species.

4.3.2 Vegetative species diversity and temperature related variables

Figure 4.12 shows the results of regression of SWI (H) by temperature related climate change variables. In general, the temperature variables explain diversity of vegetative species.

Maximum temperatures of the warmest month in Masvingo province ranged from 30^{0}C to 39^{0}C during the period under investigation. Results show a strong negative correlation (-0.799) between the Shannon weaver index of diversity H and maximum temperatures of the warmest month. As shown in figure 4.12a, about 67% of vegetative species diversity is significantly (P<0.001) explained by maximum temperature of the warmest month. An increase in maximum temperature of the warmest month is related to a decrease in vegetative species diversity. At temperatures of 39^{0}C and above, the diversity of species is extremely low.

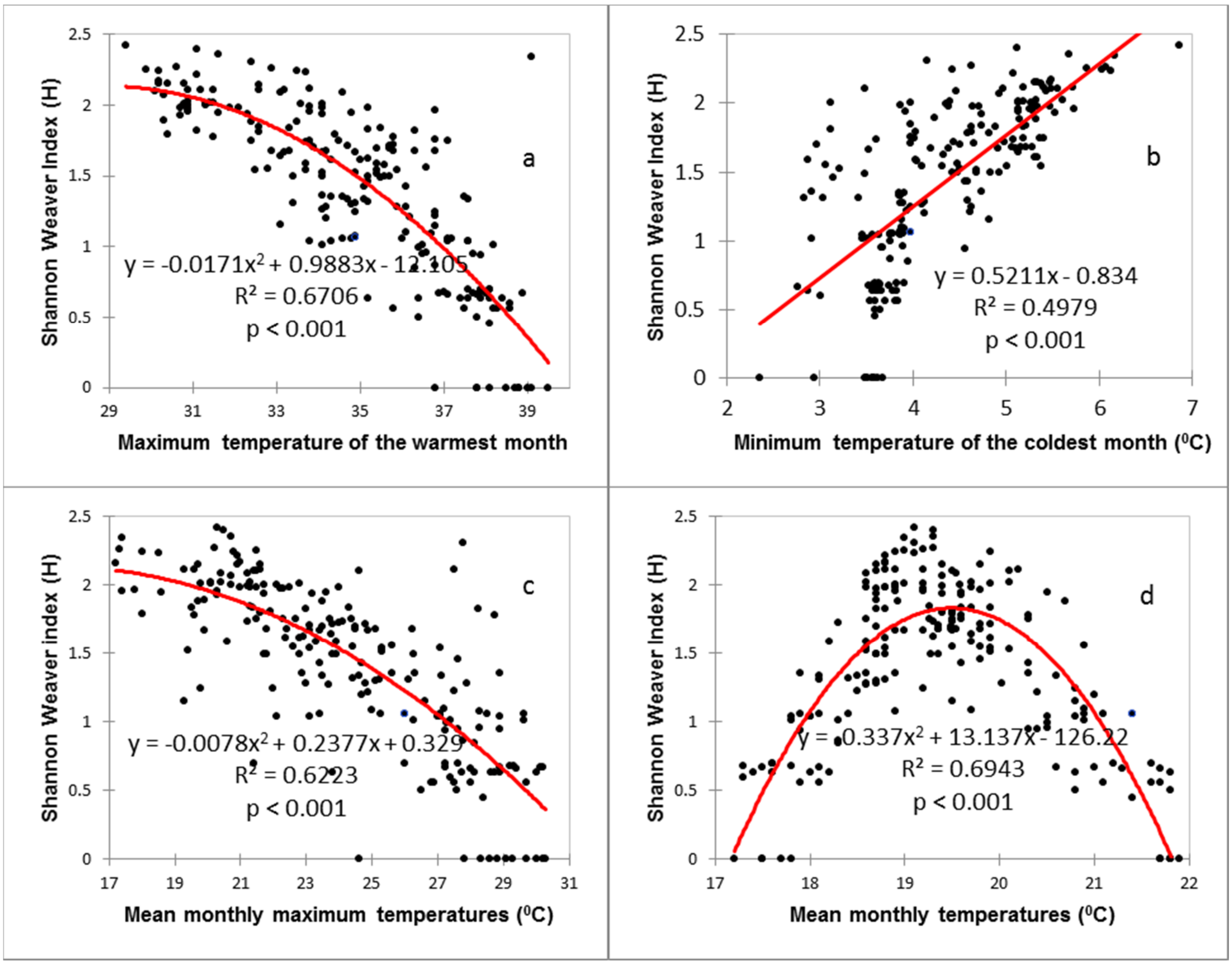


Figure 4.12. Relationship between vegetative species diversity (Shannon Weaver Index) and temperature related climate change variables (a) maximum temperature of the warmest month (b) minimum temperature of the coldest month (c) mean monthly maximum temperatures and (d) mean monthly temperatures.

Linear regression analysis shows that vegetative species diversity can be explained by minimum temperatures of the coldest month. Figure 4.12b shows a positive correlation (r=0.706) between the vegetative species diversity and minimum temperatures of the coldest month. It is illustrated that about 49% of the vegetative species diversity in Masvingo province is significantly (p<0.001) explained by minimum temperatures of the coldest month. The minimum temperatures of the coldest month in the province are ranging from 2.4^{0}C to approximately 7^{0}C. An increase in these temperatures is associated with an increase in vegetative species diversity.

Similarly, mean maximum monthly temperatures explain plant species diversity in Masvingo province (Figure 4.12c). Results indicate that the mean maximum monthly temperatures in the province range from 17^{0}C to 30.8^{0}C. There is a strong negative correlation (r=-0.776) between these temperatures and vegetation diversity. As shown in figure 4.12c, about 62 % of vegetative species diversity in the province can be explained by mean maximum monthly temperatures. Thus, an increase in mean maximum monthly temperatures is associated with a decrease in vegetative species diversity.

In addition, regression analyses results show that vegetative species diversity is a significant (p<0.05) function of the mean monthly temperatures under semi-arid conditions of Masvingo province. There is a hump-shaped relationship between the two variables. Thus, it is observed that as the mean monthly temperatures increase, vegetative species diversity also increases. However, further temperature increase beyond 19.8^{0}C is associated with a negative response from vegetation diversity.

The study also assessed the views of people with regards to the changes in vegetative species diversity in the province over the period under investigation following the perturbations in climatic patterns. Figure 4.13 shows vegetative species diversity dynamics in Masvingo Province as viewed by the respondents. Scores depict the level of a phenomenon as observed by people residing in the province. A high score is reflective of high level of a specified phenomenon. It is observed that invasive species richness has been increasing in the province since 1974. There has been a sharp increase in invasive species from 1974 to 1987. This increase slowed down afterwards. While there has been an increase in invasive alien species, indigenous tree species richness has been decreasing, the steepest decline being observed from 1994 to 2014.

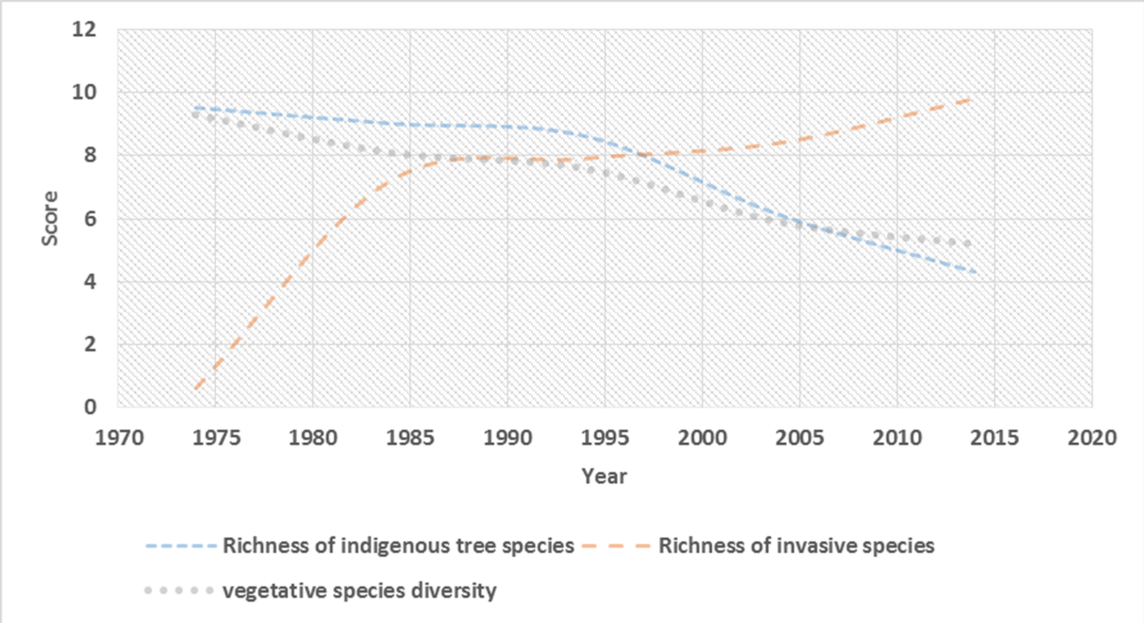


Figure 4.13. Vegetative species diversity dynamics between 1974 and 2014 as viewed by local people

Overall, it is shown that vegetative species diversity has been on the decline over the period under review. The decline is associated with changes occurring in climatic elements (Figure 4.14). Respondents reported that they have observed changes in vegetative species diversity and this change can be attributed to the changes in temperature and precipitation regimes as well as events such as extreme droughts, floods and strong sporadic winds.

Figure 4.14 shows the perceptions of local people with regards to the effect of climate change related variables on vegetative species diversity. It is shown that more than 80% of the respondents concur with the view that the increase in surface and atmospheric temperatures in Masvingo province contributes to the changes in vegetative species diversity. Most of the respondents (more than 90%) reported that from their experience, the decrease in precipitation over the period under investigation has significantly resulted in the decrease in vegetative species diversity. In addition, more than 50% of the respondents think that climate related events such as floods, frequent droughts and very strong winds have significantly contributed to the changes in vegetative species diversity in the province.

Views of local people are in concurrence with statistical data which has shown significant correlations between diversity and most of the climatic elements.

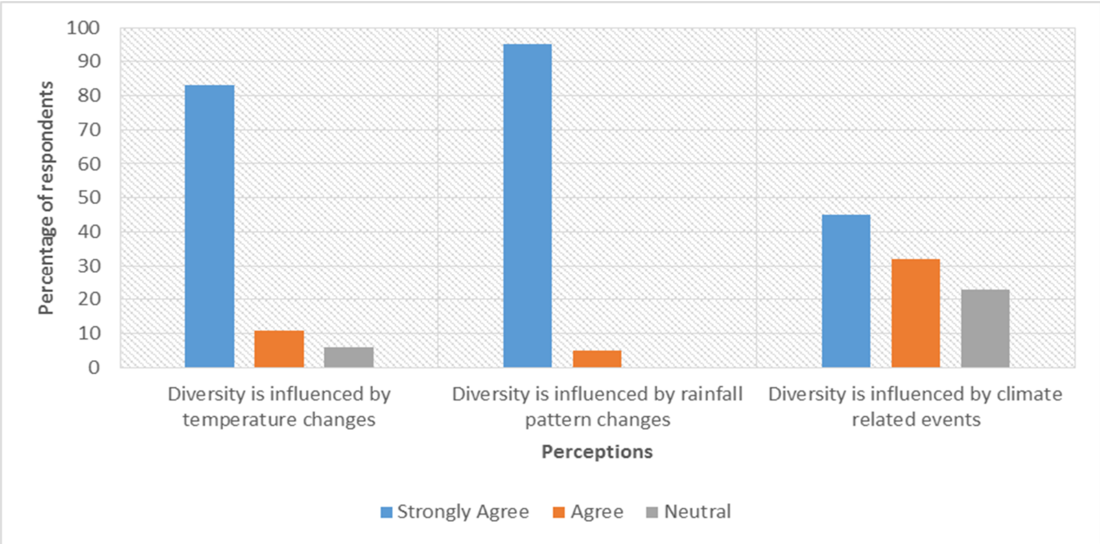


Figure 4.14. Perceptions of respondents on the association between changes in vegetative species diversity and climate elements

4.4 Relationship between NDVI and Species diversity

There is a significant (P<0.001) relationship between NDVI and SWI (H) (Figure 4.15). The SWI is used to express vegetative species diversity including species of trees, shrubs, herbs and tall graminoids.

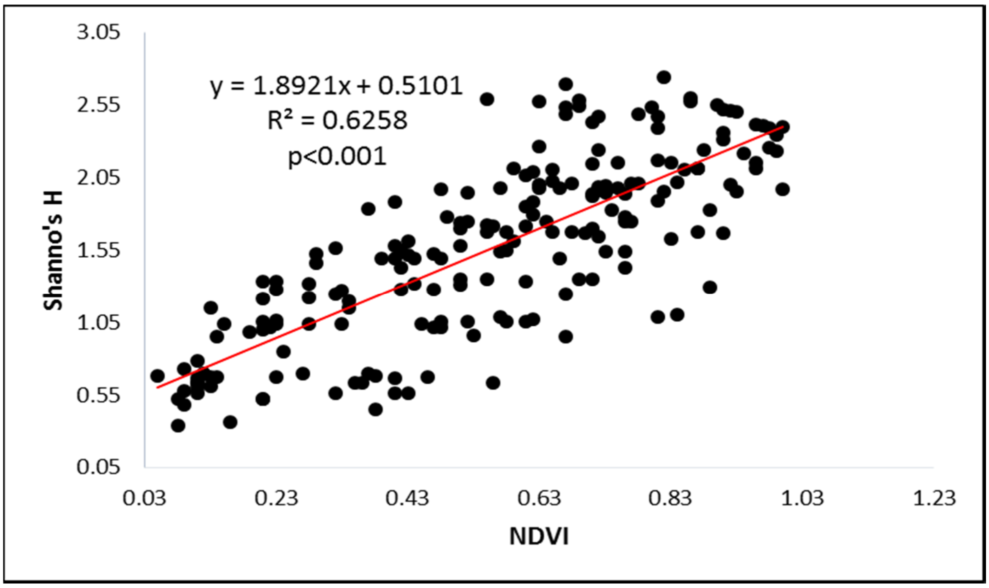


Figure 4.15. Relationship between NDVI and the Shannon Weaver Index (H)

Figure 4.15 shows regression analysis results illustrating a strong positive (r=0.79) correlation between NDVI and vegetative species diversity. NDVI explains 64% of vegetative species diversity. These results imply that NDVI can be used as a surrogate for vegetative species diversity. An increase in vegetative species diversity corresponds with an increase in NDVI but an increase beyond 2.3 of Shannon's H is associated with a decline of NDVI.

4.5 Changes in species diversity between 1974 and 2014

Man Kendal trend tests show that there is a significant (P=0.041, $\alpha = 0.05$) decrease in average December NDVI over the period 1974-2014. However, the trend for average July NDVI is not significant (p=0.062, $\alpha = 0.05$) but declining (Figure 4.16).

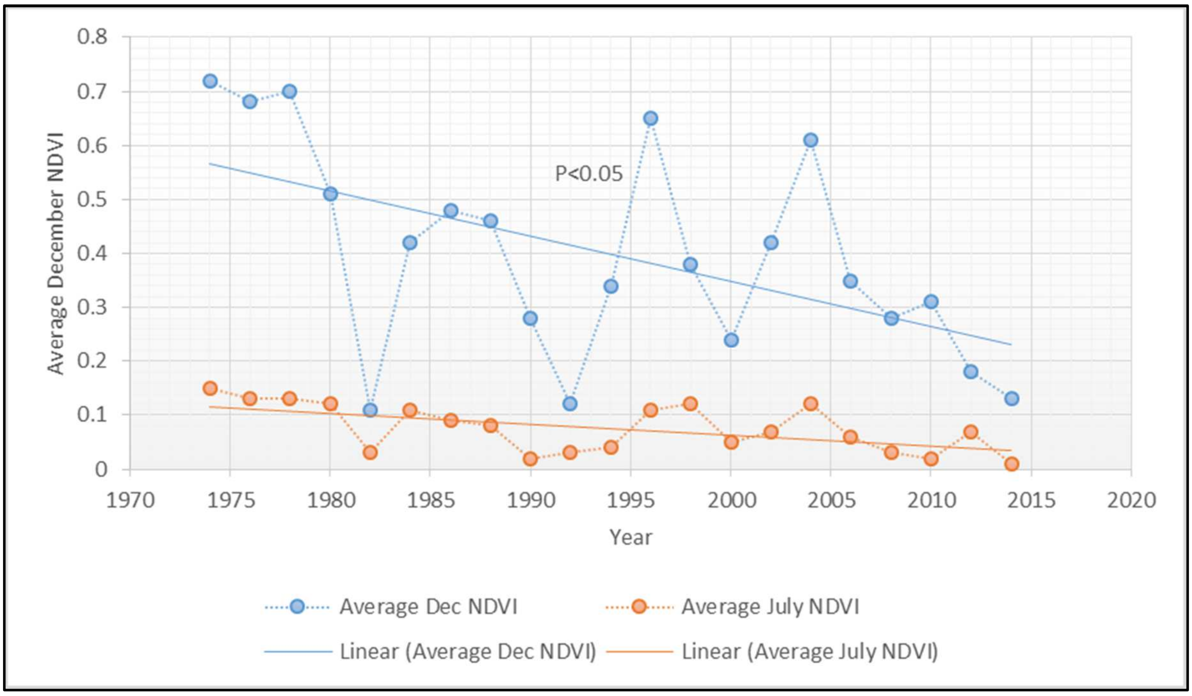


Figure 4.16. Trends for average NDVI for December and July between 1974 and 2014

As shown in Figure 4.14 average NDVI for December over the period 1974-2014 is fluctuating over time but there is an overall decrease in the average NDVI. The same fluctuating pattern and a decreasing trend can be observed for July NDVI. The trends reflect rainfall patterns experienced in the province with drought years having the lowest NDVI values. For example, the 1982 and 1992 droughts are associated with low NDVI values of around 0.1. Years of high rainfall have above 0.4 NDVI values. Figure 4.15 shows ten-year interval changes in the month of December NDVI over a 40 year period.

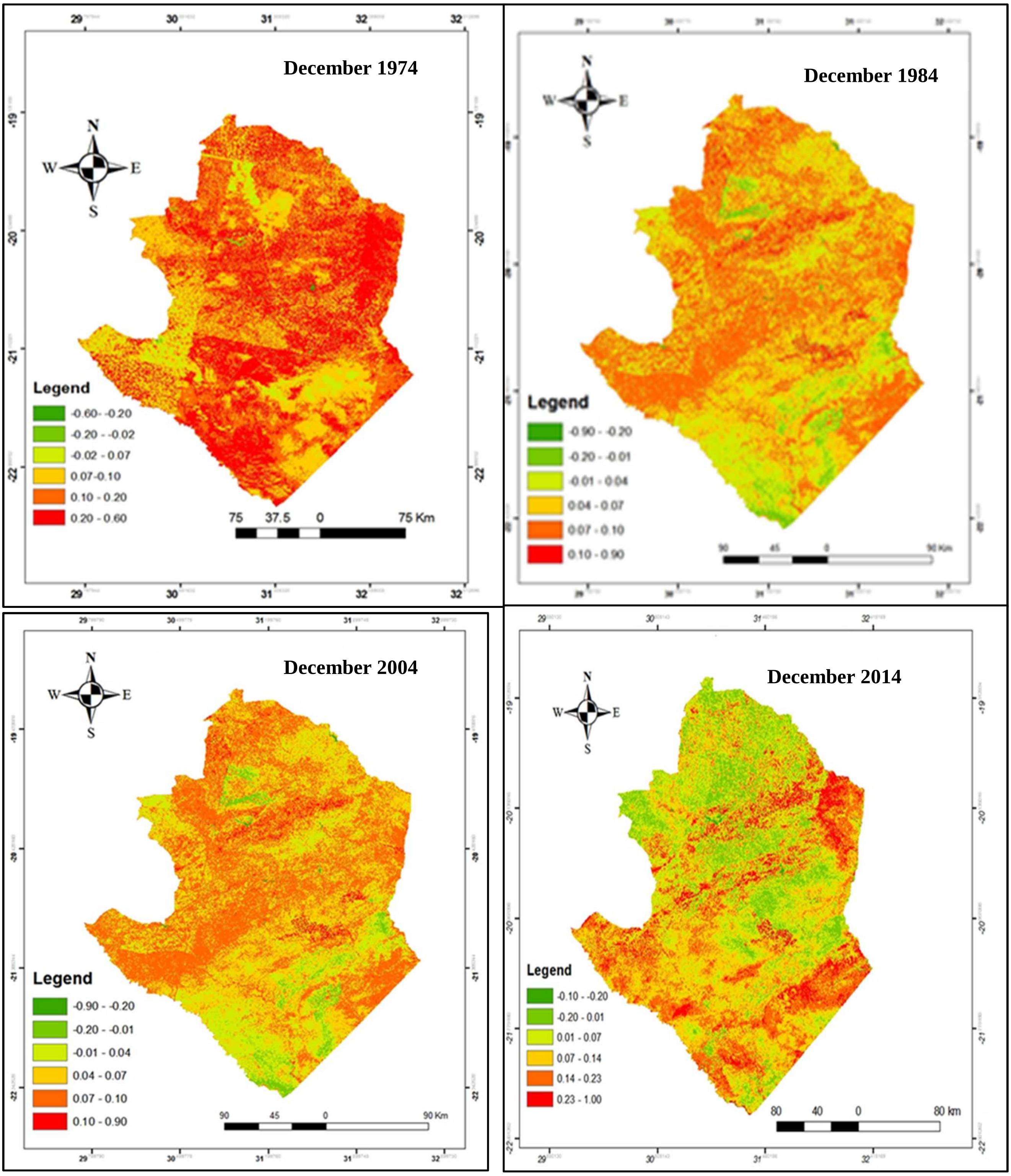


Figure 4.17. December NDVI for different years depicting changes in species diversity

It is illustrated that there are general spatial and temporal changes in NDVI over time. There is a noted decrease of NDVI areas that previously had high NDVI values. In 1974, for example, more than 50% of the province had NDVI of more than 0.1 but in 1984 the area had declined to approximately below 50%. The trend continues up to 2014 with areas of negative NDVI values increasing more than that of positive NDVI values. It should be emphasized that NDVI fluctuations are inevitable due to annual variability in climatic elements but there is a general decrease in overall NDVI over time as reflected in Figure 4.15.

The decrease in NDVI implies a decrease in species diversity as established in this study. In this case, NDVI is used as a surrogate of species diversity. Despite remote sensing evidence, respondents in the study area (92.3%) indicated that they have observed a decrease in the diversity of species over time. They indicated that there are some indigenous species whose population has declined significantly while others have actually gone extinct due to changes in the climate accompanied by land use practices across the province. Amongst the most affected species were herbaceous and graminoid species such as *Digitaria penzii, Cynodon dactylon, Eragrostis trichophora, D. penzii, E. trichophora* and *Hyperthelia dissoluta, Urochloa mozambicensis, Heteropogon contortus.* Tree species such as the *Julbernardia globiflora, Brachystegia spiciformis, Parinari curatellifolia Burkea Africana, Terminalia sericea and Colophospermum Mopane* were reported to be affected through logging by communities. The logging is presumed an indirect impact of climate change constrained environment as respondents confirmed that logging is generally observed as one of the adaptation mechanisms. Furthermore, Yospin *et al.*, (2015) observed human disturbance regimes interact with climate change to drive vegetation changes. Trees are cut down for sale as agriculture related income generating activities become impossible due to extreme weather conditions driven by climate change.

4.6. Discussion

4.6.1 Climate trends in Masvingo province

The statistically significant and human perceived increase in monthly mean maximum, monthly mean minimum, warmest month maximum, summer and winter temperatures between 1974 and 2014 implies that climate has warmed in Masvingo Province. There has been an increase of +/- 0.33^0C per decade in monthly mean maximum temperatures and a +/- 0. 27^0C increase in monthly mean temperatures per decade. This affirms observations by Lutz *et al* (2013) that there is a significant increase in temperatures in the interior of southern Africa. These temperatures are projected to increase by 2^0C (using the Statistical Analogue

Resembling Scheme (STARS) model) and by 3.5^0C (using the Regional Climate Model) by 2060 (Lutz *et al.,* 2013).

Furthermore, the findings confirm general conclusions of various separate studies (Chikodzi and Mutowo, 2014; Simba *et al.,* 2012; Mason and Jury, 1997; Unganai, 1996; Makarau, 1995) that the climate in Zimbabwe, specifically the south eastern region, is warming as indicated by significant increase in temperatures associated with prolonged occurrences of dry spells. For example, Chikodzi and Mutowo (2014) observed an increasing trend in maximum temperatures at Alheit station between 1951 and 2001. In addition, Kusangaya *et al* (2013) posit that several analyses through remote sensing and observed temperature records concur that the southern African region, in which Masvingo province lies, is undergoing a warming trend. New *et al.,*(2011), Warburton *et al.,* (2005), Kruger and Shongwe (2004), Hughes and Balling (1996), Unganai (1996) in their analyses of observed meteorological data concluded that the Southern African region is under the influence of a rising temperature regime with consequences on environmental systems. In a study that analysed temperature data between 1951 and 2010, Simba *et al.,* (2012) observed an increase in several temperature related variables. This is in line with the global warming trends which are understood to be resulting in climate change (World Bank, 2012). The changing temperature regimes are likely to be associated with ecological ramifications including plant species diversity modification.

More so, these findings support Simba *et al* (2012)'s assertion of climate change in Masvingo Province with observed increase in summer and winter temperatures. This has been accentuated by an increase in the frequency and intensity of heat waves. The changes in temperature have prospective influence on phenological and physiological characteristics of vegetation species. In some cases, the conditions become unbearable for some species and they become extinct. The increase in temperatures in Masvingo province over the period under investigation could have potentially increased evapotranspiration rate and consequently affected water availability which, in turn have affected the niches for specific species resulting in extinction or lack of productivity. Bouwer *et al*., (2007) and McCarthy *et al*., (2001) noted that an increase in temperature induces an enhanced evaporative demand which increases direct and indirect water loss leading to significant environmental changes. Simba *et al* (2012) reiterated that high evapotranspiration rate due to temperature increase results in stress on biodiversity. A change in biodiversity could be both a direct and indirect result of the changes in temperature regimes.

To that extent, the IPCC (2007b) predicts a 20-30 percent extinction rate of all plant and animal species due to a warming climate.

Both quantitative and qualitative results from this study have shown a decrease in minimum temperatures of the coldest month. This change constitutes climate change and it increases inter-seasonal variability in temperatures. Climate literature has hinted that climate change results in extreme weather conditions. Thus, the extremely low temperatures during the coldest month point to the existence of this climatological phenomenon.

This study has shown statistically significant decline in most of the precipitation related variables such as the total annual rainfall, precipitation of the warmest quarter and monthly mean precipitation. However, seasonal total precipitation shows a declining but not statistically significant trend. While the trend is not statistically significant, it contributes significantly to biodiversity changes as noted by Gitay *et al* (2002a) that ecosystem changes do not wait for precipitation changes to be significant, a slight shift in climatic elements may result in huge environmental consequences. Nevertheless, the general precipitation trend related variables indicate that the province is getting dry over the long term. This dryness is resulting in significant modification of ecosystems since water plays a pivotal role in ecosystem function.

Observations that there is a decline in precipitation in the province confirm the argument that there is climate change in Zimbabwe which is predicted to make the country dry (Makadho 1996). The trends in this study are characterised by high inter-annual variability and excessively dry spells. Respondents claim that the amount of precipitation received over time is decreasing. They further reiterated the existence of extreme climatic conditions and events such as droughts, floods and strong winds, which were previously non- existent and less severe. This buttresses Mazvimavi (2010)'s claim that the country is under the threat of climate change, which is exhibited by the changing rainfall patterns and extreme and frequent weather events. Mazvimavi (2010) also noted increased incidents of drought and a decrease in rainfall across all seasons in Zimbabwe.

In addition, the results confirm findings from various authors (Kusangaya *et al.*, 2013; Simba *et al.*, 2012; Ngongondo *et al.*, 2011; Mazvimavi, 2010) that there is a decline in precipitation in southern African region, in which Masvingo province is located. However, the precipitation trends for most authors are not statistically but environmentally significant. In Malawi, Ngongondo *et al*. (2011), observed statistically non-significant but declining precipitation trends. Sichingabula (1998) shows a declining rainfall trend in southern Zambia while Simba *et al.* (2012) report that there is high frequency of years with below normal rainfall in Masvingo province, Zimbabwe. The high inter-annual variability of rainfall, severe droughts and floods observed in this study confirm Mazvimavi (2010)'s assertion that rainfall in Zimbabwe has high inter-annual variability. Kusangaya *et al* (2013) noted that several studies in South Africa confirm high inter-annual variability of precipitation. Kane (2009) showed that annual rainfall has considerable year-to-year fluctuations (50–200% of the mean), while 5-year running means show long-term fluctuations (75–150% of the mean).

Temperature and precipitation trends observed in Masvingo in this study are consistent with the global and regional trends. There has been an upward trend in global and regional temperatures. Gitay *et al* (2002b) elucidate that there has been a 0.4^{o}C - 0.8^{o}C increase in global temperatures and these are also projected to increase further by 1.4^{o}C to 5.8 ^{o}C by 2100. Hopkins *et al.,* (2007) expounded that the mean surface temperatures have increased by 0.6^{o}C since 1970. The changes in temperature influence changes in precipitation (Koskela *et al.,* 2007; Gitay *et al.,* 2002b; Bawa and Dayanandan, 1998) due to changes in atmospheric circulation. A study by Koskela *et al* (2007) in Europe shows that average temperatures could increase by 2 - 4^{0}C over the next 50 years and cause considerable changes in regional and seasonal patterns of precipitation. Thus, there are observed changes in precipitation at the global and regional scale with the southern African region experiencing a 5 – 20 percent decrease in winter rainfall (Gitay *et al.,* 2002a) and a 3 percent decrease in rainfall in general (NAS, 2014). These changes are projected to influence all levels of biodiversity (Bellard *et al.,* 2012) across the continent.

Thus, the decrease in precipitation, whether statistically significant or not, shown in this study and confirmed by other studies is an indication that precipitation patterns are changing and this, over a long period, constitutes climate change. This change can modify several ecological processes since water is one of the principal factors that drive ecosystem processes. Biodiversity changes can be influenced due to changes in ecological niches driven by changes in water availability.

In view of these findings, this study confirms that there has been indeed a change in precipitation and temperature patterns in Masvingo Province which is an indication that climate has indeed changed over the period under review. This provides a warrant to investigate the impact of climate change on vegetative species diversity in the province.

4.6.2 Climate change and vegetation diversity

This study endeavoured to understand the relationship between climate variables and vegetative species diversity. Results have indicated that most of the precipitation related climate variables considered under this study contribute significantly to the status of vegetative species diversity in Masvingo Province. Thus, changes in these bioclimatic variables will result in changes in vegetative species diversity. The mean monthly precipitation and precipitation of the warmest quarter have the highest influence on vegetative species diversity. This observation is supported by Gwitira *et al.,* (2013)'s findings which presented precipitation of the warmest quarter as exceeding other precipitation related factors in influencing plant species diversity, specifically species richness.

The results further confirm several scientific predictions (Tivy, 1993; Stohlgren *et al.,* 1999; Thomas *et al*, 2004; MEA, 2005; Kazakis *et al.,* 2006; Montoya and Raffaelli, 2010) that climate change will become a major threat of biological diversity particularly plant species diversity. In line with the findings of this study, Koskela *et al* (2007) propounded that climate change induced evolution is already taking place with consequent shifts in composition and abundance of species in specific climate sensitive ecosystems. John *et al.,* (2008) asserted that the changes that occur in species composition and diversity are inevitable consequences of climate change. Mindas *et al.,* (2016) observed a climate change induced absence of Norway spruce and an increase in the number of beech, fir and maple species which resulted in biodiversity changes. More so, Montoya and Raffaelli (2010) claim that there is ample evidence indicating that ecological responses to climate change are occurring. Several studies) have also shown that on many taxa in the Northern Hemisphere species ranges are expanding northwards and westwards due to climate change (Parmesan *et al.,* 1999; Thomas *et al.,* 2001; Walther *et al.,* 2002; Walther 2010.

The decrease in diversity as temperatures increase implies that some vegetative species' tolerance decreases with an increase in maximum temperatures of the warmest month. These results are consistent with current understanding of the effect of temperatures of the warmest month on plant species diversity (Gwitira *et al.,* 2013) where a general negative relationship between plant species diversity and temperature is expected when temperatures go beyond 25^0C (Gwitira *et al.,* 2013). This is also confirmed by Sommer, *et al.,* (2010) whose studies projected a decrease in plant species diversity under an increase of temperatures by 1.8^0C. In addition, (Root *et al*. 2003; Edwards & Richardson, 2004; Parmesan, 2006) observed that temperature increase associated with climate change prompts spring advancement of phenology. It is important to note that studies emphasize that very high temperatures will result in less tolerance of some species therefore a decrease in diversity. Otherwise, a general increase in temperatures, which is less than 25^0C, has a positive correlation with vegetative species diversity (Gwitira *et al.,* 2013; Mindas *et al.,* 2016).

These results give credence to a study in Sierra Nevada by Calzado *et al.,* (2013) which observed that temperatures play an influential role on vegetative species diversity changes. Korner (2003) made similar assertions reiterating that climatic changes aggravate disturbances in the balance of the communities due to new migrations and modifications in the competitive relations resulting in modified composition, richness and evenness of vegetative species. However, Sarmento *et al.* (2010) and Yvon-Durocher *et al.* (2010) presented a different scenario in which ecosystem processes are affected by climatic warming independent of changes in biodiversity. Using the metabolic theory of ecology *(*Brown *et al*. 2004*)*, both studies reveal that climate change may affect metabolism of species without influencing biotic interactions and diversity. This is, however, contrary to observations in this study where warming is projected to influence biotic interactions and biological diversity. In fact, this study confirms the metabolic theory of ecology which posits that the metabolic process of an organism determines the most observed patterns in an ecosystem. Warming affects metabolism, thus, it determines the most fundamental biological rate and consequently biological diversity. In this regard, Petchey *et al* (2010) developed a theoretical model founded on suppositions from metabolic theory and foraging biology and indicated that increasing temperatures have enormous effects on food web properties such as connectome, with supplementary consequences on plant species population stability and community dynamics.

Long term changes in climate variables constitute climate change. Thus, the effect of climate variables on vegetative species diversity implies that a change in climate will lead to a change in species diversity. Koskela *et al* (2007) assumed that an increase in temperatures and the consequent alteration of precipitation patterns would modify the environmental conditions to which ecosystems are adapted and expose them to new pests and diseases. This will result in changes in vegetative species diversity. The existence of climate change in Masvingo province and the relationship between climatic variables and vegetative species diversity shown in this study implies that vegetation species are going through an evolutionary process which may alter composition, phenology, physiology and distribution of vegetation species. Hopkins *et al*

(2007) noted that shifts in suitable climatic conditions for individual species will lead to changes in abundance and range.

In this study, it is further observed that climate change indirectly impacts on vegetative species diversity. This is due to the knock on effects of land use changes influenced by climate change. For example, in Mwenezi, Chivi and some parts of Chiredzi, there is wanton and selective logging of the *Colophospermum Mopane* tree species for sell as a means of insurance against climate change induced economic hardships. Most of the communities in Masvingo province are agro based and they rely on rainfed agriculture for survival. The climate change induced severe and frequent droughts will force communities to find other means of survival and selling of wood is among them leading to selective logging which results in changes in vegetative species diversity. Hopkins *et al* (2007) confirm this observation and claim that indirect impacts of climate change on biodiversity are significant as a result of climate induced changes in land use. IPCC (2007b) weighs in propounding that climate change leads to changes on many aspects of biodiversity and also disturbance regimes such as fire, pests and disease frequency and intensity which further exacerbate ecosystem changes with regards to vegetative species diversity. It is certain that climate change will result in biodiversity changes but the change may be negative or positive contingent to the nature of other prevailing environmental conditions including edaphic factors and anthropogenic intrusion.

It is also noted that climate change does not operate independent of other environmental factors. Thus, anthropogenic activities, edaphic characteristics and natural events have contributed to the changes in vegetative species diversity in Masvingo Province. In line with this observation, Van Dobben and Slim (2012) also observed that climate change in association with soil subsidence in Ameland Island resulted in biodiversity changes. While several factors work in conjunction with climate change in influencing vegetative species diversity, it should be emphasized that there is ample scientific evidence showing that climate change has directly and indirectly dominated as the key driver of most ecological processes including changes in biodiversity.

The decrease in precipitation over the long term, as shown in this study, constitutes climate change. Precipitation provides the required water for plant growth and most species require it to reproduce. Water scarcity driven by a decrease in the amount of precipitation over the period under study has resulted in some species' climatic envelops to shift and others to fail to reproduce. This prompts physiological and phenological changes, drying up of species, migration and consequently biodiversity changes. The resultant net effect is a decrease in species richness and evenness. A change in diversity is mostly driven by differences in species level of tolerance to environmental changes. In addition, changes in environmental gradients result in the modification of interactions among the species through competence asynchronies, herbivory, pests and invasions. It is thus the position of this study that a decrease in precipitation, whether significant or not, is associated with a decrease in vegetative species diversity under semi-arid conditions.

In addition, results of this study show that plant species diversity responses to a decrease in precipitation are not simply additive and their combinational dynamics are not linear, as reviewed by Walther (2010). Plant species are ecological components rooted in complex networks of interactions. However, in spite of such complexity, there are general patterns in the way species interrelate across different environments (Montoya *et al*. 2006; Bascompte 2009). These patterns regulate the dexterity of plant species to recuperate from climate related perturbations. They too determine the magnitude of plant species extinctions on the residual species within the interaction system.

It has been established in this study that the respondents concur with statistical results from direct field measurements that climate change is indeed resulting in changes in plant species diversity. Specifically, it is shown from the perceptions of the respondents that vegetative species diversity in the province is decreasing under the influence of climate related perturbations. Results indicate that the decrease in precipitation in conjunction with an increase in temperatures is associated with the proliferation of invasive species and extinction of some indigenous plant species. Thus, the warming climate tends to support the spread of invasive species. The current study observed the momentous spread of the Cherry pie (*lantana camara)* species in Chivi, Chiredzi and Mwenezi districts and its isolated existence in the other districts. In addition, the Jointed Cactus (*Opuntia Aurantiaca*) and the *Dichrostachys Cinerea* are widely spreading in Gokomere rangelands to the north of Masvingo city. Some sporadic occurrences of Cactus Rosea (*Opuntia fulgida*), wild Oats (*Avenafatua*) are also observed in the province.

Respondents reported that these species are becoming a menace as their populations are increasing enormously resulting in the extinction of native plant species. The invasive species are proliferating due to the favourable climatic conditions created by climate change. Some of the invasive species have the propensity for modifying soil chemical properties, creating conditions that are not conducive for growth of other species. Nhokovedzo (2013) notes that the *Lantana Camara* increases the soil's pH to levels that make it impossible for other species to grow. The resultant effect is a decrease in vegetative species diversity. This problem has been seen to be prevalent in Chiredzi and Chivi districts where the *Lantana camara* species has dominated in most of the farmlands, and protected areas. In addition, the *Dichrostachys Cinerea* is invading some rangelands and out-competing other herbaceous species in Masvingo province. This has resulted in the decrease in herbaceous species richness across the province, particularly in Gokomere rangelands to the north of Masvingo city.

The observed decrease in native plant species confirms the findings from Mudzengi *et al* (2014) that the spread of invasive species reduces the diversity of plant species, particularly the herbaceous species. In a study that assessed the impact of *Lantana Camara* on herbaceous species diversity, Nhokovedzo (2013) also observed that there is a decrease in herbaceous species diversity in *Lantana Camara* invaded ecosystems. Thus, climate change has both direct and indirect effect on vegetative species diversity. Its promotion of the spread of invasive species indirectly promotes reduction in biodiversity.

The current study also posits that vegetative species diversity in Masvingo province is not only affected by a reduction in precipitation and an increase in temperatures. Several other climate related disturbances are contributing to the observed decrease in vegetative species diversity. For example, flood events that have been a key characteristic feature of the hydrological system in Masvingo province have affected some species, particularly herbaceous and graminoid species that do not have deep root systems. Floods are associated with significant erosion and deposition of alluvial soils and boulders. In the process of erosion, vegetation with shallow roots is wiped out while those with deep roots are damaged. Deposition on the other hand covers small vegetation resulting in death of some species. Herbaceous and graminoid species such as *Pogonarthria squarrosa, Hyparrhenia Filipendula, Aristida* spp., *P. maximum, D. penzii, H. dissoluta* and *R. repens* were reported to be susceptible to climate change induced flooding. Persistent flood activity may result in the extinction of some species.

4.6.3 Remote sensing and vegetation diversity

This study addresses the question whether NDVI can be used to project vegetative species diversity. In other words, the relationship between NDVI and SWI (H) was assessed to determine the usefulness of RS in estimating vegetative species diversity. This would be helpful in the process of biodiversity monitoring and reporting over time. In addition, it would be possible to ascertain the impacts of climate change or any other ecological disruption on vegetative species diversity. Results show that NDVI has a positive linear asymptotic response to vegetative species diversity. Given the case, NDVI can be used to explain vegetative species diversity. These findings endorse the productivity and biomass-biodiversity hypotheses (Lasky *et al.,* 2014; Fargione *et al.,* 2007; Van Ruijven and Berendse, 2005), which state that in the presence of adequate resources, biomass of species increases and the species become more specialised, permitting the proliferation of more species per unit area. Thus, low levels of biomass (represented by NDVI) coincide with low levels of species diversity; intermediate levels are associated with high levels of biodiversity while with very high biomass the levels of diversity begin to decline.

Furthermore, the results are consistent with the Spectral Variation Hypothesis (SVH) (Rocchini *et al.,* 2010; Palmer *et al.,* 2002) which envisages a direct correlation between differences in reflectance of remote sensing imagery with environmental heterogeneity and beta diversity. In other words, the hypothesis avers that spectral heterogeneity is related to spatial ecological heterogeneity and thus to vegetative species diversity. The positive correlation between vegetative species diversity and NDVI found in this study further confirms assertions by Rocchini *et al.,* (2010) that spatial variability obtained from remote sensing imagery can be used as a proxy for species diversity. Thus, environmental heterogeneity is among very important factors that determine biodiversity provided that areas with highly heterogeneous environments can host more vegetative species due to their high number of available niches.

The results are also in agreement with observations from other studies (Mutowo and Murwira, 2012a; Oindo and Skidmore, 2002; Skidmore *et al.,* 2003; Walker *et al.,* 1992) which confirm the feasibility of using remotely sensed data to estimate biodiversity. Skidmore *et al.,* (2003), for example, reiterated that in the last decades NDVI has been related to the distribution of both plants and animal species. They found a positive relationship between NDVI and biodiversity. The uniqueness of this study is that it considered all plant species without taxonomic separation and that it was focused on semi-arid conditions. On the other hand, Mutowo and Murwira (2012b) found a correlation between SAVI and tree species diversity and also between the standard deviation of NIR radiance and tree species diversity. In the last decade NDVI has been related to the distribution of both plant and animal species diversity. Walker *et al.* (1992) correlated plant species richness to aggregated NDVI in California, while Jorgensen and Nohr (1996) related bird diversity to landscape diversity and biomass availability in the Sahel. However, empirical evidence shows that higher productivity can be either negatively or positively correlated with species richness.

4.6.4 Changes in diversity between 1974-2014

Climate change driven decrease in NDVI and consequently species diversity observed in this study is consistent with the negatively skewed frequency distribution of the standardized anomalies of vegetation indices found by John *et al* (2013) in a study across the Mongolian plateau which examined vegetation response to climate change over a decade. Plant species adapt, migrate or die in response to climate change (Theurillat and Guisan, 2001). These three ways of how vegetation responds to climate change will have a profound effect on species diversity, specifically richness and evenness. The decrease in diversity observed in this study could be a result of migration of some species due to drying conditions or extinction of some species. Some studies have shown that plant species migrate extensively in response to climate change (Woods and Davis 1989, Sykes and prentice, 1996, Kullman, 1996). Pitelka *et al*, (1997) observed a modelled migration of species up to a kilometre per year coinciding with climate warming in the Holocene. Thus, such migrations over time will result in changes in species composition and other diversity related characteristics.

The decrease in diversity over time could be a result extinction driven by invasion by foreign species that are easily adapted to the changing climate. Such invasion will suffocate the indigenous species and they will die off. The proliferation of invasive species such as the *Lantana camara*, *Dichrostachys Cinerea and Eicchornia Crassipes* in the province can be attributed to the changing climate as these species spread under warm conditions. For example, water hyacinth (*Eicchornia Crassipes*), if cleared can resurface and invade water surfaces within 15 days under warm conditions. Consistent with the findings from this study, Pitelka *et al.,* (1997) and Mack (1986) aver that the cheat grass (*Bromus tectorum L.*), driven by climate change, spreads over 200 000 km^2 in about 40 years, replacing native plant species. More rapid plant migrations are likely to be seen in the near future in response to the accelerated climate change (Foley *et al.,* 1996, Grabherr *et al.,* 1994). This will be accompanied by land use change driven modifications of species diversity as also stated by Stohlgren *et al.,* (1998).

Chapter 5 : CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Climate trend between 1974 and 2014

The aim of this study was to assess the impacts of climate change on vegetative species diversity in Masvingo province. This aim could not be addressed without substantial evidence of the existence of climate change in the province. Thus, first objective of this study was to test whether there is a significant trend in climatic variables that substantiate the existence of climate change between 1974 and 2014 in the province. An inquiry into meteorological data, questionnaire survey responses and interview transcripts recorded from local community experiences and conventional indigenous knowledge led to the conclusion that there has been significant climate change in the study area during the period under review. Climate trend evidently manifest in the form of progressive warming, decreasing precipitation and increasing frequency and severity of climate change related events such as droughts and floods. In general, there has been further 'aridification' of the province over the study period.

It has quantitatively emerged that temperature related variables such as monthly mean maximum temperatures, monthly mean temperatures, maximum temperatures of the warmest month and minimum temperatures of the coldest month significantly changed over time. Qualitative analysis confirm the results with a greater percentage of respondents reporting high seasonal variability and increase in temperatures over time. The patterns of climatic variables show a generally warming trend with an increase in all temperature variables except minimum temperatures of the coldest month which are decreasing with time but perpetuating a warming trend.

The study also concludes that there is a significant change in precipitation related variables over the period with total annual precipitation showing a significant decrease while monthly mean precipitation and precipitation of the warmest month following suit. However, seasonal total precipitation did not show a significant trend but the pattern shows a decline. Reports from questionnaire surveys and interviews indicate that climate change related phenomenon such as droughts, floods and strong winds have been increasing in severity and frequency over time.

These conclusions confirm the scientific opinion that the global climate is generally changing and these changes vary from place to place depending on specific geographical factors. In theory, biological species are susceptible to changes in the environment. They either change their phenology in order to adapt or mitigate or they die, resulting in compositional changes.

Given the scientific evidence of changing climatic variables, it can be concluded that climate change indeed took place in Masvingo Province over the reviewed period and it could still be occurring. Basically, there is further "aridification" of the province. It is therefore worth the while to investigate its impacts on vegetative species diversity in the province to guide the designing of policies and strategies that address this environmental concern at provincial level and learn lessons for policy adoption at national and regional levels.

5.1.2 Relationship between vegetative species diversity and climate

The second objective was to assess the relationship between vegetative species diversity and climate parameters. This enabled the understanding of the effects of a changing climate on plant species diversity. However, taking into cognisance the fact that correlation does not always mean causality, the study used a multi-method approach to establish the cause-effect relationship between climate and vegetation. Thus, an analysis of extrapolated meteorological data, vegetation species data, as well as views from questionnaire surveys and interviews culminated in the conclusion that vegetative species diversity is significantly correlated with both precipitation and temperature related climate variables. Spatial and temporal changes in climatic elements have resulted in, among other effects, structural simplification of plant communities, localized extinctions and invasions with consequential changes in vegetative species diversity.

It is the conclusion of this study that vegetative species diversity denoted by the Shannon weaver Index (SWI) is influenced by precipitation related variables such as mean monthly precipitation, precipitation of the warmest quarter, seasonal total precipitation and total annual precipitation. Thus, the decrease in these precipitation parameters reduces the amount of water available for the proliferation of some climate sensitive species resulting in their desiccation and extinction. Some herbal and grass species have also succumbed to the effects of flooding and droughts. The net resultant effect is loss of biological diversity.

Furthermore, vegetative species diversity is significantly correlated with temperature variables such as maximum temperature of the warmest month, mean monthly maximum temperatures, mean monthly temperature and minimum temperature of the coldest month. In most of the temperature related variables the analysis showed that as temperature increases, diversity decreases. However, for minimum temperature of the coldest month an increase in temperature is correlated with an increase in diversity. With regards to mean monthly temperatures, an increase in temperature is positively related to increase in diversity when temperatures are below 19.5^0C, further increase in temperature is associated with a decline in vegetative species diversity.

Thus, the study concludes that vegetative species diversity is affected by precipitation and temperature variables. In other words, species diversity is influenced by climate. Therefore, climatic perturbations directly and indirectly influence vegetative species diversity through the modification of environmental conditions that are suitable for the production and health of specific species. This has resulted in a plethora of species responses, such as a change in range, abundance or in the timing of life cycle events and consequently a change of diversity patterns. The study acknowledges the direct and indirect impacts emanating from other factors such as edaphic changes, fire regime changes and land use changes. However, it is noted that climate change plays a contributory role to changes in all these changes and thus remains an important factor affecting the decline in vegetative species diversity in Masvingo Province.

5.1.3 Relationship between NDVI and vegetation diversity

The third objective was to assess the suitability of remote sensing products with specific reference to NDVI in evaluating vegetation diversity. This enabled the assessment of diversity changes over time without the arduously collected species data. Thus, an analysis of Landsat images spatial data and field collected species data represented by the SWI led to the conclusion that NDVI is significantly related to vegetative species diversity under semi-arid conditions. The analysis was based on the spectral variation hypothesis and the biomass-diversity hypothesis theoretical frameworks. This conclusion implies that we can use NDVI to investigate diversity status of ecosystems under semi-arid conditions. In this study, it was used to assess the impact of climate change on vegetative species diversity.

5.1.4 Changes in species diversity between 1974 and 2014

The last and fourth objective was to assess the impact of climate change on vegetative species diversity through considering temporal changes in NDVI as a surrogate of diversity. This was based on the previous conclusions that NDVI is correlated with vegetative species diversity. It was observed that there is a significant trend in NDVI during the rainy season. However for the dry season the trend is not significant but declining. Thus, the declining trend during the dry season and the significant declining trend during the rainy season indicate that there is a reduction in species diversity over time as the climate warms. It was observed that the impacts of climate change on vegetative species diversity is occurring through complementary effects of warming and reduction in water availability. The resultant effect is the modification of interactions (e.g. competition, asynchronies, herbivory, pests and invasions) among species. It is therefore the conclusion of this study that climate change is resulting in the decrease in vegetative species diversity over time as depicted by changes in NDVI.

Overall, the study demonstrated that climate change reduces the diversity of vegetative species under semi-arid conditions. Remote sensing can successfully be used to project and monitor changes in vegetative species through NDVI analysis. However, it should be cautioned that because this study focused on semi-arid conditions and therefore, the model may not be applicable under different climatic conditions. It is recommended that further studies be carried out to consider vegetative species responses under various climatic conditions. More so, this study did not factor out the contribution of anthropogenic activities on species diversity changes. Thus, an assumption was made that anthropogenic forces are indirectly linked to climate change. Therefore, the impact presented in this study is rather contributory than attributory. There is need for further research which considers other factors contributing to diversity changes in semi-arid regions.

5.2 Recommendations

The repercussions of climate change as shown in this study are evidenced by changes in vegetative species diversity over time. This will further cause ecological changes within the ecosystems due to the modification of interaction patterns. The consequences are the loss of ecosystem balance and this will directly and indirectly affect humanity given its dependence on ecosystems. Based on key findings of this research, several recommendations are suggested and could be considered by the ministry of Environment, Water and Climate, Climate Change office, Environmental Management Agency, Mutirikwi sub-Catchment Council, Forestry Commission and Zimbabwe, National Parks and Wildlife Authority and various environmental organisations working in semi-arid areas. These recommendations include:

1. There is need to fully understand climate change related ecosystems modifications through recording species diversity condition regularly, study the processes within the ecosystems and identify possible species specific adaptation mechanisms so that the current diversity is maintained and improved. This approach should be applied in different climate regions as effect of climate change may be regulated by prevailing climatic conditions.

2. Reducing changes in biological diversity is an international goal reaffirmed by the Aichi Targets for 2020 by Parties to the United Nations (UN) Convention on Biological Diversity (CBD) after failure to meet the 2010 target. However, there is no large scale harmonized observation system for delivering regular, timely data on biodiversity change. This study has shown the potential of remote sensing in the quest to understand vegetation diversity response to climate change using Landsat imagery. This could be a giant step towards coming up with a regional and eventually global observation system to monitor vegetation diversity. There is need for further research using satellite images with higher spectral, spatial and temporal resolution for more accurate predictions. Specifically, satellites equipped with spectral sensors which help to distinguish and record plant species based on their specific biochemical properties (chlorophyll, cellulose, leaf water content or protein content, etc.) would be recommended.

3. The hyperspectral satellite Environmental Mapping and Analysis Program (EnMAP), scheduled for launching in 2018, will provide high spectral resolution image data and is expected to significantly improve the identification of species and plant communities. If all goes according to plan it is recommended to use the EnMAP in biodiversity monitoring as it will be capable to measure processes and perturbations in ecosystems over large areas. The use of the freely available EnMAP data will go a long in biodiversity research and conservation.

4. Furthermore, this study has shown that NDVI can successfully be used in assessing vegetative species diversity over time under a changing climate. However, subtle

differences due to canopy density in the infra-red and red bands are not highlighted in the ratio-based indices. The subtle differences can be improved by using power degree of the infra-red response. Future studies should consider the use of Advanced Vegetation Index (AVI) which is more sensitive to forest density and physiognomic vegetation classes. This may improve the coefficient of determination between species diversity and vegetation indices.

5. In view of the criticality and prominence of biodiversity to humanity, there is need for institutions responsible for the management of environmental resources to be fully capacitated with regards to the monitoring of climate change aftermaths on vegetative species diversity. This would prevent the possible extinctions, invasions, structural simplifications and migration of important species within and from local plant communities. The ability to monitor climate change related impacts is dependent on well-equipped institutions in terms of remote sensing tools, skilled workforce and adequate resources to regularly collect field data for long term analysis of changes. Thus, field studies must be regular as they are indispensable for evaluating and interpreting remote sensing data. Field-work is necessary for validating remote sensing derived products as well as important for identifying ecological potency, stress behaviour and the adaptability of species and plant communities.

6. Worldwide, there is a plethora of methods used to assess biodiversity and this has led to a deluge of overlapping and contradicting conclusions. There is need for uniform methodology and standards for measuring biodiversity. Institutional collaboration is essential as there is need for a multidisciplinary approach in understanding climate change and its influence on future biodiversity. Biologists, ecologists, geographers and remote sensing specialists need to collaborate given the complex nature of biodiversity issues.

REFERENCES

Agrawal A 2005: Environmentality: Technologies of Government and the Making of Subjects. Durham, NC: Duke University Press.

Aitken SN, Yeaman S, Holliday JA, Wang TL, and Curtis-McLane S 2008: Adaptation, migration or extirpation: climate change outcomes for tree populations. Evolution Applications. 1, 95–111.

Allen CD, Macalady AK, Chenchouni H, Bachelet D, and Mcdowell N 2010: A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management. 259, 660 - 684.

Allen TFH and Hoekstra TW 1992: Toward and unified ecology. Complexity in ecological systems series. New York: Columbia University Press.

Alo CA and Wang G 2008: Potential future changes of the terrestrial ecosystem based on climate projections by eight general circulation models, Journal of geophysical Research.113, 1-21.

Altizer S, Harvell D and Friedle E 2003: Rapid evolutionary dynamics and disease threats to biodiversity. Trends in Ecology and Evolution. 18, 589–596.

Araújo MB, Pearson RG, Thuiller W and Erhard M 2005: Validation of species-climate impact models under climate change. Global Change Biology. 11, 1504–13.

Archer DR, Forsythe N, Fowler HJ and Shah SM 2010: Sustainability of water resources management in the Indus Basin under changing climatic and socio economic conditions, Hydrological Earth Systems. 14, 1669–1680

Ayyappan A and Parthasarathy N 1999: Biodiversity inventory of trees in a large scale permanent plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats, India. Biodiversity and Conservation. 8, 1533-1554.

Barbosa JM, Asner GP, Martin RE, Baldeck CA, Hughes F and Johnson T 2016: Determining Subcanopy Psidium cattleianum Invasion in Hawaiian Forests Using Imaging Spectroscopy. Remote Sensing. 8, 33.

Barnosky AD, Hadly EA and Bascompte J 2012: Approaching a state shift in Earth's biosphere. Nature. 486, 52–58.

Barreto P, Souza C, Noguerón R, Anderson A and Salomão R 2006: Human pressure on the Brazilian amazon forests. Washington DC: Amazon Institute of People and the Environment and World Resources Institute.

Barry RG and Chorley RJ 2003: Atmosphere, Weather and Climate (eigth ed). London: Routledge.

Barthlott W, Mutke J, Rafiqpoor MD, Kier G and Kreft H 2005: Global centres of vascular plant diversity. Nova Acta Leopoldina, 92.

Bascompte J 2009: Mutualistic networks. Frontiers in Ecology and the Environment, 7, 429–436.

Bast JL 2010: Seven theories of climate change. Why does climate change? What is man's role? What do leading scientists believe? Chicago: The heartland Institute.

Bawa KS and Dayanandan S 1998: Global climate change and tropical forest genetic resources. Climatic Change. 39, 473–485.

Bazazz FA, Jasienski M, Thomas SC and Wayne P 1995: Micro-evolutionary responses in experimental 47 populations of plants to CO2-enriched environments: parallel results from two model systems. Proceedings of the National Academy of Sciences. 92, 8161-8165.

Beaumont LJ, Pitman A, Perkins S, Zimmermann NE, Yoccoz NG and Thuiller W 2011: Impacts of climate change on the world's most exceptional ecoregions. Proceedings of the National Academy of Sciences. 108, 2306–2311.

Beaumont LJ, Pitman AJ, Poulsen M and Hughes L 2007: Where will species go? Incorporating new advances in climate modelling into projections of species Distributions. Global Change Biology. 13, 1368–1385.

Beckage B, Osborne B, Pucko C, Gavin DG, Siccama T and Perkins T 2008: An upward shift of a forest ecotone during 40 years of warming in the Green Mountains of Vermont, USA. Proceedings of the National Academy of Sciences (USA) 105: 4197–4202.

Beier P and Brost B 2010: Use of land facets in planning for climate change: conserving the arenas not the actors. Conservation Biology. 24, 701–710.

Bellard C, Bertelsmeier C, Leadley P, Thuiller W and Courchamp F 2012: Impacts of climate change on the future of biodiversity, Ecology letters. 15, 365–377.

Bennett KD 1985: The spread of Fagus grandifolia across eastern North America during the last 18,000 years. Journal of Biogeography. 12, 147-164.

Bernabo JC and Webb T 1977: Changing patterns of the Holocene pollen record of northeastern North America: a mapped summary. Quaternary Research. 8, 64-96.

Bernardi M and Madzudzo SJ 1990: Agro-Climatology applied to crop Production in Zimbabwe. Harare: Ministry of Lands, Agriculture and Rural Resettlement, Department of AGRITEX.

Berrang P, DF Karnosky and Bennett JP 1989: Natural selection for ozone tolerance in Populus tremuloides: field verification. Canadian Journal of Forest Research. 19, 519-522.

Berry SL and Roderick ML 2002: Estimating mixtures of leaf functional types using continental scale satellite and climatic data. Global Ecology and Biogeography. 11, 23–39.

Black R, Bennett SRG, Thomas SM, and Beddington JR 2011: Climate Change: Migration as adaptation, Nature. 478, 447-449.

Bloor JMG, Barthes L and Leadley PW 2008: Effects of elevated CO2 and N on tree-grass interactions: An experimental test using Fraxinus excelsior and Dactylis glomerata. Functional Ecology. 22, 537-546.

Bodin P and Wimen BLB 2007: The usefulness of stability concepts in forest management when coping with increasing climate uncertainties. Forest Ecology Management. 242, 541-552.

Bonneau LR, Shields KS and Civco DL 1999: Using satellite images to classify and analyse the health of hemlock forests infested by the hemlock woolly adelgid. Biological Invasions. 1, 55-267.

Botkin DB, Saxe H, Araujo MB, Betts R, Bradshaw RHW and Cedhagen T 2007: Forecasting the effects of global warming on biodiversity. Bioscience. 57, 227–236.

Bouwer L, Crompton R, Faust E, Hoppe P, and Pielke R A 2007: Confronting disaster losses. Science 318, 753.

Bradshaw AD 1991: Genostasis and the limits to evolution. Philosophical Transactions of the Royal Society. 333, 289-305.

Brando PM, Nepstad DC, Balch JK, Bolker BM, Christman MC, Coe MT and Putz FE 2012: Fire-induced tree mortality in a neotropical forest: The roles of bark traits, tree size, wood density and fire behavior. Global Change Biology. 18, 630–641.

Brown D, Chanakira RR, Chatiza K, Dhliwayo M, Dodman D, Masiiwa M, Muchadenyika D, Mugabe P and Zvigadza S 2012: Climate Change Impacts, Vulnerability and Adaptation in Zimbabwe. Climate Change Working Paper No 3: IIED.

Brown JH, Gillooly JF, Allen AP, Savage VM and West GB 2004: Toward a metabolic theory of ecology. *Ecology*. 85, 1771–1789.

Brunet J and von Oheimb G 1998: Migration of vascular plants to secondary woodlands in southern Sweden. Journal of Ecology. 86, 429-438.

Bryceson KP 1991: Likely locust infestation areas in western New South Wales, Australia, located by satellite. Geocarto International. 6, 21-37.

Bryman A 1988: Quantity and Quality in Social Research. London: Routledge.

Buchanan G, Pearce-Higgins J, Grant M, Robertson D and Waterhouse T 2005: Characterization of moorland vegetation and the prediction of bird abundance using remote sensing. Journal of Biogeography. 32, 697-707.

Burdon JJ and PH Thrall 2001: The demography and genetics of host-pathogen interactions. In Silvertown J and Antonovics J (eds.) Integrating ecology and evolution in a spatial context. London: Blackwell Science.

Burger R and Lynch M 1995: Evolution and extinction in a changing environment: a quantitative genetic analysis. Evolution. 49, 151-163.

Cahill AE, Aiello-Lammens ME, Reid CF, Xia Hua, Karanewsky CJ, Hae Yeong Ryu, Sbeglia GC, Spagnolo F, Waldron JB, Warsi O, and Wiens JJ 2012: How does climate change cause extinction? Proceedings of the Royal society B, doi:10.1098/rspb.2012.1890.

Cain ML, Damman H and Muir A 1998: Seed dispersal and the Holocene migration of woodland herbs. Ecological Monograph. 68, 325–347.

Cain ML, Milligan BG and Strand AE 2000: Long-distance seed dispersal in plant populations. American Journal of Botany. 87, 1217-1227.

Calzado RF, Mesa JM and Merzouki A 2013: Monitoring plant diversity and climatic change in Sierra Nevada (Spain). Acta Botanica Gallica. 157, 669-676.

Campbell A, Kapos V, Scharlemann JPW, Bubb P, Chenery A, Coad L, Dickson B, Doswald N, Khan MSI, Kershaw F, Rashid M 2009: Review of the Literature on the Links between Biodiversity and Climate Change: Impacts, Adaptation and Mitigation. In SotCoB (ed). Diversity. Montreal: SCBD Technical Series no 42.

Campbell BM, Dore D, Luckert M, Mukamuri B and Gambiza J 2000: Economic comparisons of livestock production in communal grazing lands in Zimbabwe. Ecological Economics. 33,413-438.

Cantin D, MF Tremblay, Lechowicz MJ and Potvin C 1997: Effects of CO2 enrichment, elevated temperature, and nitrogen availability on the growth and gas exchange of different families of jack pine seedlings. Canadian Journal of Forest Research. 27, 510-520.

Cavender-Bares J, Meireles JE, Couture JJ, Kaproth MA, Kingdon CC, Singh A, Serbin, SP, Center A, Zuniga E, Pilz G 2016: Associations of leaf spectra with genetic and phylogenetic variation in Oaks: Prospects for remote detection of biodiversity. Remote Sensing. 8, 221.

Chadwick KD and Asner GP 2016: Organismic-scale remote sensing of canopy foliar traits in lowland tropical forests. Remote Sensing. 8, 87.

Chagutah T 2010: Climate change vulnerability and adaptation preparedness in southern Africa. Zimbabwe Country report. Cape Town: Heinrich Bollstiftung.

Chander G, Brian L, Helder DL 2009: Summary of current radio metric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. Remote Sensing of the Environment. 113, 893–903.

Chapin FS, Danell K, Elmqvist T, Folke C and Fresco N 2007: Managing climate change impacts to enhance the resilience and sustainability of Fennoscandian forests. A Journal of the Human Environment. 36, 528-533.

Chapungu L and Nhamo L 2016: An Assessment of the Impact of Climate Change on Plant Species Richness Through an Analysis of the Normalised Difference Water Index (NDWI) in Mutirikwi Sub-catchment, Zimbabwe. South African Journal of Geomatics. 5, 244-268

Chapungu L and Yekeye T 2013: Estimating tree Species Diversity in small Scale farming Areas for Effective Environmental management: The Case of Bindura and Shamva Districts, Zimbabwe, Sacha Journal of Environmental Studies. 3, 23-33

Chen IC, Hill JK, Ohlemüller R, Roy DB and Thomas CD 2011: Rapid range shifts of species associated with high levels of climate warming. Science. 333, 1024-1026.

Chenje M and Johnson P 1996: State of the Environment in southern Africa. Harare, Southern African Research and Documentation Centre (SARDC), 2000. pp. 334, ISBN 1779100094, Zimbabwe.

Chenje M, Sola L and Palecnzy D (eds.) 1998: The State of Zimbabwe's Environment. Harare: Ministry of Mines, Environment & Tourism, Zimbabwe.

Chenje, M. 2000: State of the environment Zambezi basin 2000. African Journal of Ecology. 34, 331. doi:10.1111/j.1365-2028.1996.tb00626.x

Chevin LM, Lande R and Mace GM 2010: Adaptation, plasticity and extinction in a changing environment: towards a predictive theory. PLoS Biology. 8, 1000357.

Chikodzi D and Mutowo G 2013: Drought monitoring for Masvingo province in Zimbabwe. A remote sensing perspective. Herald Journal of Geography and Regional Planning. 2, 056-060.

Chikodzi D, Mutowo G 2012: Agro-Ecological Zonation of Masvingo Province: Land Suitability Classification Factoring In Climate Change, Variability Swings and New Technology. 1:318.

Chikodzi D, Zinhiva H, Simba FM and Murwendo T 2013: Reclassification of Agro-ecological zones in Zimbabwe-The rationale, methods and expected benefits. The case of Masvingo province, Journal of sustainable development in Africa. 15, 104-116.

Chishakwe NE 2010 Southern Africa sub regional framework on climate change report www.unep.org/roa/amcen/docs/AMCEN-Events/Climate -change/ South Africa/SADC-Report.

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon WT, Laprise R, Magaña Rueda V, Mearns L, Menéndez CG, Räisänen J, Rinke A, Sarr A and Whetton P 2007: Regional Climate Projections. In Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M and Miller HL (eds.) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Clark JS 1998: Why trees migrate so fast: confronting theory with dispersal biology and the paleorecord. American Nature. 152, 204-224.

Clark JS, Bell DM, Hersh MH and Nichols L 2011: Climate change vulnerability of forest biodiversity: climate and resource tracking of demographic rates. Global Change Biology. 17, 1834–1849.

Cole K I, Ironside K, Eischeid J, Garfin G, Duffy PB and Toney C 2011: Past and ongoing shifts in Joshua tree distribution support future modelled range contraction. Ecological applications. 21, 137–149

Collingham YC, Hill MO and Huntley B 1996: The migration of sessile organisms: a simulation model with measureable parameters. Journal of Vegetation Science. 7, 831-846.

Collins H 2010: Creative research: the theory and practice of research for the creative industries. Lausanne: AVA Publishing.

Coops NC, Waring RH, Plowright A, Lee J, and Dilts TE 2016: Using remotely-sensed land cover and distribution modeling to estimate tree species migration in the Pacific Northwest region of North America. Remote Sensing. 8, 65.

Corbetta P 2003: Social Research: Theory Methods and Techniques. London: SAGE

Cowling RM, Rundel PW, Lamont BB, Arroyo MK, Arianoutsou M 1996: Plant diversity in Mediterranean-climate regions. Trends in Ecology and Evolution. 11, 362-6.

Cox P, Betts R, Collins M, Harris P, Huntingford C and Jones C 2004: Amazonian forest dieback under climate-carbon cycle projections for the 21st century, Theoretical applications in Climatology. 78, 137-156.

Crespo O, Hachigonta S and Tadross M 2011: Sensitivity of southern African maize yields to the definition of sowing dekad in a changing climate. Climatic Change. 106, 267–283.

Cwynar LC and MacDonald GM 1987: Geographical variation of lodge pole pine in relation to population history. American Nature. 129, 463-469.

Davis C and Joubert A 2011: Southern Africa's climate: current state and recent historical changes. In Climate risk and vulnerability: a handbook for Southern Africa, CSIR (available at: www.csir.co.za/docs/SADC%20Handbook%202011_final_email.pdf).

Davis MB 1981: Quaternary history and the stability of forest communities. In West DC, Shugart HH and Botkin DR (eds.) Forest succession: concepts and applications. New York Springer.

Davis MB 1983: Quaternary history of deciduous forests of eastern North America and Europe. Annual Missouri Botanical Gardens. 70, 550-563.

Davis MB 1989: Lags in vegetation response to greenhouse gasses. Climate Change. 15, 75-82.

Davis MB and Shaw RG 2001: Range shifts and adaptive responses to Quaternary climate change. Science. 292, 673-679.

Davis SD, Heywood VH and Hamilton AC 1994: Centres of plant diversity. A guide and strategy for their conservation. Vol. 1: Europe, Africa and the Middle East. Cambridge: IUCN

Dawson C 2007: A Practical Guide to Research Methods: A User-friendly Manual for Mastering Research Techniques and Projects. (3rd Edition) Oxford: Spring.

Dawson TP, Jackson ST, House JI, Prentice IC and Mace GM 2011: Beyond predictions: biodiversity conservation in a changing climate. Science. 332, 53–58.

Daze A, Ambrose K and Ehrhart C 2009: Climate Vulnerability and Capacity Analysis Handbook, CARE. http://www.careclimatechange.org.

De Groot R, Brander L, van der Ploeg S, Costanza R, Bernard F, Braat L, Christie M, Crossman N, Ghermandi A, Hein L 2012: Global estimates of the value of ecosystems and their services in monetary units. Ecosystem Services. 1, 50–61

De Klerk HM, Crowe TM, Fjeldsa J and Burgess ND 2002: Biogeographical patterns of endemic terrestrial Afrotropical birds. Diversity and Distributions. 8, 147-62

Degen B, Blanc L, Caron H, Maggia L, Kremer A and Gourlet-Fleury S 2006: Impact of selective logging on genetic composition and demographic structure of four tropical tree species. Biology and Conservation. 131, 386-401.

DeHayes DH, Jacobson GL, Schaberg PG, Bongarten B, Iverson L and Dieffenbacher-Krall AC 2000: Forest responses to changing climate: lessons from the past and uncertainty for the future. In Mickler RA, Birdsey RA and Hom JL (eds.), Responses of northern U.S. forests to environmental change. New York: Springer.

Diaz S and Cabido M. 2001: Vive la difference: plant functional diversity matters to ecosystem processes. Trends Ecological Evolution. 16: 646-655.

Diaz S, Kattge J, Cornelissen JHC, Wright IJ, Lavorel S, Dray S, Reu B, Kleyer M, Wirth C, Prentice IC 2016: The global spectrum of plant form and function. Nature. 159, 167-171

Diaz S, Symstad AJ, Chapin FS, Wardle DA and Huenneke LF 2003: Functional diversity revealed by removal experiments. Trends in Ecological Evolution. 18, 140-146.

Dillon ME, Wang G and Huey RB 2010: Global metabolic impacts of recent climate warming. Nature, 467, 704–706.

Drever CR, Peterson G, Messier C, Bergeron Y and Flannigan MD 2006: Can forests management based on natural disturbances maintain ecological resilience? Canadian Journal of Forest Resources. 36: 2285-2299.

Duffy JF 2003: Biodiversity loss, trophic skew and ecosystem functioning. Ecological letters. 6, 680-687.

Dyer JM 1995: Assessment of climate warming using a model of forest species migration. Ecological Modelling. 79, 199-219.

EASAC 2005: A user’s guide to biodiversity indicators. London: The Royal society,

Edwards M and Richardson AJ 2004: Impact of climate change on marine pelagic phenology and trophic mismatch. Nature. 430, 881–884.

Erasmus BFN, Van Jaarsveld AS, Chown SL, Kshatriya M and Wessels KJ 2002: Vulnerability of South African animal taxa to climate change. Global Change Biology, 8, 679-693.

Etterson JR 2004: Evolutionary potential of Chamaecrista fasciculate in relation to climate change. Evolution. 58, 1446-1458.

FAO 2000: Global forest resources assessment. FAO Forestry Paper 140. Rome.

Fargione JD, Tilman R, Dybzinski JHR, Lambers C, Clark WS, Harpole JMH, Knops PB, Reich and M. Loreau 2007: From selection to complementarity: shifts in the causes of biodiversity–productivity relationships in a long-term biodiversity experiment." Proceedings of the royal Society. 274, 871–876.

Farley KA, Bremer LL, Harden CP and Hartsig J 2013: Changes in carbon storage under alternative land uses in biodiverse Andean grasslands: implications for payment for ecosystem services, Conservation Letters. 6, 21–27.

Farwig N, Braun C and Boehning-Gaese K 2008: Human disturbance reduces genetic diversity of an endangered tropical tree, Prunus Africana (Rosaceae). Conservation and Genetics. 9, 317-326.

Fernandez-Gonzalez F, Loidi J, and Moreno CJ 2005: Impacts on Biodiversity, In José Manuel Moreno Rodríguez (ed), A Preliminary General Assessment of the Impacts in Spain Due to the Effects of Climate Change, ECCE project, final report, Ministry of environment, Spain.

Fischlin A, Midgley GF, Price JT, Leemans R, Gopal B, Turley C, Rounsevell MDA, Dube OP, Tarazona J and Velichko AA 2007: Ecosystems, their properties, goods, and services.in Foley JA, Prentice IC, Ramankutty N, Levis S, Pollard D, Sitch S and Haxeltine A 1996: An integrated biosphere model of land surface processes, terrestrial carbon balance and vegetation dynamics. Global Biogeochemical Cycles 10, 603–628.

Fisher RA 1930: The genetical theory of natural selection. Oxford: Oxford University Press.

Fjeldsa J and Lovett JC 1997: Geographical patterns of old and young species in African forest biota: The significance of specific montane areas as evolutionary centres' *Biodiversity and Conservation*. 6, 325-246.

Fontana A and Frey J 1994: Interviewing: The art of science. In Denzin N Lincoln Y (Eds.) Handbook of qualitative research. Thousand Oaks, CA: Sage.

Frodin DG 2001: Floras in retrospect and for the future. Plant Talk. 25, 36–39.

Gao BC 1996: NDWI—a normalized difference water index for remote sensing of vegetation liquid water from space. Remote Sensing of Environment. 58, 257–266.

Garcia-Ramos G and Kirkpatrick M 1997: Genetic models of adaptation and gene flow in peripheral populations. Evolution. 51, 21–28.

Garroutte EL, Hansen AJ and Lawrence RL 2016: Using NDVI and EVI to map spatiotemporal variation in the biomass and quality of forage for migratory elk in the greater Yellowstone ecosystem. Remote Sensing. 8,404.

Gavin DG and Hu FS 2006: Spatial variation of climatic and non-climatic controls on species distribution: The range limit of Tsuga heterophylla. Journal of Biogeography. 33, 1384−1396.

Geber MA and Dawson TE 1993: Evolutionary responses of plants to global change. In Kareiva PM, Kingsolver JG and Huey RB (eds.). Biotic interactions and global change. Sunderland: Sinauer Association.

Geng Q, Lian C, Goto S, Tao J, Kimura M, Islam MD and Hogetsu T 2008: Mating system, pollen and propagule dispersal and spatial genetic structure in a high-density population of the mangrove tree Kandelia cande. Molecular Ecology. 17, 4724-4739.

Gill D, Magin G and Bertram E 2013: Trees and Climate Change. A Guide to factors that influence species vulnerability and a summary of adaptation options. Fauna and Flora International, Cambridge.

Gillespie TW 2001: Remote sensing of animals. Progress in Physical Geography.25, 355–62.

Gilman SE, Urban MC, Tewksbury J, Gilchrist GW and Holt RD 2010: A framework for community interactions under climate change. Trends Ecological Evolution. 25, 325–331.

Gitay H, Suarez A, Watson RT and Dokken DJ 2002a Climate Change and Biodiversity. IPCC Technical Paper. Intergovernmental Panel on Climate Change.

Gitay H, Suarez A, Watson RT, Dokken DJ (eds.), (2002b). Intergovernmental Panel on Climate Change, Technical paper V.

Gizaw MS and Gan TY 2016: Impact of climate change and Elnino episodes on droughts in Sub-Saharan Africa. Climate Dynamics. 7, 1-18.

Glantz MH, Betsill M and Crandall K 1997: Food security in southern Africa. Assessing the use and value of ENSO information. National Center for Atmospheric Research, New York: Boulder.

Goldblatt P and Manning J 2000: Cape plants – A conspectus of the cape flora of South Africa. Strelitzia. 9, 7-13.

Goose H 2015: Climate System Dynamics and Modelling. New York: Cambridge University Press.

Gornitz V 2009: Sea level change, post-glacial. In Gornitz V (ed) *Encyclopedia of Paleoclimatology and Ancient Environments*. Encyclopedia of Earth Sciences Series, New York: Springer.

Gould W 2000: Remote Sensing of Vegetation, Plant Species Richness, and Regional Biodiversity Hotspots. Ecological Applications. 10, 1861-1870.

Grabherr G, Gottfried M and Pauli H (1994) Climate effects on mountain plants. Nature. 369, 448.

Graves SJ, Asner GP, Martin RE, Anderson CB, Colgan MS, Kalantari L, Bohlman SA 2016: Tree species abundance predictions in a tropical agricultural landscape with a supervised classification model and imbalanced data. Remote Sensing. 8, 161.

Gray DE 2011: Doing Research in the Real World. London: SAGE.

Gregorius HR 1996: The contribution of the genetics of populations to ecosystem stability. Silvae Genetica. 45, 267-271.

Groombridge B and Jenkins MD 2002: World atlas of biodiversity. Berkeley: University of California Press.

Groves CR, Game ET, Anderson MG, Cross M, Enquist C, Ferdana Z, Girvetz E, Gondor A, Hall KR, and Higgins J 2012: Incorporating climate change into systematic conservation planning. Biodiversity and Conservation. 21, 1651–1671.

Guo Q. 2006: The diversity–biomass–productivity relationships in grassland management and restoration. Basic and Applied Ecology. 8, 199-208.

Gwitira I, Murwira A, Shekede MD, Masocha M and Chapano C 2013: Precipitation of the warmest quarter and temperature of the warmest month are key to understanding the effect of climate change on plant species diversity in Southern African savannah. African Journal of Ecology. 52, 209–216.

Halpin PN 1997: Global climate change and natural-area protection: Management responses and research directions. Ecological Applications. 7, 828-843.

Hamed KH and Rao AR 1998: A modified Mann-Kendall trend test for autocorrelated data. Journal of Hydrology. 204, 182–196.

Hamrick JL, Godt MJW 1996: Effects of life history traits on genetic diversity in plant species. Philosophical Transactions of the Royal Society. 351, 1291–1298.

Hannah L, Midgley GF, Lovejoy T, Bond WJ, Bush ML, Scott D and Woodward FI 2002: Conservation of biodiversity in a changing climate. Conservation Biology. 16, 11–15.

Hansen J, Sato M, Kharecha P and von Schuckmann K 2011: Earth's energy imbalance and implications. *Atmospheric Chemistry and Physics.* 11, 13421-13449.

Hansen L, Hoffman J, Drews C, and Mielbrecht E 2009: Designing climate-smart conservation: guidance and case studies. Conservation Biology. 24, 63-69.

Hare FK 1979: Climatic variation and variability: empirical evidence from meteorological and other sources. Proceedings of the world climate conference. 537, 51-87.

Hector A, Schmid B, Beierkuhnlein C, Caldeira MC, Diemer M, Imitrakopoulos PG, Finn JA, Freitas H, Giller PS, Good J, Harris R, Hogberg P, Huss-Danell K, Joshi J, Jumpponen A, Korner C, Leadley PW, Loreau M, Minns A, Mulder CP, O'Donovan G, Otway SJ, Pereira JS, Prinz A, Read DJ 1999: Plant diversity and productivity experiments in European grasslands, Science. 286, 1123-7.

Hellamann JJ, Byers JE, Berwagen BG and Dakes JS 2008: Five potential consequences of climate change for invasive species, Conservation biology. 22, 534-543.

Heller NE and Zavaleta ES 2009: Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation. 142, 14-32.

Heyder U, Schaphoff S, Gerten D and Lutch W 2011: Risk of severe climate change impact on the terrestrial biosphere. Environment Research Letters. 6, 034-036.

Higgins SI, and Richardson DM 1999: Predicting plant migration rates in a changing world: The role of long-distance dispersal. American Nature. 153, 464–475.

Higgins SI, Nathan R and Cain ML 2003: Are long-distance dispersal events in plants usually caused by nonstandard means of dispersal? Ecology. 84, 1945-1956.

Hirsch RM, Helsel DR, Cohn TA and Gilroy E J 1993: Statistical analysis of hydrologic data. New York: McGraw Hill.

Hof C, Araujo MB, Jetz W, and Rahbek C 2011: Additive threats from pathogens, climate and land-use change for global amphibian diversity. Nature. 480, 516–519.

Hoffman AA and Sgro CM 2011: Climate change and evolutionary adaptation. Nature. 470, 479–485.

Holling CS 1973: Resilience and stability of ecosystems. Annual Review of Ecological Systems. 4,1-23.

Hooper DU and PM Vitousek 1997: The effects of plant composition and diversity on ecosystem processes. Science. 277, 1302-1305.

Hooper DU, Chapin FS, Ewel JJ, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge DM, Loreau M, Naeem S, Schmid B, Setala H, Symstad AJ, Vandermeer J and Wardle DA 2005: Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecology Monograph. 75, 3-35.

Hopkins JJ, Alison HM, Walmsley CA, Gaywood M and Thurgate G 2007: Conserving biodiversity in a changing climate: Guidance on building capacity to adapt. London: DEFRA

Hopper S and Gioia P 2004: The Southwest Australian Floristic Region: evolution and conservation of a global hot spot of biodiversity. Annual Review of Evolutionary Systems. 35, 623-50.

Houghton JT, Jenkins GJ, and Ephraums JJ 1990: Climate change: the IPCC scientific assessment. Cambridge: Cambridge University Press.

http://www.fes.uwaterloo.ca/research/vincera/and

Huete A, Didan K, Miura T, Rodriguez EP, Gao X and Ferreira LG 2002: Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote Sensing of Environment. 83, 195–213.

Huete AR, Liu H and van Leeuwen WJD 1997: Use of vegetation indices in forested regions: Issues of linearity and saturation. In Anon (Ed.), *International Geoscience and Remote Sensing Symposium (IGARSS)* 4, 1966-1968.

Hughes L 2000: Biological consequences of global warming: is the signal already apparent? Trends in Ecology and Evolution. 15, 56–61.

Hughes WS and Balling RC 1996: Urban influences on South African temperature trends. International Journal of Climatology. 16, 935–940.

Huntley B 1990: Lessons from climates of the past. In Leggett J (ed) Global warming: The Green peace report. Oxford: Oxford University press.

Huntley B 1991: How plants respond to climate change: migration rates, individualism and the consequences for plant communities. Annals of botany. 67, 11-22.

Huntley B and Birks HJB 1983: An Atlas of past and present pollen maps for Europe: 0-13000 years ago. Cambridge. Cambridge University press.

Huntley B and Webb T 1988 Discussion. In Huntley B and Webb T (eds). Vegetation history. Kluwer, Dordretch.

Hushaw J 2015: Climate change and extreme weather Part I: Trends and projections, Climate smart land network bulletin, Manomet.

Hutchinson ge 1958: Concluding remarks. Cold spring harbor symposium on quantitative biology. *22* 415–427.

Ian D 1996: Qualitative Data analysis: A user friendly guide for social scientists. New York: Routledge.

INGC (2005) national Institute of Disaster Management (INGC) Phase II Synthesis Report

Inouye DW 2008: Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. Ecology, 89, 353–362.

IPCC 2001a: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. In Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K and Johnson CA (eds.). Cambridge: Cambridge University Press.

IPCC 2001b: Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change Watson, R.T. and the Core Writing Team (eds.). Cambridge: Cambridge University Press.

IPCC 2007b. Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Online at: http://www.ipcc.ch/ipccreports/ar4-wg1.htm

IPCC, 2007a. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Annex I., In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge, Cambridge University Press,.

Jewitt D, Erasmus BFN, Goodman PS, O'Connor TG, Hargrove WW, Maddalena DM and Witkowski ETF 2015: Climate-induced change of environmentally defined floristic domains: A conservation based vulnerability framework. Applied Geography. 63, 33-42.

Johansen JL and Jones GP 2011: Increasing ocean temperature reduces the metabolic performance and swimming ability of coral reef damselfishes. Global Change Biology. 2011, 17, 2971–2979.

John R, Chen J, Lu N, Guo K, Liang C, Wei Y, Noormets A, Ma K and Han X 2008: Predicting plant diversity based on remote sensing products in the semi-arid region of Inner Mongolia, Remote Sensing of the Environment. 112, 2018–2032

John R., Chen J, Yang Z, Xiao J, Becker R, Samanta A, Ganguly S, Yuan W and Batkhishig O 2013: Vegetation response to extreme climate events on the Mongolian Plateau from 2000 to 2010. Environmental Research letters. 8, 1-12

Jones PD and Briffa KR 1992: Global surface air temperature variations over the twentieth century part I, spatial, temporal and seasonal details. Holocene 2, 105-179.

Jorgensen AF and Nohr H 1996: The use of satellite images for mapping of landscape and biological diversity in Sahel. International Journal of Remote Sensing. 17, 91−109.

Jump AS and Penuelas J 2005: Running to stand still: adaptation and the response of plants to rapid climate change. Ecology Letters 8, 1010-1020.

Kandji ST, Verchot L and Mackensen J 2006: Climate Change Climate and Variability in Southern Africa: Impacts and Adaptation in the Agricultural Sector. Nairobi: UNEP

Kane RP 2009: Periodicities, ENSO effects and trends of some South African rainfall series – an update. South African Journal of Science, 105.

Kattge J, Diaz S, Lavorel S, Prentice IC, Leadley P, Bönisch G, Garnier E, Westoby M, Reich PB, and Wright IJ 2016: TRY–A global database of plant traits. Global Change Biology. 17, 2905–2935.

Keely D 2011: Climate variability and climate change. What is the difference? http://www.miseagrant.umich.edu/climate

Kellomaki S, Peltola H, Nuutinen T, Korhonen KT and Strandman H 2008: Sensitivity of managed boreal forests in Finland to climate change, with implications for adaptive management. Philosophical Transactions of the Royal Society. 363, 2341-2351.

Kendall M G 1975: Rank Correlation Methods. (4th edition). London: Charles Griffin.

Kenneth l. Ironside CK, Eischeid J, Garfin G, Duffy P and Toney C 2011: Past and ongoing shifts in Joshua tree distribution support future modeled range contraction. Ecological Applications. 21, 137–149.

Kerr JT and Ostrovsky M 2003: From space to species: ecological applications of remote sensing. Trends in Ecology and Evolution. 18, 299-305.

Kerr JT, Southwood TRE and Cihlar J 2001: Remotely sensed habitat diversity predicts butterfly species richness and community similarity in Canada. Proceedings of the National Academy of Sciences of the United States of America. 98, 11365–11370.

Kiers ET, Palmer TM, Ives AR, Bruno JF and Bronstein JL 2010: Mutualisms in a changing world: an evolutionary perspective. Ecological Letters. 13, 1459–1474.

Koh LP, Dunn RR, Sodhi NS, Colwell RK, Proctor HC and Smith VS 2004: Species co-extinctions and the biodiversity crisis. Science. 305, 1632– 1634.

Korner C 2003: Carbon limitation in trees. Journal of Ecology. 91, 4–17.

Koskela J, Buck A and Cross TD (eds) 2007: Climate Change and Forest Genetic Diversity: Implications for sustainable forest management in Europe. Rome: Biodiversity International.

Kotecha P (Ed) 2010: Climate change, adaptation and higher education: Securing our future. SARUA leadership dialogue Series, volume 2 (4). WITS: SARUA

Kriegler E, Hall JW, Held H, Dawson R and Schellnhuber HJ 2009: Imprecise probability assessment of tipping points in the climate system. Proceeding of the National Academy of Sciences. 106, 5041–5046.

Kromkamp J and Morris EP 2006: Relationship of intertidal surface sediment chlorophyll concentration to hyperspectral reflectance and chlorophyll fluorescence. Estuaries and Coasts 29, 183–196.

Kruger AC and Shongwe S 2004: Temperature trends in South Africa: 1960–2003. International Journal of Climatology 24, 1929–1945.

Kull O, Sober A, Coleman MD, Dickson RE, Isebrands JG, Gagnon Z and Karnosky DF 1996: Photosynthetic responses of aspen clones to simultaneous exposure of ozone and CO2. Can. Jour. For. Res. 26: 639-648.

Kullman L 1996: Recent cooling and Recession of Norway spruce (picea abies (L)) Karst in the forest alpine tundra ecotone of the Swedish Scanders. Journal of Biogeography. 23, 843-854.

Kusangaya S, Warburton ML, Garderen EA, and Jewitt GPW 2013: Impacts of climate change on water resources in southern Africa: A review. Physics and Chemistry of the Earth, http://dx.doi.org/10.1016/j.pce.2013.09.014

La Sorte FA and Jetz W 2010: Projected range contractions of montane biodiversity under global warming. Proceeding of the Royal Society. 277, 3401–3410.

Lafferty KD 2009: The ecology of climate change and infectious diseases. Ecology. 90, 888–900.

Landman W, Tadross M, Engelbrecht F, Archer EG and Joubert A 2011: Seasonal forecasts. In communicating current climate variability in southern Africa http://www.csir.co.za/docs/SADC%20Handbook%202011_final_email.pdf).

Lapola DM, Oyama MD and Nobre CA 2009: Exploring the range of climate biome projections for tropical South America: The role of Co2 fertilisation and seasonality. Global biogeochemical cycles. 23, 1-16.

Lasky JR, Uriarte M, Boukili VK, Erickson DL, Kress WJ and Chazdon RL 2014: The relationship between tree biodiversity and biomass dynamics changes with tropical forest succession. Ecology Letters. doi: 10.1111/ele.12322.

Lavergne S, Mouquet N, Thuiller W and Ronce O 2010: Biodiversity and climate change: integrating evolutionary and ecological responses of species and communities. Annual Review. Ecological Evolution Systems. 41, 41.

Lavorel S and Garnier E 2002: Predicting changes in community composition and ecosystem functioning from plant trait: revisiting the Holy Grail. Functional Ecology, 16, 545–556.

Law BE, Falge E, Gu L, Baldocchi DD, Bakwin P, Berbigier P, Davis K, Dolman AJ, Falk M, Fuentes JD, Goldstein A, Granier A, Grelle A, Hollinger D, Janssens IA, Jarvis P, Jensen NO, Katul G, Mahli Y, Matteucci G, Meyers T, Monson R, Munger W, Oechel W, Olson R, Pilegaard K 2002: Environmental controls over carbon dioxide and water vapour exchange of terrestrial vegetation. Agriculture and Forest Meteorology. 113, 97-120.

Leadley P, Pereira HM, Alkemade R, Fernandez-Manjarres JF, Proenca V, and Scharlemann JPW 2010: Biodiversity scenarios: projections of 21st century change in biodiversity and associated ecosystem services. Montreal: Secretariat of the Convention on Biological Diversity, Technical Series no. 50.1–132.

Ledig FT and Kitzmiller JH 1992: Genetic strategies for reforestation in the face of global climate change. Forest Ecology Management. 50, 153-169.

Lee R, Yu F and Price KP 2002: Evaluating vegetation phenological patterns in Inner Mongolia using NDVI time-series analysis. International Journal of Remote Sensing. 23, 2505−2512.

Leedy P 1989: Practical Research: Planning and Design. (4th Edition). New York: Macmillan.

Lenton TM, Held H, Kriegler E, Hall JW, Lucht W, Rahmstorf S and Schellnhuber HJ 2008: Tipping elements in Earth's climate system. Proceedings of the National Academy of Sciences. 105, 1786–1793.

Lettenmaier DP 1976: Detection of trends in water quality data from records with dependent observations. Water Resources. 12, 1037-1046.

Levina E 2006: Domestic policy frameworks for adaptation to climate change in the water sector part II. Non Annex I countries: Lessons learned from Mexico, India, Argentina and Zimbabwe. Paris: OECD.

Lincoln YS and Guba EG 2000: Paradigmatic Controversies, Contradictions and Emerging Confluences. In N. K. Denzin and Y. S. Lincoln (Eds.). Handbook of Qualitative Research. Thousand Oaks. CA: Sage

Loreau M and Hector A 2001: Partitioning selection and complementarity in biodiversity experiments, Nature. 412, 72-76.

Loreau M, Naeem S, Inchausti P, Bengtsson J, Grime JP, Hector A, Hooper DU, Huston MA, Raffaelli D, Schmid B, Tillman D and Wardle DA 2001: Biodiversity and ecosystem functioning: current knowledge and future challenges. Science. 294, 804-808.

Ludwig JA and Reynolds JF 1988: Statistical Ecology, A primer on methods and computing. London: John Willey and Sons.

Lutz J, Volkholz J and Gerstengarbe FW 2013: Climate projections for southern Africa using complementary methods. International Journal of Climate Change Strategies and Management. 5, 130-15.

Lynch M and Lande R 1993: Evolution and extinction in response to environmental change. In Kareiva PM, Kingsolver JG and Huey RB (eds.). Biotic interactions and global change. Sunderland: Sinauer Association.

Mack RN 1986: Alien Plant Invasion into the intermountain west. A case history. In Mooney HA and Drake JA (eds) Ecology of biological invasions of North America and Hawaii. New York: Springer.

Makadho JM 1996 Potential Effects of Climate on Corn Production in Zimbabwe. Climate Research. 6, 146-151.

Makarau A 1995: Intra-Seasonal Oscillatory Models of the Southern Africa Summer Circulation. PhD Thesis, University of Cape Town.

Malanson GP, Resler LM and Tomback DF 2017: Ecotone response to climatic variability depends on stress gradient interactions. Climate Change Responses. 4:1.

Malcolm JR, Markham A, Neilson RP and Garaci M 2002: Estimated migration rates under scenarios of global climate change. Journal of Biogeography. 29, 835-849.

Malhi Y, Roberts JT, Betts RA, Killeen TJ, Li WH and Nobre CA 2008: Climate change, deforestation, and the fate of the Amazon. Science. 319, 169-172.

Malisawa MS and Rautenbach CJ 2012: Evaluating water scarcity in the southern African Development Community (SADC) region by using a climate moisture index (CMI) indicator. Water Science & Technology. 12 (1) IWA.

Maltitz GPV and Scholes RJ 2006: Vulnerability of Southern African Fauna and Flora to Climate Change, AIACC Working Paper No. 24.

Mambondiyani A 2016: Amid drought, mystery disease kills Zimbabwe's Baobabs. www.reuters.com/article/Zimbabwe-baobab-drought.

Mann HB 1945, Nonparametric tests against trend. Econometrica. 13, 245–259.

Mantyka-Pringle CS, Martin TG, and Rhodes JR 2012: Interactions between climate and habitat loss effects on biodiversity: A systematic review and meta-analysis. Global Change Biology. 18, 1239–1252.

Mapira J 2015: Zimbabwe's environmental education programme and its implications for sustainable development. Unpublished PhD Thesis. Stellenbosch University. Department of curriculum studies.

Mason SJ and Jury M R 1997: Climatic Change and Variability over Southern Africa: A Reflection on Underlying Processes. Progress in Physical Geography. 21, 23–50.

Mazvimavi D 2010: Climate change, water availability and supply. In: Kotecha P (Ed.), Climate Change, Adaptation and Higher Education: Securing our future. SARUA Leadership Dialogue Series. 2, 4, 81–100.

McCarthy JJ, Canziani OF, Leary NA, Dokken DJ and White KS (eds) 2001: Climate change 2001: impacts, adaptation, and vulnerability. Cambridge, Cambridge University Press.

McCormick CM 2002: Mapping exotic vegetation in the Everglades from large-scale aerial photographs. Photogrammetric Engineering and Remote Sensing. 65, 179-184.

McDowell N, Pockman WT and Allen CD 2008: Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought? New Phytologist. 178, 719–739.

McKenzie DA, Tinker DB 2012: Fire-induced shifts in overstory tree species composition and associated understory plant composition in Glacier National Park, Montana. Plant Ecology. 213, 207-224.

McMahon SM, Harrison SP, Armbruster WS, Bartlein PJ, Beale CM and Edwards ME 2011: Improving assessment and modelling of climate change impacts on global terrestrial biodiversity. Trends Ecological Evolution. 26, 249–259.

McManus KM, Asner GP, Martin RE, Dexter KG, Kress WJ and Field CB 2016: Phylogenetic structure of foliar spectral traits in tropical forest canopies. Remote Sensing. 8, 196.

MEA 2005: Ecosystem and human wellbeing: Biodiversity Synthesis. Washington DC: Island press.

Meyers LA and Bull JJ 2002: Fighting change with change: adaptive variation in an uncertain world. Trends Ecological Evolution. 17, 551–557.

Midgley GF and Thuiller W: 2011 Potential responses of terrestrial biodiversity in Southern Africa to anthropogenic climate change. Regional Environmental Change. 11, 127–135.

Millar CI, Stephenson NL and Stephens SL 2007: Climate change and forests of the future: Managing in the face of uncertainty. Ecological Applications. 17, 2145-2151.

Mindas J, Skavarenina J and Skavareninova J 2016: Biodiversity and Climate Change: Consequences for Norway Spruce Mountain Forests in Slovakia, International Journal of Environmental, Ecological, Geological and Geophysical Engineering.10, 5.

Mirza MMQ 2003: Climate change and extreme weather events: can developing countries adapt? *Climate Policy*. 3, 233–248.

Mitchell K 2007: Quantitative Analysis by the Point Centered Quarter Method, New York. Hobart and William Smith Colleges.

Mockel T, Dalmayne J, Schmid BC, Prentice HC and Hall K 2016: Airborne hyperspectral data predict fine-scale plant species diversity in grazed dry grasslands. Remote Sensing. 8, 133.

Mohammed HID 2005: Climate change and changes in global precipitation patterns: What do we know? Environment International. 31, 1167 – 1181.

Montoya JM and Raffaelli D 2010: Climate Change, Biotic interactions and Ecosystem Services. Philosophical transactions of the Royal Society. 365, 2013-2018.

Montoya JM, Pimm SL and Sole RV 2006: Ecological networks and their fragility. Nature. 442, 259–264.

Mooney HA and Cleland EE 2001: The evolutionary impact of invasive species. Proceedings of the National Academy of Sciences 98, 5446-5451.

Morgan DL 2008: Pragmatism as a Philosophical Foundation for Mixed Research' In Vicki CPL and Creswell J (Eds). The Mixed Methods Reader. London: SAGE.

Mosseler A, Innes DJ Roberts BA 1991: Lack of allozyme variation found in disjunct Newfoundland populations of red pine (Pinus resinosa). Canadian Journal of Forest Research. 21, 525–528.

Mosseler A, Major JE, Rajora OP and Kim KH 2004: Reproductive and genetic characteristics of rare, disjunct pitch pine populations at the northern limits of its range in Canada. Conservation and Genetics 5, 571-583.

Mudzengi BK, Simba FM, Murwendo T, and Mdlongwa T 2013: Perspectives in climate change and gender issues: a case study of Masvingo Province in Zimbabwe. Sacha Journal of Environmental Studies. 3, 1-10.

Mudzengi CP, Kativu S, Dahwa E, Poshiwa X, Murungweni C 2014: Effects of Dichrostachys cinerea (l.) Wight & Arn (Fabaceae) on herbaceous species in a semi-arid rangeland in Zimbabwe. Nature Conservation 7: 51-60.

Muller-Starck G, Ziehe M and Schubert R 2005: Genetic diversity parameters associated with viability selection, reproductive efficiency, and growth in forest tree species. In Scherer-Lorenzen M, Korner C and Schulze ED (eds) Forest diversity and function: temperate boreal systems. Berlin: Springer.

Murwendo, T and Munthali, A. 2008: The value of backyard trees to people's lives in Masvingo City. Zimbabwe Journal of Geographical Research. 2, 24-37.

Murwira A (Unpublished): Climate Change in Zimbabwe: Opportunities for Adaptation and Mitigation through Africa. Biocarbon Initiative Draft Report Submitted To Centre For International Forestry Research.

Murwira K. 2000: Beating Hunger: The Chivi Experience, London, ITDG Publications.

Musiyiwa K, Leal Filho W, Harris D and Nyamangara J 2014: Implications of Climate Variability and Change for Smallholder Crop Production in Different Areas of Zimbabwe, Research Journal of Environmental and Earth Sciences 6, 394-401.

Mutke J and Barthlott W 2005: Patterns of vascular plant diversity at continental to global scales. Biologiske Skrifter. 55, 521-537.

Mutke J, Kier G, Braun G, Schultz C and Barthlott W 2001: Patterns of African vascular plant diversity – a GIS based analysis. Systematics and Geography of Plants. 71, 1125-36.

Mutowo G and Murwira A 2012a: The spatial prediction of tree species diversity in Savanna woodlands of Southern Africa, Geocarto International. 27, 627-645.

Mutowo G and Murwira A 2012b: Relationship between remotely sensed variables and tree species diversity in Savanna woodlands of Southern Africa, International Journal of Remote Sensing. 33, 6378-6402.

Naeem S, Bunker DE, Hector A, Loreau M, Perrings C (Eds) 2009: Biodiversity, Ecosystem functioning and human wellbeing: An ecological and economic perspective. Washington DC: Oxford.

NCAR 2005. A continent split by climate change: New study projects stronger drought in southern Africa more rain in Sahel. http:// www.ucar.ed/new/ releases/2005.

New M, Hewitson B, Stephenson DB, Tsiga A, Kruger A, Manhique A, Gomez B, Coelho CAS, Masisi DN, Kululanga ME, Adesina F, Saleh H, Kanyanga J, Adosi J, Bulane L, Ngongondo CS, Yu XC, Gottschalk L and Alemaw B 2011. Evaluation of spatial and temporal characteristics of rainfall in Malawi: A case of data scarce region. Theoretical and Applied Climatology. 106, 79–93.

Nhandara E, Mutsvangwa L, Shumbayawonda N 1991: Geography Today physical. Harare: Zimbabwe Publishing Housing.

Nhokovedzo H 2013: Distribution of the invasive Lantana camara (L) and its influence on soil chemical properties and herbaceous species diversity in Chibi Farm, Chivi, Zimbabwe. Unpublished MSC Thesis. Department of biological Sciences. Bindura University of Science Education.

Noss RF 1991: From endangered species to biodiversity. In: Kohm K (ed). Balancing on the brink of extinction: the Endangered Species Act and lessons for the future. Washington DC: Island Press. .

Noss RF and Cooperlider AY 1994: Saving nature's legacy: Protecting and restoring biodiversity. Washington DC: Island Press.

Nussey DH, Clutton-Brock TH, Albon SD, Pemberton J and Kruuk LEB 2005: Constraints on plastic responses to climate variation in red deer. Biology Letters. 1: 457–460.

O'Connell LM, Mosseler A and Rajora OP 2007: Extensive long-distance pollen dispersal in a fragmented landscape maintains genetic diversity in white spruce. Journal of Heredity 98, 640-645.

Oindo BO, Skidmore AK 2002: Inter-annual variability of NDVI and species richness in Kenya. International. Journal of Remote Sensing. 23, 285–298.

Olesen JE, Carter TR, Az-Ambrona CH, Fronzek S, Heidmann T, Hickler T, Holt T, Quemeda M, Ruiz-Ramos M, Rubeak GH, Sau F, Smith B and Sykes MT 2007: Uncertainties in projected impacts of climate change on European agriculture and terrestrial ecosystems. Climatic Change. 81, 123-143.

Oran S 2016: Plant diversity of Al- Balqa Governorate, Jordan. International Journal of biodiversity and conservation. 8, 93-104.

Palmer MW, Earls P, Hoagland BW, White PS, Wohlgemuth T 2002: Quantitative tools for perfecting species lists. Environmetrics. 13, 121–137.

Palmer MW, Wohlgemuth T, Earls P, Arévalo JR, Thompson SD 2000: Opportunities for long-term ecological research at the Tall grass Prairie Preserve, Oklahoma. In: Lajtha K Vanderbilt K. (Eds) Cooperation in Long Term Ecological Research in Central and Eastern Europe: Proceedings of ILTER Regional Workshop. Budapest.

Parker IM and Gilbert GS 2004: The evolutionary ecology of novel plant-pathogen interactions. Annual Review of Ecological Evolution Systems. 35, 675-700.

Parmesan C 2006: Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution and Systematics. 37, 637–669.

Parmesan C and Yohe G 2003: A globally coherent fingerprint of climate change impacts across natural systems. Nature, 421, 37–42.

Parmesan C, Duarte CM, Poloczanska E, Richardson AJ and Singer MC 2011: Overstretching attribution. Nature and Climate Change. 1, 2–4.

Parmesan, C. Ryrholm N, Stefanescu C, Hill JK, Thomas CD, Descimon H, Huntley B, Kaila L, Kullberg J, Tammaru T, Tennent WJ, Thomas JA and Warren M 1999: Poleward shifts in geographical ranges of butterfly species associated with regional warming. Nature. 399, 579–583.

Patterson W, Saint CJW and Russell D 2007: Conservation of Tropical Forests and Biological diversity. FAA 118-119 Report.

Patton M 1990: Qualitative Evaluation and Research Methods. Beverly Hills: Sage.

Pearson RG and Dawson TP 2003: Predicting the Impacts of Climate Change on the Distribution of Species: Are Bioclimate Envelope Models Useful? Global Ecology and Biogeography. 12, 361-371.

Pease CM, Lande R and Bull JJ 1989: A model of population growth, dispersal and evolution in a changing environment. Ecology. 70, 1657-1664.

Pereira HM, Leadley PW, Proenca V, Alkemade R, Scharlemann JPW, Fernandez-Manjarres JF 2010: Scenarios for global biodiversity in the 21st century. Science. 330, 1496–1501.

Perrings C 2010: Biodiversity, ecosystem services and climate change. The economic Problem. Environment department papers, Environmental economics series, paper number 120.

Petchey OL, Brose U and Rall BC 2010: Predicting the effects of temperature on food web connectance. Philosophical Transactions of the Royal Society. 365, 2081–2091.

Peters A, Eve MK, Holt EH and Whitford WG 1997: Analysis of desert plant community growth patterns with high temporal resolution satellite spectra. Journal of Applied Ecology 34, 418−32.

Peterson AT, Ortega-Huerta MA, Bartley J, Sanchez-Cordero V, Soberon J, Buddemeier RH and Stockwell DRB 2002: Future projections for Mexican faunas under global climate change scenarios. Nature, 416, 626–629.

Peterson G, Allen CR and Holling CS 1998: Ecological resilience, biodiversity and scale. Ecosystems 1, 6-18.

Petrou ZI, Manakos I, Stathaki T 2015: Remote sensing for biodiversity monitoring: A review of methods for biodiversity indicator extraction and assessment of progress towards international targets. Biodiversity and Conservation. 24, 2333–2363.

Pettorelli N, Vik JO, Mysterud A, Gaillard JM, Tucker CJ and Stenseth NC 2005: Using the satellite-derived Normalized Difference Vegetation Index (NDVI) to assess ecological effects of environmental change. Trends in Ecology and Evolution 20, 503-510.

Phillips OL, Lewis SL, Baker TR, Chao KJ, Higuchi N 2008: The changing Amazon forest. Philosophical Transactions of the Royal Society. 363, 1819–1827.

Pitelka LF 1988: Evolutionary responses of plants to anthropogenic pollutants. Trends in Ecology and Evolution. 3, 233-236.

Pitelka LF, Gardner RH, Ash J, Berry S, Gitay H, Noble IR, Saunders A, Bradshaw RHW, Brubaker L, Clark JS, Davis MB, Sugita S, Dyer JM, Hengeveld R, Hope G, Huntley B, King GA, Mack RN, Malanson GP, McGlone M, Prentice IC, Rejmanek M, and Skyes M 1997: “Plant migration and climate change.” American Scientist. 85, 464-473.

Plano CVL 2010: The adoption and practice of mixed methods: U.S. trends in federally funded health-related research. Qualitative Inquiry. 6, 428-440.

Plaut JA, Yepez EA, Hill J, Pangle R, Sperry JS, Pockman WT and McDowell NG 2012: Hydraulic limits preceding mortality in a piñon-juniper woodland under experimental drought. Plant, Cell & Environment 35, 1601–1617.

Pressey RL, Cabeza M, Watts ME, Cowling RM and Wilson KA 2007: Conservation planning in a changing world. Trends in Ecology and Evolution. 22, 583-592.

Punch K 2011: Introduction to Social Research. London: SAGE.

Rafferty NE and Ives AR 2010: Effects of experimental shifts in flowering phenology on plant–pollinator interactions. Ecological Letters. 14, 69–74.

Rahbek C 1995: The elevational gradient of species richness: a uniform pattern? Ecography. 18, 200-205

Rahel FJ and Olden JD 2008: Assessing the effects of climate change on aquatic invasive species. Conservation Biology. 22, 521-533.

Randin CF, Engler R, Normand S, Zappa M, Zimmermann NE, and Pearman PB: 2009: Climate change and plant distribution: local models predict high elevation persistence. Global Change Biology. 15, 1557–1569.

Ratajczak Z, Nippert JB and Collins SL 2012: Woody encroachment decreases diversity across North American grasslands and savannas. Ecology 93, 697–703.

Reason CJC and Keibel A 2004: Cyclone Eline and its unusual penetration over the southern African Mainland. Weather and Forecasting. 19, 789–805.

Reason CJC, 2007: Tropical cyclone Dera, the unusual 2000 01 tropical cyclone season in the South West Indian Ocean and associated rainfall anomalies over southern Africa. Meteorology and Atmospheric Physics. 97, 181–188.

Rekacewicz P 2005: Vital Climate change graphics, UNEP/GRID-arendal maps and graphicslibrary.http:maps.grida.no/go/graphic/sensitivity-adaptability-and-vulnerability.

Reu B, Zaehle S, Proulx R, Bohn K and Kleidon A 2011: The role of plant functional trade-offs for biodiversity changes and biome shifts under scenarios of global climatic change. Biogeosciences. 8, 1255–1266.

Reusch TBH, Ehler A, Hammerli A and Worm B 2005: Ecosystem recovery after climatic extremes enhanced by genetic diversity. Proceedings of the National Academy of Sciences.102, 2826-2831.

Revermann R, Finckh M, Stellmes M, Strohbach BJ, Frantz D and Oldeland J 2016: Linking land surface phenology and vegetation-plot databases to model terrestrial plant α-diversity of the Okavango basin. Remote Sensing. 8, 370.

Richardson DM and Petr P 2006: Plant invasions: Merging the concepts of species invasiveness and community invasibility. Progress in Physical Geography. 30, 409–431.

Riitters KJ, Wickham R, Jones OB and Smith E 2004. Global-scale patterns of forest fragmentation. Conservation Ecology. 4: 3.

Ritchie JC and MacDonald GM 1986: The patterns of postglacial spread of white spruce. Journal of Biogeography. 13, 527–540.

Rocchini D, Balkenhol N, Carter GA, Foody GM, Gillespie TW, He KS, Kark S, Levini N, Lucas K, Luoto M , Nagendra H , Oldeland J , Ricotta C, Southworth J and Neteler M 2010: Remotely sensed spectral heterogeneity as a proxy of species diversity: Recent advances and open challenges, Ecological Informatics doi:10.1016/j.ecoinf.2010.06.001.

Rocchini D, Ricotta C and Chiarucci A 2007: Using satellite imagery to assess plant species richness: the role of multispectral systems. Applied Vegetation Science. 10, 325–31.

Rodrigo FS, Esteban-Parra MJ, Pozo-Vazquez D and Castro-Diez Y 2000: ‘Rainfall Variability in Southern Spain on Decadal to Centennial Time Scales’. *International Journal of Climatology*. 20, 721–732.

Root TL, Price JT, Hall KR, Schneider SH, Rosenzweig C and Pounds JA 2003: Fingerprints of global warming on wild animals and plants. Nature 421:57-60.

Rosenzweig C, Iglesius A, Yang XB, Epstein PR and Chivian E 2001: Climate change and extreme weather events - Implications for food production, plant diseases, and pests. NASA Publications. Paper 24.

Rulinda CM, Wietske B and Stein A 2010: Image mining for drought monitoring in eastern Africa using Meteosat SEVIRI data. In: Remote sensing for Africa: special collection from African Association of Remote Sensing and the Environment (AARSE). International Journal of Applied Earth Observation and Geoinformation. 1, S63–S68.

Saatchi S, Buermann W, Mori S, Ter Steege H and Smith T 2008: Modeling distribution of Amazonian tree species and diversity using remote sensing measurements. Remote Sensing of the Environment. 112, 2000-2017.

Sade N, Gebremedhin A and Moshelion M 2012: Risk-taking plants: anisohydric behavior as a stress-resistance trait. Plant Signal Behaviour. 7, 767–770.

Sage RF and Kubien DS 2007: The temperature response of C3 and C4 photosynthesis. Plant, Cell & Environment 30, 1086–1106.

Sakai AFW, Allendorf JS, Holt DM, Lodge J, Molofsky KA, With S, Baughman RJ, Cabin JE, Cohen NC, Ellstrand DE, McCauley P, O’Neil IM, Parker JN, Thompson and Weller SG 2001: The population biology of invasive species. Annual Review of the Ecological Systems. 32, 305-332.

Sala O, van Vuuren D, Pereira H, Lodge D, Alder J, Cumming G, Dobson A, Wolters V and Xenopoulos M 2005: Biodiversity across scenarios. In Carpenter S, Pingali P, Bennett E, and Zurek M (eds) Scenarios of the Millennium Ecosystem Assessment. Oxford: Island Press.

Salamin N, Wu¨est RO, Lavergne S, Thuiller W and Pearman PB 2010: Assessing rapid evolution in a changing environment. Trends in Ecological Evolution. 25, 692–698.

Sango I 2013: An investigation of communal farmers' livelihoods and climate change challenges and opportunities in Makonde rural district of Zimbabwe. Unpublished PhD Thesis. University of South Africa. Department of Environmental Science.

Santos MJ, Baumann M and Esgalhado C 2016: Drivers of productivity trends in cork oak woodlands over the last 15 years. Remote Sensing. 8, 486.

Sarmento H, Montoya JM, Va´zquez-Domı´nguez E, Vaque D and Gasol JM 2010: Warming effects on marine microbial food web processes: how far can we go when it comes to predictions? Philosophical Transactions of the Royal Society. 365, 2137–2149.

Saxon E, Baker B, Hargrove W, Hoffman F and Zganjar C 2005: Mapping environments at risk under different global climate change scenarios. Ecology Letters. 8, 53–60.

Scafetta N 2010: Climate Change and its Causes. A discussion about some key issues. La Chimica el Industria. 1, 70-75.

SCBD (Secretariat of the Convention on Biological Diversity) 2010: Global Biodiversity Outlook 3, Canada, Montreal, 94 pages..

Schaberg PG, DeHayes DH, Hawley GJ and Nijensohn SE 2008: Anthropogenic alterations of genetic diversity within tree populations: Implications for forest ecosystem resilience. Forest Ecology Management. 256, 855-862.

Schneider SH and Root TL (eds.) 2002: Wildlife responses to climate change: North America case studies, Washington DC, Island press.

Schneider SH, Semenov S, Patwardhan A, Burton I, Magadza CHD, Oppenheimer M, Pittock AB, Rahman A, Smith JB, Suarez A and Yamin F 2007: Assessing key vulnerabilities and the risk from climate change. In Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J. and. Hanson C.E, (Eds) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Scholes RJ, Walters M, Turak E, Saarenmaa H, Heip CHR, Tuama ÉÓ, Faith DP, Mooney HA, Ferrier S, Jongman RHG, Harrison IJ, Yahara T, Pereira HM, Larigauderie A and Geller G 2012: Building a global observing system for biodiversity. Current Opinion in Environmental Sustainability. 4, 139–146.

Scholze M, Knorr W, Arnell NW and Prentice IC 2006: A climate change risk analysis for world ecosystems. Proceedings of the National Academy of Sciences. 103, 13116–13120.

Schwallier R, Raes N, de Boer H, Vos R, and van Vugt R 2016: Phylogenetic analysis of niche divergence reveals distinct evolutionary histories and climate change implications for tropical carnivorous pitcher plants. Diversity & distributions. 22, 97-110.

Seto KC, Fleishman E, Fay JP and Betrus CJ 2004: Linking spatial patterns of bird and Butterfly species richness with Landsat TM derived NDVI. International Journal of Remote Sensing. 25, 4309–4324.

Shan D, Hejing L, Liuyan P, and Xing'en D 2013: Effects of climate change on Vegetation in Desert Steppe Inner Mongolia. Natural Resources, 4, 319-322.

Shannon CE and Weaver W 1949: The Mathematical Theory of Communication. Urbana University of Illinois Press.

Sichingabula HM 1998. Rainfall variability, drought and implications of its impacts on Zambia – 1886–1996. Water resources variability in Africa during the XXth century. In: Proceedings of the Abidjan 98 Conference held at Abidjan, Cote de Ivoire, November 1998. IAHS Publication No. 252.

Simba FM, Murwendo T, Chikodzi D, Mapurisa B, Munthali A, and Seyitini 2012: Environmental Change and Farm Productivity: An Assessment of Masvingo Province of Zimbabwe. Sacha Journal of Environmental Studies. 2, 114-129.

Skellam JG 1951: Random dispersal in theoretical populations. Biometrika. 38,196-218.

Skidmore A, Pettorelli N, Coops NC, Geller GN, Hansen M and Lucas R 2015: Agree on biodiversity metrics to track from space. Nature. 523, 403–405.

Skidmore AK, Oindo BO and Said MY, 2003: Biodiversity assessment by remote sensing. In Proceedings of the 30th International symposium on remote sensing of the environment: information for risk management and sustainable development, November 10-14, 2003, Honolulu, Hawaii.

Smith JB, Schellnhuber HJ and Mirza MM 2001: Vulnerability to climate change and reasons for concern: a synthesis. In McCarthy JJ, Canziani OF, Leary NA, Dokken DJ and White KS (Eds): Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge: Cambridge University Press.

Sommer JH, Kreft H, Kier G, Jetz W, Mutke J and Barthlott W 2010: Projected Impacts of Climate Change on Regional Capabilities for Global Plant Species' Richness. Proceedings of the Royal Society B-Biological Sciences. 277, 2271–2280.

Spradley JP 1980: The Ethnographic Interview. New York: Holt.

Stenseth NC, Mysterud A, Ottersen G, Hurrell JW, Chan KS and Lima M 2002: Ecological effects of climate fluctuations. Science. 297, 1292–1296.

Steyaert LT, Hall FG and Loveland TR 1997: Land cover mapping, fire regeneration, and scaling studies in the Canadian boreal forest with 1km AVHRR and Landsat TM data. Journal of Geophysical Research. 102, 581-598.

Stimpson P 1996: Questionnaire Survey in Research in Environmental and Geographical Education. In Williams M (Ed).Understanding Geographical and Environmental Education: The Role of Research, Cassel: Cassel Education.

Stohlgren TJ, Binkley D, Chong GW, Kalkhan MA, Schell LD, Bull KA, Otsuki Y, Newman G, Bashkin M and Son Y 1999: Exotic plant species invade hot spots of native plant diversity. Ecological Monographs. 69, 25–46.

Stohlgren TJ, Bull KA, Otsuki Y, Villa CA and Lee M 1998: Riparian zones as havens for exotic plant species in the Central Grasslands. Plant Ecology, 138, 113–125.

Stritfholt JR, Noguerón R., Alvarez M and Bergquist J 2006: Mapping undisturbed landscapes in Alaska: An overview report. Conservation Biology, Institute and World Resources Institute. www.globalforestwatch.org/ english/about/publications.

Sutherland WJ 1996: Ecological Census Techniques, a Handbook, Cambridge, Cambridge University Press.

Swingland IR 2001: Biodiversity, definition of. In Levin SA (ed). Encyclopedia of biodiversity. San Diego: Academic Press.

Sykes MT and Prentice IC 1996: Climate change, tree species distributions and forest dynamics: a case study in the mixed conifer northern hardwoods zone of northern Europe. Climatic Change. 34, 161–178.

Tacoli C 2009: Crisis or adaptation? Migration and Climate Change in a context of high mobility. Environment and urbanization. 21, 513-525.

Tadross M, Hewitson B and Usman M 2003: Calculating the onset of the maize growing season over southern Africa using GTS and CMAP data. Clivar Exchanges. 27, 48–50.

Tadross M, Jack C and Hewitson B 2005: On RCM based projections of change in southern African summer climate. Geophysical Research Letters. 32, L23713, 4.

Tadross M, Suarez P, Lotsch A, Hachigonta S, Mdoka M, Unganai L, Lucio F, Kamdonyo D and Muchinda M 2009: Growing-season rainfall and scenarios of future change in southeast Africa: implications for cultivating maize. Climate Research. 40, 147–161.

Theurillat JP and Guisan A 2001: Potential impact of climate change on vegetation in European Alps: A review. Climate change. 50, 77-109.

Thibault KM and Brown JH 2008: Impact of an extreme climate event on community assembly. Proceedings of the National Academy of Sciences 105, 3410-3415.

Thomas CD, Bodsworth EJ, Wilson RJ, Simmons AD, Davies ZG, Musche M and Conradt L 2001: Ecological and evolutionary processes at expanding range margins. Nature. 411, 577-581.

Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BFN, Ferreira de Siquiera M, Grainger A, Hannah L, Hughes L, Huntley B, van Jaarseveld AS, Midgley GF, Miles L, Ortega-Huerta MA, Peterson AT, Phillips OL and Williams SE 2004: Extinction risk from climate change. Nature, 427, 145–148.

Thompson I, Mackey B, Mcnulty S and Mosseler A 2009: Forest resilience, biodiversity and climate change. A synthesis of the biodiversity/Resilience/Stability relationship in forest ecosystems, Secretariat of the convention on biological diversity, technical series no.43.

Thompson JG, and Purves WD 1978: A guide to the soils of Rhodesia. Department of Research and Specialist Services, Harare.

Thuiller W, Lavorel S, Arau´jo MB, Sykes MT and Prentice IC 2005: Climate change threats to plant diversity in Europe. Proceedings of the National Academy of Sciences. 102, 8245– 8250.

Tilman D, Wedin D and Knops J 1996: Productivity and sustainability influenced by biodiversity in grassland ecosystems. Nature. 379,718–720.

Tittensor DP, Walpole M, Hill SLL, Boyce DG, Britten GL, Burgess ND, Butchart SHM, Leadley PW, Regan EC and Alkemade R 2014: A mid-term analysis of progress toward international biodiversity targets. Science. 346, 241–244.

Tivy J 1993: Biogeography: a study of the plants in the ecosphere (3rd edition). Harlow. Longman.

Tol RSJ 2005: The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties. Energy Policy. 33, 2064–2074.

Tomback DF, Resler LM, Keane RE, Pansing ER, Andrade AJ and Wagner AC 2016: Community structure, biodiversity, and ecosystem services in treeline whitebark pine communities: potential impacts from a non-native pathogen. Forests, 7(1): doi http://dx.doi.org/10.3390/f7010021.

Tripathi KP and Singh B 2009: Species diversity and vegetation structure across various strata in natural and plantation forests in Katerniaghat Wildlife Sanctuary, North India. Tropical Ecology. 50, 191-200.

Tucker C 1979: Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of the Environment. 8, 127–150.

Turner., W, Spector S, Gardiner N, Fladeland M, Sterling EJ and Steininger M 2003: Remote sensing for biodiversity science and conservation. Trends in Ecology and Evolution. 18, 306–314

UNFCCC 2002: Report of the conference of the parties on its seventh session-Addendum part II: Action taken by conference of parties.

Unganai L 1996: Historic and future climatic change in Zimbabwe. Climate Research. 6, 137 – 145

Unganai L 2009: Adaptation to Climate Change among Agropastoral Systems: Case for Zimbabwe. Earth and Environmental Science. 6, 412045.

Unganai L and Mason 2002: Long range predictability of Zimbabwe Summer rainfall, International Journal of Climatology 22, 1091-1103.

Unganai LS and Murwira A 2010: Challenges and opportunities for climate change adaptation among smallholder farmers in southeast Zimbabwe. In: ICID+18 2nd International Conference: Climate, Sustainability and Development in Semi-arid Regions. 16 – 20 August 2010, Fortaleza - Ceará, Brazil.

Urban DL and Liu T 2002: Tactical monitoring of landscapes. Integrating landscape ecology into natural resource management. Cambridge, Cambridge University Press.

Usman MT, Archer E, Johnston P and Tadross M 2005: A conceptual framework for enhancing the utility of rainfall hazard forecasts for agriculture in marginal environments. Natural Hazards. 34, 111–129.

USNAS 2012: A national Strategy for advancing climate modelling. Washington DC: The National Academies Press.

USNAS 2014: Climate Change: Evidence and Choices, Washington DC: National Academies press.

Ustin SL 2016: Preface: Remote sensing and biodiversity. Remote Sensing. 8. 508.

Van Dobben HF and Slim PA 2012: Past and future plant diversity of a coastal wetland driven by soil subsidence and climate change. Climate change. 110, 597-618.

Van Ruijven J and Berendse F 2005: Diversity–productivity relationships: Initial effects, long-term patterns, and underlying mechanisms. Proceedings from the National Academy of Science 102, 695-7.

Van Vuuren DP, Sala OE and Pereira HM 2006: The future of vascular plant diversity under four global scenarios. Ecological Society. 11, 1–19.

Vincent V and Thomas RG 1960: An agricultural survey of Southern Rhodesia: Part I: Agro-ecological survey. Salisbury: Government Printer.

Von Storch H 1995: Misuses of statistical analysis in climate research In: Analysis of Climate Variability: Applications of Statistical Techniques. Berlin: Springer.

Wainhouse D and Inward DJG 2016: The influence of climate change on forest insect pests in Britain. *Forestry Commission Research Note,* 10pp

Walker B 1995: Conserving biological diversity through ecosystem resilience. Conservation Biology. 9, 747-752.

Walker RE, Stoms DM, Estes JE and Cayocca KD 1992: Relationships between biological diversity and multi-temporal vegetation index data in California. American Society for Photogrammetry and Remote Sensing. 7, 562-571.

Walther GR 2010: Community and ecosystem responses to recent climate change. Philosophical Transactions of the Royal Society B-Biological Sciences. 365, 2019–2024.

Walther GR, Post E, Convey P, Menzel A, Parmesank C, Beebee TJC, Fromentin JM, GuldbergI O and Bairlein F 2002: Ecological responses to recent climate change, Nature. 416.

Wang K, Franklin SE, Guo X, Cattet M 2010: Remote Sensing of Ecology, Biodiversity and Conservation: A Review from the Perspective of Remote Sensing Specialists. Sensors. 10, 9647-9667.

Wang R, Gamon JA, Emmerton CA, Li H, Nestola E, Pastorello GZ and Menzer O 2016b: Integrated analysis of productivity and biodiversity in a Southern Alberta prairie. Remote Sensing. 8, 214.

Wang R, Gamon JA, Montgomery RA, Townsend PA, Zygielbaum AI, Bitan K, Tilman D and Cavender-Bares J 2016a: Seasonal variation in the NDVI–species richness relationship in a prairie grassland experiment. Remote Sensing. 8, 128.

Warburton ML and Schulze RE 2005: Detection of climate change: a review of literature on changes in temperature, rainfall and stream flow, on detection methods and data problems. In: Schulze RE (Ed.) Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation. Pretoria: Water Research Commission.

Warburton ML, Schulze RE and Maharaj M 2005: Is South Africa’s temperature changing? An analysis of trends from daily records, 1950–2000. In: Schulze RE (Ed.) Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation. Pretoria: Water Research Commission.

Waring RH, Coops NC, Fan W and Nightingale JM 2006: MODIS enhanced vegetation index predicts tree species richness across forested ecoregions in the contiguous U.S.A. Remote Sensing of Environment. 103, 218−226.

WCED 1991 Our Common Future: World Commission on Environment and Development, Oxford: Oxford University Press.

Weart SR 2004: The Discovery of Global Warming. Cambridge: Harvard University Press, Cambridge, U.S.A.

Webb T and Bartlein PJ 1992: Global changes during the last 3 million years: climatic controls and biotic responses. Annual Review of Ecological Systems. 23, 141–73.

Wernberg T, Smale DA, Tuya F, Thomsen MS, Langlois TJ, de Bettignies T, Bennett S and Rousseaux CS 2012: An extreme climatic event alters marine ecosystem structure in a global biodiversity hotspot. Nature and Climate Change. 3, 78–82.

West GB, Brown JH and Enquist BJ 1997: A general model for the origin of allometric scaling laws in biology. Science. 276, 122–126.

West NE 1995: Biodiversity on rangelands: Definitions and Values. In West NE (Ed). Biodiversity on Rangelands. Logan: Utah State University.

White F 1983: Vegetation of Africa – a descriptive memoir to accompany the Unesco/AETFAT/UNSO vegetation map of Africa. Natural Resources Research Report No. 20. Paris: UNESCO.

White M and Nemani R 2006: Real-time monitoring and short-term forecasting of land surface phenology. Remote Sensing of Environment. 104, 43-49.

Wiens JJ 2016: Climate-Related Local Extinctions Are Already Widespread among Plant and Animal Species. PLoS Biology. 14, 12.

Wild H and Barbosa G 1967: Vegetation Map of the flora Zambesiaca Area. Salisbury: Collins.

Wilkinson DM 1997: Plant colonization: Are wind dispersed seeds really dispersed by birds at large spatial and temporal scales? Journal of Biogeography. 24, 61-65.

Willis CG, Ruhfel B, Primack RB, Miller-Rushing AJ and Davis CC 2008: Phylogenetic patterns of species loss in Thoreau’s woods are driven by climate change. Proceedings of the. National Academy of Sciences.105, 17029–17033.

Woods KD and Davis MB 1989: Paleoecology of range limits: beech in the Upper Peninsula of Michigan. Ecology. 70, 681–696.

Woodward FI 1987: Climate and plant distribution, Cambridge: Cambridge University press.

Woodward FI, Smith TM, Emanuel WR 1995: A global land primary productivity and phytogeography model. Global Biogeochemical Cycles. 9, 471–490.

World Bank 2012: Turn down the heat; why a 40C warmer world must be avoided. Washington DC. World Bank.

Yanda PZ 2010: Climate Change Impacts, Vulnerability and Adaptation in Southern Africa, In Kotecha P (ed) 2010: Climate Change Adaptation and Higher Education: Securing our Future, SARUA leadership dialogue Series 2, (4) 2010.

Yang LH and Rudolf VHW 2010: Phenology, ontogeny and the effects of climate change on the timing of species interactions. Ecological Letters. 13, 1–10.

Yates CJ, Elith J, Latimer AM, Le Maitre D, Midgley GF and Schurr FM 2010: Projecting climate change impacts on species distributions in megadiverse South African Cape and Southwest Australian Floristic regions: opportunities and challenges. Austral Ecology. 35, 374-391.

Yohe GW and Schlesinger ME 2002: The Economic Geography of the Impacts of Climate Change. Journal of Economic Geography. 2, 311–41.

Yospin GI, Bridgham SD, Neilson RP, Bolte JP, Bachelet DM, Gould PJ and Johnson BR 2015: A new model to simulate climate-change impacts on forest succession for local land management. Ecological Applications. 25, 226-242.

Yvon-Durocher G, Jones JI, Trimmer M, Woodward G and Montoya JM 2010: Warming alters the metabolic balance of ecosystems. Philosophical Transactions of the Royal Society. 365, 2117– 2126.

Zelazowski P, Malhi Y, Huntingford C, Sitch S and Fisher JB 2011: Changes in the potential distribution of humid tropical forests on a warmer planet. Philosophical Transactions of the Royal Society A. 369, 137–160.

Zhakata W, Tsiga A, Mharapara I, Sithole D, Mapanda F, Shekede MD, Ndidzano K, Matingo E, Dzvairo W, Machona M(eds.) 2016: Zimbabwe Third National Communication to the United Nations Framework Convention on Climate Change. Harare: Design@7 Visual Works.

Zhao Y, Zeng Y, Zhao D, Wu B, and Zhao Q 2016: The optimal leaf biochemical selection for mapping species diversity based on imaging spectroscopy. Remote Sensing. 8, 216.

Zhou NM 2004: Vegetation Soil Relationships as Aids to Soil Survey in Semi-Arid Areas. A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy. Department of Soil Science and Agricultural Engineering. Faculty of Agriculture. University of Zimbabwe.

Ziervogel G and Calder R 2003: Climate variability and rural livelihoods: Assessing the impact of seasonal climate forecasts. Area. 35, 403–417.

ZimStat 2012: Zimbabwe Population Census 2012.Masvingo Province. Harare. ZIMSTATS.

Ziska LH, Blumenthal DM, Runion GB, Hunt ER and Diaz-Soltero H 2011: Invasive species and climate change: an agronomic perspective. Climate Change. 105, 13–42.

Appendix 1: Observations and Measurements Guide

Plot ID…...……………………………………………………

(Land use initial, 2-digits number, district Initial)

OBSERVATIONS GUIDE: IMPACT OF CLIMATE CHANGE ON NATURAL VEGETATIVE SPECIES DIVERSITY

1. **Initial position**	UTM Datum WGS84			Final position	UTM Datum WGS84		
X				X			
Y				Y			
Error				Error			
Elevation (3 data)				Elevation (3 data)			
Reason of change of position							
2. Site description							

3. Level of human disturbance	High	Medium	Low	None
4. Major landform	level	sloping	Steep	Composite
5. Landform designation	Plain	med gradient mountain	high gradient mountain	valley
	Plateau	medium gradient hill	high gradient hill	Narrow plateau
	Major depression	med gradient escarpment	High gradient escarpment	major depression
	Low gradient foot slope	ridges	high gradient valley	
	Valley floor	Mountainous highland		
		Dissected plain		

6. Main Land cover class	primarily vegetated area	Primarily non vegetated area	Cultivated/managed	artificial surfaces	bare areas

7. Dominant vegetation type	trees	shrubs	Graminoids	forbs	other:

8. Wood leaf type and phenology	1. Broad leaf	2. Needle leaf	3. Allophytic (aphylous)	
	1. Evergreen	2. Deciduous	3. mixed	
9. Woody cover rating	1. absent	2. <15%	3. 16-65%	4. >65%
10. Woody cover spatial distribution	1. Continuous	2. Fragmented stripped		
11. Woodland type	1. Natural	2. plantation	3. Orchard	4. other

12. Vegetation strata description				
13. General vegetation distribution	**1.** continuous	**2.** scattered clustered	**3.** scattered isolated	
14. Veg. cover>4%	1. Yes	2. No		
15. Herbaceous cover type	**1.** Graminoids	**2.** Non Graminoids		
16. Herbaceous cover rating	**1.** absent	**2.** <15%	**3.** 16-65%	**4.** >65%
17. Herbaceous height (cm)	**1.** 0_30	**2.** 31_99	**3.** 100_199	**4.** 200_300
18. Herbaceous annual?	1. Yes	2. No		
19. Grassland type	1. Natural	2. Lawns	3. Parkland	4. Paddock

20. Site	**Environmental aspect**	**Level of climate change impact**					**Remark**
		No Impact	Negligible impact	Significant Impact	Severe Impact	N/A	
Forest	Herbaceous diversity						
	Tree diversity						
	Graminoids diversity						

Comments………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

……………………………………………………………

Name of vegetative species identified	Description (native/non native)	Av. height	DBH	No.	A.R.
Total number of species					

DBH=Diameter at breast height,   A.R=Abundance ranking

Appendix II: Sampling Plot Locations

Plot number	District	Lat	Lon
1	Gutu	-19.2964	30.9267
2	Gutu	-19.2988	30.9721
3	Gutu	-19.3302	30.9496
4	Gutu	-19.4705	30.8809
5	Gutu	-19.5078	30.8793
6	Gutu	-19.5297	30.9203
7	Gutu	-19.4882	31.2031
8	Gutu	-19.4452	31.1531
9	Gutu	-19.4841	31.139
10	Gutu	-19.5955	30.7581
11	Gutu	-19.6059	30.76
12	Gutu	-19.5937	30.7732
13	Gutu	-19.3505	31.2018
14	Gutu	-19.3571	31.1917
15	Gutu	-19.3727	31.2182
16	Gutu	-19.4407	31.3707
17	Gutu	-19.4279	31.3408
18	Gutu	-19.4604	31.3407
19	Gutu	-19.5381	31.5749
20	Gutu	-19.5649	31.5523
21	Gutu	-19.5862	31.5884
22	Gutu	-19.6453	31.3989
23	Gutu	-19.624	31.3414
24	Gutu	-19.6807	31.4219
25	Gutu	-21.3525	31.8344
26	Gutu	-19.6343	31.2174
27	Gutu	-19.6689	31.2293
28	Gutu	-19.704	31.1707
29	Gutu	-19.752	31.7788
30	Gutu	-19.7846	31.7637
31	Gutu	-19.759	31.7288
32	Gutu	-19.7477	30.7802
33	Gutu	-19.7688	30.7423
34	Gutu	-19.7647	30.768
35	Masvingo	-19.9559	30.789
36	Masvingo	-19.9572	30.7558
37	Masvingo	-19.9417	30.7755
38	Gutu	-19.915	30.9958
39	Masvingo	-19.8823	31.5212
40	Masvingo	-19.9384	31.2221
41	Gutu	-19.9631	30.9487
42	Gutu	-19.9761	31.0091
43	Bikita	-19.9739	31.2311
44	Bikita	19.8723	31.4894
45	Bikita	-19.9149	31.512
46	Bikita	-19.9307	31.9193
47	Bikita	-19.9575	31.8525
48	Bikita	-19.912	31.8572
49	Bikita	-20.0392	32.2057
50	Bikita	-20.0984	32.213
51	Bikita	-20.0671	32.2093
52	Bikita	-20.1254	31.9274
53	Bikita	-20.1187	31.9781
54	Bikita	-20.1664	31.9344
55	Bikita	-20.1502	31.6301
56	Zaka	-20.1668	31.5759
57	Bikita	-20.1977	31.5338
58	Bikita	-20.2876	32.2192
59	Bikita	-20.2464	32.2103
60	Bikita	-20.2465	32.175
61	Masvingo	-20.1687	31.2507
62	Masvingo	-20.2064	31.1863
63	Zaka	-20.249	31.2575
64	Masvingo	-20.1958	30.7956
65	Masvingo	-20.1954	30.7238
66	Masvingo	-20.2227	30.8049
67	Chivi	-20.0872	30.3381
68	Chivi	-20.125	30.304
69	Chivi	-20.1722	30.3155
70	Chiredzi	-20.5	32.2069
71	Chiredzi	-20.4911	32.1515
72	Chiredzi	-20.4933	32.178
73	Chiredzi	-20.4419	31.8201
74	Chiredzi	-20.4889	31.8106
75	Chiredzi	-20.4598	31.746
76	Zaka	-20.4639	31.4237
77	Zaka	-20.475	31.3593
78	Zaka	-20.4973	31.2924
79	Masvingo	-20.4941	31.0059
80	Masvingo	-20.4449	30.9991
81	Masvingo	-20.4985	30.9628
82	Chivi	-20.4942	30.5156
83	Chivi	-20.53	30.4877
84	Chivi	-20.5931	30.5374
85	Chivi	-20.7186	30.7129
86	Chivi	-20.7166	30.7608
87	Chivi	-20.7948	30.7363
88	Masvingo	-20.718	31.067
89	Masvingo	-20.8276	31.0761
90	Masvingo	-20.7694	31.0692
91	Chiredzi	-20.7121	31.3588
92	Chiredzi	-20.6809	31.421
93	Chiredzi	-20.7413	31.4353
94	Chiredzi	-20.6743	31.7011
95	Chiredzi	-20.6855	31.785
96	Chiredzi	-20.7191	31.7395
97	Chiredzi	-20.8555	32.0429
98	Chiredzi	-20.8711	32.1178
99	Chiredzi	-20.9407	32.0601
100	Chiredzi	-20.9319	31.7183

Plot number	District	Lat	Lon
101	Chiredzi	-20.9363	31.651
102	Chiredzi	-20.934	31.579
103	Chiredzi	-20.9558	31.2624
104	Chiredzi	-21.07	31.2333
105	Chiredzi	-21.0117	31.2191
106	Chivi	-20.8971	30.9193
107	Chivi	-20.9239	30.912
108	Chivi	-20.9487	30.9646
109	Mwenezi	-21.0668	30.8537
110	Mwenezi	-21.1001	30.7984
111	Mwenezi	-21.1138	30.8535
112	Chiredzi	-21.1464	32.1295
113	Chiredzi	-21.1891	32.1296
114	Chiredzi	-21.1601	32.0713
115	Mwenezi	-21.1041	30.3854
116	Mwenezi	-21.1023	30.4407
117	Mwenezi	-21.1474	30.486
118	Mwenezi	-21.0622	29.9571
119	Mwenezi	-21.1137	29.9444
120	Mwenezi	-21.1584	29.9243
121	Mwenezi	-21.3168	30.0793
122	Mwenezi	-21.2791	30.133
123	Mwenezi	-21.3308	30.1492
124	Mwenezi	-21.2681	30.4656
125	Mwenezi	-21.3243	30.4819
126	Mwenezi	-21.3224	30.5445
127	Mwenezi	-21.2929	30.8787
128	Mwenezi	-21.2615	30.8623
129	Mwenezi	-21.3259	30.8994
130	Mwenezi	-21.4865	30.2305
131	Mwenezi	-21.4652	30.1944
132	Mwenezi	-21.5113	30.1817
133	Mwenezi	-21.4405	30.4361
134	Mwenezi	-21.4616	30.46
135	Mwenezi	-21.5036	30.4656
136	Mwenezi	-21.6384	30.5532
137	Mwenezi	-21.6432	30.6
138	Mwenezi	-21.6532	30.639
139	Mwenezi	-21.4834	30.7423
140	Mwenezi	-21.4636	30.7004
141	Mwenezi	-21.5239	30.727
142	Mwenezi	-21.7879	30.7328
143	Mwenezi	-21.8271	30.743
144	Mwenezi	-21.8142	30.6995
145	Mwenezi	-21.6331	30.7743
146	Mwenezi	-21.6204	30.7534
147	Mwenezi	-21.5886	30.8212
148	Mwenezi	-21.2951	31.1124
149	Mwenezi	-21.3355	31.0957
150	Mwenezi	-21.3566	31.1406
151	Mwenezi	-21.2703	31.381
152	Mwenezi	-21.3609	31.382
153	Mwenezi	-21.3156	31.3834
154	Chiredzi	-21.2739	31.5382
155	Chiredzi	-21.2774	31.5906
156	Chiredzi	-21.3123	31.5593
157	Chiredzi	-21.2413	31.7444
158	Chiredzi	-21.1853	31.7545
159	Chiredzi	-21.2133	31.7557
160	Chiredzi	-21.0992	31.7732
161	Chiredzi	-21.0783	31.7907
162	Chiredzi	-21.1004	31.8231
163	Mwenezi	-21.4878	31.0393
164	Mwenezi	-21.495	31.0967
165	Mwenezi	-21.5134	31.0642
166	Mwenezi	-21.6211	30.9588
167	Mwenezi	-21.6015	31.0151
168	Mwenezi	-21.6107	30.9863
169	Chiredzi	-21.4759	31.359
170	Chiredzi	-21.5188	31.3126
171	Chiredzi	-21.5213	31.3626
172	Mwenezi	-21.7461	31.1069
173	Mwenezi	-21.7822	31.1268
174	Mwenezi	-21.8038	31.0166
175	Mwenezi	-21.9437	30.8903
176	Mwenezi	-21.9486	30.9342
177	Mwenezi	-22.0033	30.9464
178	Chiredzi	-21.6783	31.4645
179	Chiredzi	-21.6761	31.5508
180	Chiredzi	-21.7109	31.5132
181	Chiredzi	-21.7516	31.7085
182	Chiredzi	-21.769	31.6634
183	Chiredzi	-21.7876	31.6233
184	Chiredzi	-21.3926	31.7782
185	Chiredzi	-21.3926	31.8431
186	Chiredzi	-21.4321	31.8169
187	Chiredzi	-21.3349	32.0955
188	Chiredzi	-21.3884	32.0807
189	Chiredzi	-21.3616	32.0894
190	Chiredzi	-21.5289	31.9274
191	Chiredzi	-21.5183	31.9775
192	Chiredzi	-21.5592	31.9162
193	Chiredzi	-22.0421	31.2573
194	Chiredzi	-22.068	31.3311
195	Chiredzi	-22.0907	31.2663
196	Chiredzi	-22.2108	31.2318
197	Chiredzi	-22.2293	31.1885
198	Chiredzi	-22.2623	31.2115

Appendix III: Household Questionnaire Survey

QUESTIONNAIRE ID____________________**RES CONTACT** __________________________

(LAND USE INITIAL, 2 DIGIT NUMBER, DISTRICT INITIAL) (OPTIONAL FOR FOLLOW UP SURVEYS)

HOUSEHOLD QUESTIONNAIRE SURVEY

Introduction

My name is Chapungu Lazarus, a student from the University of South Africa (UNISA). I am carrying out a research which is part of requirements towards the fulfilment of my studies for DPhil in Environmental Sciences. The research is purely academic but it is sincerely expected that the findings will sift to the local, national and regional policy makers as a body of knowledge that will help in decision making, planning and management of vegetative species diversity in the face of environmental modifications driven by climate change. The broad objective of the study is to assess the impact of climate change on vegetative species diversity in Masvingo province.

The success of this study depends on your participation as an important source of data. In that regard, I kindly seek your support and cooperation through sparing part of your valuable time to respond to this questionnaire document. Kindly note that throughout the entire process, the responses you give are virtuously for academic purposes and will be treated with highest confidentiality to protect your rights and privacy.

SECTION A: BACKGROUND INFORMATION

1. Age in years		**2.** Gender		**3.** Marital status		**4**. Education level	
16-24		Male		Single		Primary	
25-39		Female		Married		Secondary	
40-49				widowed		Tertiary	
50 and above				Other (specify			

5. For how long have you resided in this village? (Tick appropriate box).

i	0-10 years	
ii	11-19 years	
iii	20 years or above	

SECTION B: CLIMATE CHANGE EXPERIENCE

6. Are you aware of the problem of climate change?

Yes ☐ **No** ☐

7. If your answer in 6 is 'Yes', how much climate change have you experienced in your area in terms of:

a. Mean temperature increase? a) None ☐ b) Little ☐ c) Much ☐

b. Mean annual rainfall? a) None ☐ (b) Little ☐ c) Much ☐

c. Minimum seasonal temperatures? a) None ☐ b) Little ☐ c) Much ☐

d. Maximum seasonal temperatures? a)None ☐ b) Little ☐ c) Much ☐

e. Length of the growing season? a) None ☐ b) Little ☐ c) Much ☐

Others: Specify---

8. In terms of mean temperature, how do you describe the changes you experienced in the last 20 – 40 years in the area?

a) None ☐ b) Increase ☐ c) Decrease ☐ d) Not sure ☐

9. In terms of mean rainfall, how do you describe the changes you experienced in the last 20 – 40 years in the area?

a)None ☐ b) Increase ☐ c) Decrease ☐ d) Not sure ☐

10. How do you describe rainfall variability in your area between years?

a) None ☐ b) Little ☐ c) High ☐

11. How frequent is your response in 10?

a) None ☐ b) rare ☐ c) high ☐ d) very high ☐

12. How do you describe rainfall variability in your area within rainy season?

a)None ☐ b) Little ☐ c) High ☐

13. How frequent is your response in 12?

a) None ☐ b) rare ☐ c) high ☐ d) very high ☐

14. How often do you experience drought conditions in your area?

a) None ☐ b) Once every 10 years ☐ c) Twice every 10 years ☐

d) More than twice every 10 years ☐ e) Almost every year ☐

15. How do you describe the frequency of drought conditions in your area?

a) None ☐ b) Low ☐ c) Moderate ☐ d) High ☐

16. How do you describe the severity of the drought conditions in your area?

a) Not severe ☐ b) Less severe ☐ c) Moderately severe ☐ d) High severity ☐

17. How often do you experience floods in your area?

a) Rare ☐ b) Often ☐ c) Very often ☐

18. Overall, what is your experience with regards climate change in your area?

SECTION C: VEGETATIVE SPECIES CHANGES OVER 20-40 YEARS

19. Have you observed any changes in natural vegetation over the past 20-40 years?

a) Yes ☐ b) No ☐

20. If yes, what kind of changes do you observe? *Tick all appropriate.*

a) Increase in invasive species.	
b) Decrease in the number of some indigenous species.	
c) Extinction of some species	

d) Increase in the number of some indigenous species	
e) Others (Specify)	

21. Describe the changes in herbaceous cover. *Tick all applicable.*

a) Change in morphology ☐ b) Change in composition ☐ c) Change in cover ☐

d) Change in phenology ☐

Specify…………………………………………………………………….

22. Describe the changes in tree cover. *Tick all applicable.*

a) Change in morphology ☐ b) Change in composition ☐ c) Change in cover ☐

d) Change in phenology ☐

Specify…………………………………………………………………….

23. What could be the driver(s) of changes in vegetation? *Tick all applicable.*

a) Changes in climatic patterns ☐ b) human activities ☐

c) Others ☐ (Specify)…………………………………………………………………….

24. If you ticked b) in 23. What could be the reason for human activities to drive natural vegetation changes?

a. Agricultural activities	
b. Harvesting tree species for selling.	
c. Harvesting for domestic purposes	
d. Other (*Specify*)	

25. Do you think climate change is contributing to hardships and unemployment in your area?

Yes ☐ No ☐

26. To what extend do you think Climate Change results in changes in the variety of vegetation species?

a) None ☐ b) Little ☐ c) Moderate ☐ d) Great ☐

27. Kindly list natural vegetation species that have decreased in number in your area over the past 20-40 years.

……
……
……………………………………………………………………………………
…………………………………………………………………………………………………
28. Kindly list natural vegetation species that have increased in number in your area over the past 20-40 years.
……
……
……………………………………………………………………………………
…………………………………………………………………………………………………
29. Overall, what is your comment about climate change and its impact on vegetative species diversity?
……
……
……………………………………………………………………………………
…………………………………………………………………………………………………

The END

Thank you so much for your participation in this survey. Your contribution is greatly valued.

Appendix IV: Computed H and 1/D indices

District	Lat	Lon	No. tree species	Species	number	Pi	Pi2	Log Pi	Pi Ln pi	H	1/D
Gutu	-19.296	30.927	2	a	3	0.375	0.140625	-0.9808293	-0.367811	0.66	1.88
				b	5	0.625	0.390625	-0.4700036	-0.2937523		
					8		0.53125		-0.6615632		
Gutu	-19.299	30.972	3	a	2	0.2222222	0.0493827	-1.5040774	-0.3342394	1.06	2.79
				b	3	0.3333333	0.1111111	-1.0986123	-0.3662041		
				c	4	0.4444444	0.1975309	-0.8109302	-0.3604134		
					9		0.3580247		-1.0608569		
Gutu	-19.33	30.95	2	a	2	0.25	0.0625	-1.3862944	-0.3465736	0.56	1.60
				b	6	0.75	0.5625	-0.2876821	-0.2157616		
					8		0.625		-0.5623351		
Gutu	-19.471	30.881	2	a	2	0.6666667	0.4444444	-0.4054651	-0.2703101	0.64	1.80
				b	1	0.3333333	0.1111111	-1.0986123	-0.3662041		
					3		0.5555556		-0.6365142		
Gutu	-19.508	30.879	6	a	4	0.2	0.04	-1.6094379	-0.3218876	1.58	4.08
				b	2	0.1	0.01	-2.3025851	-0.2302585		
				c	8	0.4	0.16	-0.9162907	-0.3665163		
				d	3	0.15	0.0225	-1.89712	-0.284568		
				e	1	0.05	0.0025	-2.9957323	-0.1497866		
				f	2	0.1	0.01	-2.3025851	-0.2302585		
					20		0.245		-1.5832755		
Gutu	-19.53	30.92	5	a	3	0.2727273	0.0743802	-1.299283	-0.3543499	1.55	4.48
				b	2	0.1818182	0.0330579	-1.7047481	-0.3099542		
				c	2	0.1818182	0.0330579	-1.7047481	-0.3099542		
				d	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
				e	3	0.2727273	0.0743802	-1.299283	-0.3543499		
					11		0.2231405		-1.5465987		
Gutu	-19.488	31.203	7	a	2	0.0952381	0.0090703	-2.3513753	-0.2239405	1.79	5.31
				b	5	0.2380952	0.0566893	-1.4350845	-0.3416868		
				c	6	0.2857143	0.0816327	-1.252763	-0.3579323		
				d	1	0.047619	0.0022676	-3.0445224	-0.1449773		
				e	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				f	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
				g	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
					21		0.1882086		-1.794405		
Gutu	-19.445	31.153	6	a	4	0.2	0.04	-1.6094379	-0.3218876	1.66	4.65
				b	2	0.1	0.01	-2.3025851	-0.2302585		
				c	7	0.35	0.1225	-1.0498221	-0.3674377		
				d	2	0.1	0.01	-2.3025851	-0.2302585		
				e	3	0.15	0.0225	-1.89712	-0.284568		
				f	2	0.1	0.01	-2.3025851	-0.2302585		

					20		0.215		-1.6646689		
Gutu	-19.484	31.139	4	a	3	0.25	0.0625	-1.3862944	-0.3465736	1.36	3.79
				b	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				c	4	0.3333333	0.1111111	-1.0986123	-0.3662041		
				d	3	0.25	0.0625	-1.3862944	-0.3465736		
					12		0.2638889		-1.3579779		
Gutu	-19.596	30.758	2	a	4	0.5	0.25	-0.6931472	-0.3465736	0.69	2.00
				b	4	0.5	0.25	-0.6931472	-0.3465736		
					8		0.5		-0.6931472		
Gutu	-19.606	30.76	4	a	1	0.0833333	0.0069444	-2.4849066	-0.2070756	1.20	2.88
				b	3	0.25	0.0625	-1.3862944	-0.3465736		
				c	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				d	6	0.5	0.25	-0.6931472	-0.3465736		
					12		0.3472222		-1.1988493		
Gutu	-19.594	30.773	6	a	3	0.2307692	0.0532544	-1.4663371	-0.3383855	1.67	4.83
				b	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				c	2	0.1538462	0.0236686	-1.8718022	-0.2879696		
				d	4	0.3076923	0.0946746	-1.178655	-0.3626631		
				e	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				f	2	0.1538462	0.0236686	-1.8718022	-0.2879696		
					13		0.2071006		-1.6715953		
Gutu	-19.351	31.202	5	a	3	0.2	0.04	-1.6094379	-0.3218876	1.49	4.09
				b	2	0.1333333	0.0177778	-2.014903	-0.2686537		
				c	4	0.2666667	0.0711111	-1.3217558	-0.3524682		
				d	5	0.3333333	0.1111111	-1.0986123	-0.3662041		
				e	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
					15		0.2444444		-1.4897503		
Gutu	-19.357	31.192	3	a	2	0.3333333	0.1111111	-1.0986123	-0.3662041	1.01	2.57
				b	3	0.5	0.25	-0.6931472	-0.3465736		
				c	1	0.1666667	0.0277778	-1.7917595	-0.2986266		
					6		0.3888889		-1.0114043		
Gutu	-19.373	31.218	4	a	3	0.3333333	0.1111111	-1.0986123	-0.3662041	1.31	3.52
				b	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
				c	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				d	3	0.3333333	0.1111111	-1.0986123	-0.3662041		
					9		0.2839506		-1.3107837		
Gutu	-19.441	31.371	3	a	2	0.4	0.16	-0.9162907	-0.3665163	1.05	2.78
				b	1	0.2	0.04	-1.6094379	-0.3218876		
				c	2	0.4	0.16	-0.9162907	-0.3665163		
					5		0.36		-1.0549202		
Gutu	-19.428	31.341	12	a	3	0.1	0.01	-2.3025851	-0.2302585	2.42	#####
				b	1	0.0333333	0.0011111	-3.4011974	-0.1133732		
				c	2	0.0666667	0.0044444	-2.7080502	-0.1805367		
				d	4	0.1333333	0.0177778	-2.014903	-0.2686537		
				e	3	0.1	0.01	-2.3025851	-0.2302585		

				f	2	0.0666667	0.0044444	-2.7080502	-0.1805367		
				g	3	0.1	0.01	-2.3025851	-0.2302585		
				h	3	0.1	0.01	-2.3025851	-0.2302585		
				i	2	0.0666667	0.0044444	-2.7080502	-0.1805367		
				j	1	0.0333333	0.0011111	-3.4011974	-0.1133732		
				k	3	0.1	0.01	-2.3025851	-0.2302585		
				l	3	0.1	0.01	-2.3025851	-0.2302585		
					30		0.0933333		-2.4185613		
Gutu	-19.46	31.341	12	a	2	0.0769231	0.0059172	-2.5649494	-0.1973038	2.40	#####
				b	2	0.0769231	0.0059172	-2.5649494	-0.1973038		
				c	1	0.0384615	0.0014793	-3.2580965	-0.1253114		
				d	3	0.1153846	0.0133136	-2.1594842	-0.2491713		
				e	2	0.0769231	0.0059172	-2.5649494	-0.1973038		
				f	4	0.1538462	0.0236686	-1.8718022	-0.2879696		
				g	3	0.1153846	0.0133136	-2.1594842	-0.2491713		
				h	3	0.1153846	0.0133136	-2.1594842	-0.2491713		
				i	2	0.0769231	0.0059172	-2.5649494	-0.1973038		
				j	1	0.0384615	0.0014793	-3.2580965	-0.1253114		
				k	1	0.0384615	0.0014793	-3.2580965	-0.1253114		
				l	2	0.0769231	0.0059172	-2.5649494	-0.1973038		
					26		0.0976331		-2.3979365		
Gutu	-19.538	31.575	8	a	1	0.0625	0.0039063	-2.7725887	-0.1732868	1.98	6.74
				b	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				c	3	0.1875	0.0351563	-1.6739764	-0.3138706		
				d	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				e	2	0.125	0.015625	-2.0794415	-0.2599302		
				f	2	0.125	0.015625	-2.0794415	-0.2599302		
				g	3	0.1875	0.0351563	-1.6739764	-0.3138706		
				h	3	0.1875	0.0351563	-1.6739764	-0.3138706		
					16		0.1484375		-1.9813325		
Gutu	-19.565	31.552	4	a	3	0.3	0.09	-1.2039728	-0.3611918	1.28	3.33
				b	4	0.4	0.16	-0.9162907	-0.3665163		
				c	1	0.1	0.01	-2.3025851	-0.2302585		
				d	2	0.2	0.04	-1.6094379	-0.3218876		
					10		0.3		-1.2798542		
Gutu	-19.586	31.588	4	a	2	0.2222222	0.0493827	-1.5040774	-0.3342394	1.31	3.52
				b	3	0.3333333	0.1111111	-1.0986123	-0.3662041		
				c	3	0.3333333	0.1111111	-1.0986123	-0.3662041		
				d	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
					9		0.2839506		-1.3107837		
Gutu	-19.645	31.399	1	a	14	1	1	0	0	0.00	1.00
					14	1	1		0		
Gutu	-19.624	31.341	8	a	4	0.2	0.04	-1.6094379	-0.3218876	2.00	6.90
				b	1	0.05	0.0025	-2.9957323	-0.1497866		
				c	2	0.1	0.01	-2.3025851	-0.2302585		
				d	4	0.2	0.04	-1.6094379	-0.3218876		

				e	2	0.1	0.01	-2.3025851	-0.2302585		
				f	3	0.15	0.0225	-1.89712	-0.284568		
				g	2	0.1	0.01	-2.3025851	-0.2302585		
				h	2	0.1	0.01	-2.3025851	-0.2302585		
					20		0.145		-1.9991638		
Gutu	-19.681	31.422	6	a	3	0.25	0.0625	-1.3862944	-0.3465736	1.70	5.14
				b	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				c	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				d	3	0.25	0.0625	-1.3862944	-0.3465736		
				e	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				f	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
					12		0.1944444		-1.7045514		
Gutu	-21.353	31.834	7	a	6	0.3	0.09	-1.2039728	-0.3611918	1.81	5.41
				b	4	0.2	0.04	-1.6094379	-0.3218876		
				c	1	0.05	0.0025	-2.9957323	-0.1497866		
				d	2	0.1	0.01	-2.3025851	-0.2302585		
				e	2	0.1	0.01	-2.3025851	-0.2302585		
				f	3	0.15	0.0225	-1.89712	-0.284568		
				g	2	0.1	0.01	-2.3025851	-0.2302585		
					20		0.185		-1.8082096		
Gutu	-19.634	31.217	5	a	3	0.2	0.04	-1.6094379	-0.3218876	1.59	4.79
				b	4	0.2666667	0.0711111	-1.3217558	-0.3524682		
				c	2	0.1333333	0.0177778	-2.014903	-0.2686537		
				d	3	0.2	0.04	-1.6094379	-0.3218876		
				e	3	0.2	0.04	-1.6094379	-0.3218876		
					15		0.2088889		-1.5867847		
Gutu	-19.669	31.229	3	a	2	0.5	0.25	-0.6931472	-0.3465736	1.04	2.67
				b	1	0.25	0.0625	-1.3862944	-0.3465736		
				c	1	0.25	0.0625	-1.3862944	-0.3465736		
					4		0.375		-1.0397208		
Gutu	-19.704	31.171	6	a	2	0.0952381	0.0090703	-2.3513753	-0.2239405	1.75	5.58
				b	4	0.1904762	0.0362812	-1.6582281	-0.315853		
				c	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
				d	5	0.2380952	0.0566893	-1.4350845	-0.3416868		
				e	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
				f	4	0.1904762	0.0362812	-1.6582281	-0.315853		
					21		0.1791383		-1.7533076		
Gutu	-19.752	31.779	4	a	1	0.0769231	0.0059172	-2.5649494	-0.1973038	1.27	3.31
				b	4	0.3076923	0.0946746	-1.178655	-0.3626631		
				c	3	0.2307692	0.0532544	-1.4663371	-0.3383855		
				d	5	0.3846154	0.147929	-0.9555114	-0.3675044		
					13		0.3017751		-1.2658568		
Gutu	-19.785	31.764	7	a	5	0.25	0.0625	-1.3862944	-0.3465736	1.85	5.88
				b	3	0.15	0.0225	-1.89712	-0.284568		

				c	2	0.1	0.01	-2.3025851	-0.2302585		
				d	4	0.2	0.04	-1.6094379	-0.3218876		
				e	1	0.05	0.0025	-2.9957323	-0.1497866		
				f	3	0.15	0.0225	-1.89712	-0.284568		
				g	2	0.1	0.01	-2.3025851	-0.2302585		
					20		0.17		-1.8479008		
Gutu	-19.759	31.729	8	a	4	0.1904762	0.0362812	-1.6582281	-0.315853	2.00	7.00
				b	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
				c	4	0.1904762	0.0362812	-1.6582281	-0.315853		
				d	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				e	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				f	1	0.047619	0.0022676	-3.0445224	-0.1449773		
				g	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				h	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
					21		0.1428571		-2.004479		
Gutu	-19.748	30.78	8	a	1	0.05	0.0025	-2.9957323	-0.1497866	1.97	6.67
				b	3	0.15	0.0225	-1.89712	-0.284568		
				c	2	0.1	0.01	-2.3025851	-0.2302585		
				d	4	0.2	0.04	-1.6094379	-0.3218876		
				e	2	0.1	0.01	-2.3025851	-0.2302585		
				f	3	0.15	0.0225	-1.89712	-0.284568		
				g	1	0.05	0.0025	-2.9957323	-0.1497866		
				h	4	0.2	0.04	-1.6094379	-0.3218876		
					20		0.15		-1.9730014		
Gutu	-19.769	30.742	10	a	3	0.1111111	0.0123457	-2.1972246	-0.2441361	2.24	9.00
				b	4	0.1481481	0.0219479	-1.9095425	-0.2828952		
				c	2	0.0740741	0.005487	-2.6026897	-0.1927918		
				d	1	0.037037	0.0013717	-3.2958369	-0.122068		
				e	3	0.1111111	0.0123457	-2.1972246	-0.2441361		
				f	2	0.0740741	0.005487	-2.6026897	-0.1927918		
				g	4	0.1481481	0.0219479	-1.9095425	-0.2828952		
				h	3	0.1111111	0.0123457	-2.1972246	-0.2441361		
				i	3	0.1111111	0.0123457	-2.1972246	-0.2441361		
				j	2	0.0740741	0.005487	-2.6026897	-0.1927918		
					27		0.1111111		-2.2427781		
Gutu	-19.765	30.768	8	a	3	0.15	0.0225	-1.89712	-0.284568	2.02	7.14
				b	3	0.15	0.0225	-1.89712	-0.284568		
				c	4	0.2	0.04	-1.6094379	-0.3218876		
				d	1	0.05	0.0025	-2.9957323	-0.1497866		
				e	2	0.1	0.01	-2.3025851	-0.2302585		
				f	3	0.15	0.0225	-1.89712	-0.284568		
				g	2	0.1	0.01	-2.3025851	-0.2302585		
				h	2	0.1	0.01	-2.3025851	-0.2302585		
					20		0.14		-2.0161537		
Masvingo	-19.956	30.789	6	a	5	0.3846154	0.147929	-0.9555114	-0.3675044	1.63	4.33
				b	2	0.1538462	0.0236686	-1.8718022	-0.2879696		

				c	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				d	2	0.1538462	0.0236686	-1.8718022	-0.2879696		
				e	2	0.1538462	0.0236686	-1.8718022	-0.2879696		
				f	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
					13		0.2307692		-1.6260207		
Masvingo	-19.957	30.756	11	a	6	0.2142857	0.0459184	-1.540445	-0.3300954	2.27	8.52
				b	2	0.0714286	0.005102	-2.6390573	-0.1885041		
				c	3	0.1071429	0.0114796	-2.2335922	-0.2393135		
				d	1	0.0357143	0.0012755	-3.3322045	-0.1190073		
				e	2	0.0714286	0.005102	-2.6390573	-0.1885041		
				f	2	0.0714286	0.005102	-2.6390573	-0.1885041		
				g	3	0.1071429	0.0114796	-2.2335922	-0.2393135		
				h	4	0.1428571	0.0204082	-1.9459101	-0.2779872		
				i	1	0.0357143	0.0012755	-3.3322045	-0.1190073		
				j	2	0.0714286	0.005102	-2.6390573	-0.1885041		
				k	2	0.0714286	0.005102	-2.6390573	-0.1885041		
					28		0.1173469		-2.2672445		
Masvingo	-19.942	30.776	9	a	5	0.2941176	0.0865052	-1.2237754	-0.359934	2.00	6.15
				b	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				c	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				d	2	0.1176471	0.0138408	-2.1400662	-0.2517725		
				e	2	0.1176471	0.0138408	-2.1400662	-0.2517725		
				f	3	0.1764706	0.0311419	-1.7346011	-0.3061061		
				g	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				h	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				i	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
					17		0.1626298		-2.002883		
Gutu	-19.915	30.996	9	a	5	0.15625	0.0244141	-1.856298	-0.2900466	2.15	8.26
				b	4	0.125	0.015625	-2.0794415	-0.2599302		
				c	2	0.0625	0.0039063	-2.7725887	-0.1732868		
				d	4	0.125	0.015625	-2.0794415	-0.2599302		
				e	5	0.15625	0.0244141	-1.856298	-0.2900466		
				f	3	0.09375	0.0087891	-2.3671236	-0.2219178		
				g	2	0.0625	0.0039063	-2.7725887	-0.1732868		
				h	4	0.125	0.015625	-2.0794415	-0.2599302		
				i	3	0.09375	0.0087891	-2.3671236	-0.2219178		
					32		0.1210938		-2.150293		
Masvingo	-19.882	31.521	10	a	9	0.2903226	0.0842872	-1.2367626	-0.3590601	2.10	6.72
				b	4	0.1290323	0.0166493	-2.0476928	-0.2642184		
				c	3	0.0967742	0.0093652	-2.3353749	-0.226004		
				d	2	0.0645161	0.0041623	-2.74084	-0.1768284		
				e	3	0.0967742	0.0093652	-2.3353749	-0.226004		
				f	1	0.0322581	0.0010406	-3.4339872	-0.1107738		
				g	2	0.0645161	0.0041623	-2.74084	-0.1768284		
				h	3	0.0967742	0.0093652	-2.3353749	-0.226004		
				i	3	0.0967742	0.0093652	-2.3353749	-0.226004		
				j	1	0.0322581	0.0010406	-3.4339872	-0.1107738		

					31		0.1488033		-2.102499		
Masvingo	-19.938	31.222	8	a	8	0.3478261	0.120983	-1.0560527	-0.3673227	1.82	5.04
				b	1	0.0434783	0.0018904	-3.1354942	-0.1363258		
				c	3	0.1304348	0.0170132	-2.0368819	-0.2656803		
				d	1	0.0434783	0.0018904	-3.1354942	-0.1363258		
				e	1	0.0434783	0.0018904	-3.1354942	-0.1363258		
				f	2	0.0869565	0.0075614	-2.442347	-0.212378		
				g	3	0.1304348	0.0170132	-2.0368819	-0.2656803		
				h	4	0.173913	0.0302457	-1.7491999	-0.3042087		
					23		0.1984877		-1.8242474		
Gutu	-19.963	30.949	9	a	5	0.1470588	0.0216263	-1.9169226	-0.2819004	2.17	8.50
				b	3	0.0882353	0.0077855	-2.4277482	-0.2142131		
				c	4	0.1176471	0.0138408	-2.1400662	-0.2517725		
				d	4	0.1176471	0.0138408	-2.1400662	-0.2517725		
				e	5	0.1470588	0.0216263	-1.9169226	-0.2819004		
				f	3	0.0882353	0.0077855	-2.4277482	-0.2142131		
				g	4	0.1176471	0.0138408	-2.1400662	-0.2517725		
				h	2	0.0588235	0.0034602	-2.8332133	-0.1666596		
				i	4	0.1176471	0.0138408	-2.1400662	-0.2517725		
					34		0.1176471		-2.1659765		
Gutu	-19.976	31.009	6	a	3	0.2142857	0.0459184	-1.540445	-0.3300954	1.73	5.44
				b	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
				c	3	0.2142857	0.0459184	-1.540445	-0.3300954		
				d	1	0.0714286	0.005102	-2.6390573	-0.1885041		
				e	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
				f	3	0.2142857	0.0459184	-1.540445	-0.3300954		
					14		0.1836735		-1.7347645		
Bikita	-19.974	31.231	5	a	4	0.2857143	0.0816327	-1.252763	-0.3579323	1.51	4.26
				b	1	0.0714286	0.005102	-2.6390573	-0.1885041		
				c	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
				d	4	0.2857143	0.0816327	-1.252763	-0.3579323		
				e	3	0.2142857	0.0459184	-1.540445	-0.3300954		
					14		0.2346939		-1.5124512		
Bikita	19.8723	31.489	8	a	5	0.2083333	0.0434028	-1.5686159	-0.326795	1.99	6.86
				b	2	0.0833333	0.0069444	-2.4849066	-0.2070756		
				c	4	0.1666667	0.0277778	-1.7917595	-0.2986266		
				d	3	0.125	0.015625	-2.0794415	-0.2599302		
				e	1	0.0416667	0.0017361	-3.1780538	-0.1324189		
				f	2	0.0833333	0.0069444	-2.4849066	-0.2070756		
				g	3	0.125	0.015625	-2.0794415	-0.2599302		
				h	4	0.1666667	0.0277778	-1.7917595	-0.2986266		
					24		0.1458333		-1.9904785		
Bikita	-19.915	31.512	11	a	3	0.1034483	0.0107015	-2.2686835	-0.2346914	2.31	9.45
				b	2	0.0689655	0.0047562	-2.6741486	-0.184424		
				c	4	0.137931	0.019025	-1.9810015	-0.2732416		
				d	1	0.0344828	0.0011891	-3.3672958	-0.1161136		

				e	3	0.1034483	0.0107015	-2.2686835	-0.2346914		
				f	2	0.0689655	0.0047562	-2.6741486	-0.184424		
				g	4	0.137931	0.019025	-1.9810015	-0.2732416		
				h	2	0.0689655	0.0047562	-2.6741486	-0.184424		
				i	1	0.0344828	0.0011891	-3.3672958	-0.1161136		
				j	4	0.137931	0.019025	-1.9810015	-0.2732416		
				k	3	0.1034483	0.0107015	-2.2686835	-0.2346914		
					29		0.1058264		-2.3092984		
Bikita	-19.931	31.919	6	a	3	0.2	0.04	-1.6094379	-0.3218876	1.71	5.23
				b	4	0.2666667	0.0711111	-1.3217558	-0.3524682		
				c	2	0.1333333	0.0177778	-2.014903	-0.2686537		
				d	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
				e	3	0.2	0.04	-1.6094379	-0.3218876		
				f	2	0.1333333	0.0177778	-2.014903	-0.2686537		
					15		0.1911111		-1.7140875		
Bikita	-19.958	31.853	9	a	1	0.047619	0.0022676	-3.0445224	-0.1449773	2.09	7.47
				b	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
				c	1	0.047619	0.0022676	-3.0445224	-0.1449773		
				d	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
				e	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				f	4	0.1904762	0.0362812	-1.6582281	-0.315853		
				g	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
				h	1	0.047619	0.0022676	-3.0445224	-0.1449773		
				i	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
					21		0.1337868		-2.0866739		
Bikita	-19.912	31.857	9	a	3	0.1428571	0.0204082	-1.9459101	-0.2779872	2.15	8.32
				b	1	0.047619	0.0022676	-3.0445224	-0.1449773		
				c	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				d	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				e	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				f	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
				g	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				h	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
				i	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
					21		0.1201814		-2.1526879		
Bikita	-20.039	32.206	11	a	2	0.0487805	0.0023795	-3.0204249	-0.1473378	2.36	#####
				b	4	0.097561	0.0095181	-2.3272777	-0.2270515		
				c	5	0.1219512	0.0148721	-2.1041342	-0.2566017		
				d	3	0.0731707	0.005354	-2.6149598	-0.1913385		
				e	5	0.1219512	0.0148721	-2.1041342	-0.2566017		
				f	4	0.097561	0.0095181	-2.3272777	-0.2270515		
				g	2	0.0487805	0.0023795	-3.0204249	-0.1473378		
				h	4	0.097561	0.0095181	-2.3272777	-0.2270515		
				i	3	0.0731707	0.005354	-2.6149598	-0.1913385		
				j	5	0.1219512	0.0148721	-2.1041342	-0.2566017		
				k	4	0.097561	0.0095181	-2.3272777	-0.2270515		
					41		0.0981559		-2.3553638		

Bikita	-20.098	32.213	9	a	4	0.1481481	0.0219479	-1.9095425	-0.2828952	2.11	7.67
				b	2	0.0740741	0.005487	-2.6026897	-0.1927918		
				c	1	0.037037	0.0013717	-3.2958369	-0.122068		
				d	5	0.1851852	0.0342936	-1.686399	-0.3122961		
				e	4	0.1481481	0.0219479	-1.9095425	-0.2828952		
				f	3	0.1111111	0.0123457	-2.1972246	-0.2441361		
				g	4	0.1481481	0.0219479	-1.9095425	-0.2828952		
				h	2	0.0740741	0.005487	-2.6026897	-0.1927918		
				i	2	0.0740741	0.005487	-2.6026897	-0.1927918		
					27		0.1303155		-2.1055612		
Bikita	-20.067	32.209	9	a	3	0.1363636	0.018595	-1.9924302	-0.271695	2.11	7.81
				b	1	0.0454545	0.0020661	-3.0910425	-0.1405019		
				c	2	0.0909091	0.0082645	-2.3978953	-0.2179905		
				d	4	0.1818182	0.0330579	-1.7047481	-0.3099542		
				e	3	0.1363636	0.018595	-1.9924302	-0.271695		
				f	3	0.1363636	0.018595	-1.9924302	-0.271695		
				g	1	0.0454545	0.0020661	-3.0910425	-0.1405019		
				h	2	0.0909091	0.0082645	-2.3978953	-0.2179905		
				i	3	0.1363636	0.018595	-1.9924302	-0.271695		
					22		0.1280992		-2.1137191		
Bikita	-20.125	31.927	10	a	4	0.16	0.0256	-1.8325815	-0.293213	2.21	8.56
				b	2	0.08	0.0064	-2.5257286	-0.2020583		
				c	4	0.16	0.0256	-1.8325815	-0.293213		
				d	3	0.12	0.0144	-2.1202635	-0.2544316		
				e	1	0.04	0.0016	-3.2188758	-0.128755		
				f	2	0.08	0.0064	-2.5257286	-0.2020583		
				g	3	0.12	0.0144	-2.1202635	-0.2544316		
				h	2	0.08	0.0064	-2.5257286	-0.2020583		
				i	1	0.04	0.0016	-3.2188758	-0.128755		
				j	3	0.12	0.0144	-2.1202635	-0.2544316		
					25		0.1168		-2.2134059		
Bikita	-20.119	31.978	7	a	4	0.2222222	0.0493827	-1.5040774	-0.3342394	1.88	6.23
				b	3	0.1666667	0.0277778	-1.7917595	-0.2986266		
				c	1	0.0555556	0.0030864	-2.8903718	-0.1605762		
				d	2	0.1111111	0.0123457	-2.1972246	-0.2441361		
				e	3	0.1666667	0.0277778	-1.7917595	-0.2986266		
				f	2	0.1111111	0.0123457	-2.1972246	-0.2441361		
				g	3	0.1666667	0.0277778	-1.7917595	-0.2986266		
					18		0.1604938		-1.8789675		
Bikita	-20.166	31.934	7	a	2	0.1428571	0.0204082	-1.9459101	-0.2779872	2.01	6.13
				b	3	0.2142857	0.0459184	-1.540445	-0.3300954		
				c	1	0.0714286	0.005102	-2.6390573	-0.1885041		
				d	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
				e	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
				f	3	0.2142857	0.0459184	-1.540445	-0.3300954		
				g	1	0.0714286	0.005102	-2.6390573	-0.1885041		

					14		0.1632653		-1.8711604		
Bikita	-20.15	31.63	8	a	4	0.1818182	0.0330579	-1.7047481	-0.3099542	2.01	7.12
				b	2	0.0909091	0.0082645	-2.3978953	-0.2179905		
				c	3	0.1363636	0.018595	-1.9924302	-0.271695		
				d	4	0.1818182	0.0330579	-1.7047481	-0.3099542		
				e	3	0.1363636	0.018595	-1.9924302	-0.271695		
				f	2	0.0909091	0.0082645	-2.3978953	-0.2179905		
				g	1	0.0454545	0.0020661	-3.0910425	-0.1405019		
				h	3	0.1363636	0.018595	-1.9924302	-0.271695		
					22		0.1404959		-2.0114764		
Zaka	-20.167	31.576	8	a	6	0.3333333	0.1111111	-1.0986123	-0.3662041	1.88	5.40
				b	1	0.0555556	0.0030864	-2.8903718	-0.1605762		
				c	2	0.1111111	0.0123457	-2.1972246	-0.2441361		
				d	1	0.0555556	0.0030864	-2.8903718	-0.1605762		
				e	3	0.1666667	0.0277778	-1.7917595	-0.2986266		
				f	2	0.1111111	0.0123457	-2.1972246	-0.2441361		
				g	2	0.1111111	0.0123457	-2.1972246	-0.2441361		
				h	1	0.0555556	0.0030864	-2.8903718	-0.1605762		
					18		0.1851852		-1.8789675		
Bikita	-20.198	31.534	6	a	2	0.2	0.04	-1.6094379	-0.3218876	1.70	5.00
				b	1	0.1	0.01	-2.3025851	-0.2302585		
				c	1	0.1	0.01	-2.3025851	-0.2302585		
				d	2	0.2	0.04	-1.6094379	-0.3218876		
				e	3	0.3	0.09	-1.2039728	-0.3611918		
				f	1	0.1	0.01	-2.3025851	-0.2302585		
					10		0.2		-1.6957425		
Bikita	-20.288	32.219	9	a	4	0.2	0.04	-1.6094379	-0.3218876	2.09	7.41
				b	3	0.15	0.0225	-1.89712	-0.284568		
				c	1	0.05	0.0025	-2.9957323	-0.1497866		
				d	3	0.15	0.0225	-1.89712	-0.284568		
				e	2	0.1	0.01	-2.3025851	-0.2302585		
				f	1	0.05	0.0025	-2.9957323	-0.1497866		
				g	2	0.1	0.01	-2.3025851	-0.2302585		
				h	3	0.15	0.0225	-1.89712	-0.284568		
				i	1	0.05	0.0025	-2.9957323	-0.1497866		
					20		0.135		-2.0854684		
Bikita	-20.246	32.21	8	a	6	0.2307692	0.0532544	-1.4663371	-0.3383855	1.96	6.50
				b	3	0.1153846	0.0133136	-2.1594842	-0.2491713		
				c	5	0.1923077	0.0369822	-1.6486586	-0.3170497		
				d	2	0.0769231	0.0059172	-2.5649494	-0.1973038		
				e	4	0.1538462	0.0236686	-1.8718022	-0.2879696		
				f	1	0.0384615	0.0014793	-3.2580965	-0.1253114		
				g	3	0.1153846	0.0133136	-2.1594842	-0.2491713		
				h	2	0.0769231	0.0059172	-2.5649494	-0.1973038		
					26		0.1538462		-1.9616663		
Bikita	-20.247	32.175	5	a	4	0.3076923	0.0946746	-1.178655	-0.3626631	1.52	4.33

				b	2	0.1538462	0.0236686	-1.8718022	-0.2879696		
				c	3	0.2307692	0.0532544	-1.4663371	-0.3383855		
				d	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				e	3	0.2307692	0.0532544	-1.4663371	-0.3383855		
					13		0.2307692		-1.5247074		
Masvingo	-20.169	31.251	9	a	4	0.1538462	0.0236686	-1.8718022	-0.2879696	2.11	7.68
				b	5	0.1923077	0.0369822	-1.6486586	-0.3170497		
				c	3	0.1153846	0.0133136	-2.1594842	-0.2491713		
				d	4	0.1538462	0.0236686	-1.8718022	-0.2879696		
				e	2	0.0769231	0.0059172	-2.5649494	-0.1973038		
				f	2	0.0769231	0.0059172	-2.5649494	-0.1973038		
				g	2	0.0769231	0.0059172	-2.5649494	-0.1973038		
				h	3	0.1153846	0.0133136	-2.1594842	-0.2491713		
				i	1	0.0384615	0.0014793	-3.2580965	-0.1253114		
					26		0.1301775		-2.1085542		
Masvingo	-20.206	31.186	8	a	7	0.3684211	0.1357341	-0.9985288	-0.367879	1.84	4.95
				b	2	0.1052632	0.0110803	-2.2512918	-0.2369781		
				c	1	0.0526316	0.0027701	-2.944439	-0.1549705		
				d	3	0.1578947	0.0249307	-1.8458267	-0.2914463		
				e	2	0.1052632	0.0110803	-2.2512918	-0.2369781		
				f	1	0.0526316	0.0027701	-2.944439	-0.1549705		
				g	1	0.0526316	0.0027701	-2.944439	-0.1549705		
				h	2	0.1052632	0.0110803	-2.2512918	-0.2369781		
					19		0.2022161		-1.835171		
Zaka	-20.249	31.258	5	a	4	0.4444444	0.1975309	-0.8109302	-0.3604134	1.43	3.52
				b	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				c	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				d	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
				e	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
					9		0.2839506		-1.427061		
Masvingo	-20.196	30.796	6	a	5	0.4545455	0.2066116	-0.7884574	-0.3583897	1.54	3.67
				b	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
				c	2	0.1818182	0.0330579	-1.7047481	-0.3099542		
				d	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
				e	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
				f	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
					11		0.2727273		-1.5403058		
Masvingo	-20.195	30.724	6	a	7	0.4666667	0.2177778	-0.7621401	-0.3556654	1.52	3.57
				b	2	0.1333333	0.0177778	-2.014903	-0.2686537		
				c	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
				d	2	0.1333333	0.0177778	-2.014903	-0.2686537		
				e	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
				f	2	0.1333333	0.0177778	-2.014903	-0.2686537		
					15		0.28		-1.5226999		
Masvingo	-20.223	30.805	5	a	3	0.375	0.140625	-0.9808293	-0.367811	1.49	4.00
				b	1	0.125	0.015625	-2.0794415	-0.2599302		

				c	2	0.25	0.0625	-1.3862944	-0.3465736		
				d	1	0.125	0.015625	-2.0794415	-0.2599302		
				e	1	0.125	0.015625	-2.0794415	-0.2599302		
					8		0.25		-1.4941751		
Chivi	-20.087	30.338	7	a	4	0.3333333	0.1111111	-1.0986123	-0.3662041	1.79	5.14
				b	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				c	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				d	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				e	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				f	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				g	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
					12		0.1944444		-1.7917595		
Chivi	-20.125	30.304	9	a	6	0.2857143	0.0816327	-1.252763	-0.3579323	2.02	6.39
				b	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
				c	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				d	1	0.047619	0.0022676	-3.0445224	-0.1449773		
				e	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
				f	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				g	1	0.047619	0.0022676	-3.0445224	-0.1449773		
				h	1	0.047619	0.0022676	-3.0445224	-0.1449773		
				i	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
					21		0.1564626		-2.0206599		
Chivi	-20.172	30.316	8	a	6	0.3	0.09	-1.2039728	-0.3611918	1.95	6.06
				b	2	0.1	0.01	-2.3025851	-0.2302585		
				c	2	0.1	0.01	-2.3025851	-0.2302585		
				d	3	0.15	0.0225	-1.89712	-0.284568		
				e	2	0.1	0.01	-2.3025851	-0.2302585		
				f	1	0.05	0.0025	-2.9957323	-0.1497866		
				g	2	0.1	0.01	-2.3025851	-0.2302585		
				h	2	0.1	0.01	-2.3025851	-0.2302585		
					20		0.165		-1.946839		
Chiredzi	-20.5	32.207	6	a	5	0.5	0.25	-0.6931472	-0.3465736	1.94	1.92
				b	3	0.3	0.09	-1.2039728	-0.3611918		
				c	2	0.2	0.04	-1.6094379	-0.3218876		
				d	2	0.2	0.04	-1.6094379	-0.3218876		
				e	1	0.1	0.01	-2.3025851	-0.2302585		
				f	3	0.3	0.09	-1.2039728	-0.3611918		
					16		0.52		-1.9429909		
Chiredzi	-20.491	32.152	2	a	3	0.6	0.36	-0.5108256	-0.3064954	0.67	1.92
				b	2	0.4	0.16	-0.9162907	-0.3665163		
					5		0.52		-0.6730117		
Chiredzi	-20.493	32.178	3	a	1	0.25	0.0625	-1.3862944	-0.3465736	1.04	2.67
				b	2	0.5	0.25	-0.6931472	-0.3465736		
				c	1	0.25	0.0625	-1.3862944	-0.3465736		
					4		0.375		-1.0397208		
Chiredzi	-20.442	31.82	2	a	1	0.3333333	0.1111111	-1.0986123	-0.3662041	0.64	1.80

				b	2	0.6666667	0.4444444	-0.4054651	-0.2703101		
					3		0.5555556		-0.6365142		
Chiredzi	-20.489	31.811	2	a	3	0.75	0.5625	-0.2876821	-0.2157616	0.56	1.60
				b	1	0.25	0.0625	-1.3862944	-0.3465736		
					4		0.625		-0.5623351		
Chiredzi	-20.46	31.746	6	a	3	0.1875	0.0351563	-1.6739764	-0.3138706	1.72	5.33
				b	2	0.125	0.015625	-2.0794415	-0.2599302		
				c	4	0.25	0.0625	-1.3862944	-0.3465736		
				d	3	0.1875	0.0351563	-1.6739764	-0.3138706		
				e	3	0.1875	0.0351563	-1.6739764	-0.3138706		
				g	1	0.0625	0.0039063	-2.7725887	-0.1732868		
					16		0.1875		-1.7214023		
Zaka	-20.464	31.424	8	a	4	0.2352941	0.0553633	-1.446919	-0.3404515	1.96	6.42
				b	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				c	2	0.1176471	0.0138408	-2.1400662	-0.2517725		
				d	3	0.1764706	0.0311419	-1.7346011	-0.3061061		
				e	3	0.1764706	0.0311419	-1.7346011	-0.3061061		
				g	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				h	2	0.1176471	0.0138408	-2.1400662	-0.2517725		
				i	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
					17		0.1557093		-1.9561875		
Zaka	-20.475	31.359	6	a	5	0.3571429	0.127551	-1.0296194	-0.3677212	1.67	4.67
				b	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
				c	1	0.0714286	0.005102	-2.6390573	-0.1885041		
				d	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
				e	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
				g	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
					14		0.2142857		-1.668174		
Zaka	-20.497	31.292	2	a	1	0.5	0.25	-0.6931472	0.25	0.50	2.00
				b	1	0.5	0.25	-0.6931472	0.25		
					2		0.5		0.5		
Masvingo	-20.494	31.006	3	a	1	0.2	0.04	-1.6094379	-0.3218876	1.05	2.78
				b	2	0.4	0.16	-0.9162907	-0.3665163		
				c	2	0.4	0.16	-0.9162907	-0.3665163		
					5		0.36		-1.0549202		
Masvingo	-20.445	30.999	6	a	2	0.2	0.04	-1.6094379	-0.3218876	1.70	5.00
				b	3	0.3	0.09	-1.2039728	-0.3611918		
				c	1	0.1	0.01	-2.3025851	-0.2302585		
				d	1	0.1	0.01	-2.3025851	-0.2302585		
				e	1	0.1	0.01	-2.3025851	-0.2302585		
				f	2	0.2	0.04	-1.6094379	-0.3218876		
					10		0.2		-1.6957425		
Masvingo	-20.499	30.963	8	a	1	0.0714286	0.005102	-2.6390573	-0.1885041	2.01	7.00
				b	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
				c	1	0.0714286	0.005102	-2.6390573	-0.1885041		
				d	2	0.1428571	0.0204082	-1.9459101	-0.2779872		

				e	3	0.2142857	0.0459184	-1.540445	-0.3300954		
				f	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
				g	1	0.0714286	0.005102	-2.6390573	-0.1885041		
				h	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
					14		0.1428571		-2.0075563		
Chivi	-20.494	30.516	10	a	4	0.2666667	0.0711111	-1.3217558	-0.3524682	2.15	7.26
				b	2	0.1333333	0.0177778	-2.014903	-0.2686537		
				c	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
				d	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
				e	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
				f	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
				g	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
				h	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
				i	2	0.1333333	0.0177778	-2.014903	-0.2686537		
				j	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
					15		0.1377778		-2.1535325		
Chivi	-20.53	30.488	6	a	4	0.2352941	0.0553633	-1.446919	-0.3404515	1.71	5.25
				b	3	0.1764706	0.0311419	-1.7346011	-0.3061061		
				c	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				d	2	0.1176471	0.0138408	-2.1400662	-0.2517725		
				e	4	0.2352941	0.0553633	-1.446919	-0.3404515		
				f	3	0.1764706	0.0311419	-1.7346011	-0.3061061		
					17		0.1903114		-1.7115473		
Chivi	-20.593	30.537	6	a	1	0.1428571	0.0204082	-1.9459101	-0.2779872	1.75	5.44
				b	2	0.2857143	0.0816327	-1.252763	-0.3579323		
				c	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
				d	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
				e	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
				f	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
					7		0.1836735		-1.7478681		
Chivi	-20.719	30.713	8	a	2	0.1818182	0.0330579	-1.7047481	-0.3099542	1.97	6.37
				b	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
				c	3	0.2727273	0.0743802	-1.299283	-0.3543499		
				d	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
				e	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
				f	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
				g	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
				h	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
					11		0.1570248		-1.972247		
Chivi	-20.717	30.761	8	a	11	0.55	0.3025	-0.597837	-0.3288104	1.54	2.99
				b	2	0.1	0.01	-2.3025851	-0.2302585		
				c	1	0.05	0.0025	-2.9957323	-0.1497866		
				d	2	0.1	0.01	-2.3025851	-0.2302585		
				e	1	0.05	0.0025	-2.9957323	-0.1497866		
				f	1	0.05	0.0025	-2.9957323	-0.1497866		
				g	1	0.05	0.0025	-2.9957323	-0.1497866		

				h	1	0.05	0.0025	-2.9957323	-0.1497866		
					20		0.335		-1.5382604		
Chivi	-20.795	30.736	3	a	2	0.5	0.25	-0.6931472	-0.3465736	1.04	2.67
				b	1	0.25	0.0625	-1.3862944	-0.3465736		
				c	1	0.25	0.0625	-1.3862944	-0.3465736		
					4		0.375		-1.0397208		
Masvingo	-20.718	31.067	7	a	3	0.2307692	0.0532544	-1.4663371	-0.3383855	1.78	5.12
				b	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				c	2	0.1538462	0.0236686	-1.8718022	-0.2879696		
				d	4	0.3076923	0.0946746	-1.178655	-0.3626631		
				e	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				f	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				g	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
					13		0.1952663		-1.7782333		
Masvingo	-20.828	31.076	8	a	3	0.25	0.0625	-1.3862944	-0.3465736	1.98	6.55
				b	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				c	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				d	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				e	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				f	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				g	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				h	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
					12		0.1527778		-1.9792045		
Masvingo	-20.769	31.069	11	a	1	0.0526316	0.0027701	-2.944439	-0.1549705	2.26	8.40
				b	2	0.1052632	0.0110803	-2.2512918	-0.2369781		
				c	1	0.0526316	0.0027701	-2.944439	-0.1549705		
				d	1	0.0526316	0.0027701	-2.944439	-0.1549705		
				e	2	0.1052632	0.0110803	-2.2512918	-0.2369781		
				f	3	0.1578947	0.0249307	-1.8458267	-0.2914463		
				g	1	0.0526316	0.0027701	-2.944439	-0.1549705		
				h	1	0.0526316	0.0027701	-2.944439	-0.1549705		
				i	1	0.0526316	0.0027701	-2.944439	-0.1549705		
				j	2	0.1052632	0.0110803	-2.2512918	-0.2369781		
				k	4	0.2105263	0.0443213	-1.5581446	-0.3280304		
					19		0.1191136		-2.2602339		
Chiredzi	-20.712	31.359	8	a	4	0.2222222	0.0493827	-1.5040774	-0.3342394	1.94	6.23
				b	3	0.1666667	0.0277778	-1.7917595	-0.2986266		
				c	2	0.1111111	0.0123457	-2.1972246	-0.2441361		
				d	4	0.2222222	0.0493827	-1.5040774	-0.3342394		
				e	1	0.0555556	0.0030864	-2.8903718	-0.1605762		
				f	1	0.0555556	0.0030864	-2.8903718	-0.1605762		
				g	1	0.0555556	0.0030864	-2.8903718	-0.1605762		
				h	2	0.1111111	0.0123457	-2.1972246	-0.2441361		
					18		0.1604938		-1.9371062		
Chiredzi	-20.681	31.421	8	a	2	0.1666667	0.0277778	-1.7917595	-0.2986266	2.02	7.20
				b	1	0.0833333	0.0069444	-2.4849066	-0.2070756		

				c	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				d	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				e	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				f	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				g	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				h	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
					12		0.1388889		-2.0228085		
Chiredzi	-20.741	31.435	10	a	1	0.0625	0.0039063	-2.7725887	-0.1732868	2.25	8.00
				b	4	0.25	0.0625	-1.3862944	-0.3465736		
				c	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				d	2	0.125	0.015625	-2.0794415	-0.2599302		
				e	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				f	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				g	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				h	2	0.125	0.015625	-2.0794415	-0.2599302		
				i	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				j	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				k	1	0.0625	0.0039063	-2.7725887	-0.1732868		
					16		0.125		-2.2527283		
Chiredzi	-20.674	31.701	9	a	2	0.1111111	0.0123457	-2.1972246	-0.2441361	2.11	7.71
				b	3	0.1666667	0.0277778	-1.7917595	-0.2986266		
				c	1	0.0555556	0.0030864	-2.8903718	-0.1605762		
				d	2	0.1111111	0.0123457	-2.1972246	-0.2441361		
				e	1	0.0555556	0.0030864	-2.8903718	-0.1605762		
				f	3	0.1666667	0.0277778	-1.7917595	-0.2986266		
				g	1	0.0555556	0.0030864	-2.8903718	-0.1605762		
				h	2	0.1111111	0.0123457	-2.1972246	-0.2441361		
				i	3	0.1666667	0.0277778	-1.7917595	-0.2986266		
					18		0.1296296		-2.1100166		
Chiredzi	-20.686	31.785	11	a	4	0.2352941	0.0553633	-1.446919	-0.3404515	2.23	7.81
				b	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				c	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				d	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				e	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				f	3	0.1764706	0.0311419	-1.7346011	-0.3061061		
				g	2	0.1176471	0.0138408	-2.1400662	-0.2517725		
				h	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				i	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				j	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				k	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
					17		0.1280277		-2.231607		
Chiredzi	-20.719	31.74	10	a	6	0.2857143	0.0816327	-1.252763	-0.3579323	2.11	6.78
				b	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
				c	1	0.047619	0.0022676	-3.0445224	-0.1449773		
				d	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				e	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				f	2	0.0952381	0.0090703	-2.3513753	-0.2239405		

				g	1	0.047619	0.0022676	-3.0445224	-0.1449773			
				h	2	0.0952381	0.0090703	-2.3513753	-0.2239405			
				i	1	0.047619	0.0022676	-3.0445224	-0.1449773			
				j	1	0.047619	0.0022676	-3.0445224	-0.1449773			
					21		0.1473923		-2.1115905			
Chiredzi	-20.856	32.043	9	a	3	0.1666667	0.0277778	-1.7917595	-0.2986266	1.96	5.59	
				b	1	0.0555556	0.0030864	-2.8903718	-0.1605762			
				c	2	0.1111111	0.0123457	-2.1972246	-0.2441361			
				d	6	0.3333333	0.1111111	-1.0986123	-0.3662041			
				e	2	0.1111111	0.0123457	-2.1972246	-0.2441361			
				f	1	0.0555556	0.0030864	-2.8903718	-0.1605762			
				g	1	0.0555556	0.0030864	-2.8903718	-0.1605762			
				h	1	0.0555556	0.0030864	-2.8903718	-0.1605762			
				i	1	0.0555556	0.0030864	-2.8903718	-0.1605762			
					18		0.1790123		-1.9559838			
Chiredzi	-20.871	32.118	10	a	4	0.2857143	0.0816327	-1.252763	-0.3579323	2.14	7.00	
				b	2	0.1428571	0.0204082	-1.9459101	-0.2779872			
				c	1	0.0714286	0.005102	-2.6390573	-0.1885041			
				d	1	0.0714286	0.005102	-2.6390573	-0.1885041			
				e	1	0.0714286	0.005102	-2.6390573	-0.1885041			
				f	1	0.0714286	0.005102	-2.6390573	-0.1885041			
				g	1	0.0714286	0.005102	-2.6390573	-0.1885041			
				h	1	0.0714286	0.005102	-2.6390573	-0.1885041			
				i	1	0.0714286	0.005102	-2.6390573	-0.1885041			
				j	1	0.0714286	0.005102	-2.6390573	-0.1885041			
					14		0.1428571		-2.1439522			
Chiredzi	-20.941	32.06	12	a	1	0.0588235	0.0034602	-2.8332133	-0.1666596	2.34	8.76	
				b	1	0.0588235	0.0034602	-2.8332133	-0.1666596			
				c	2	0.1176471	0.0138408	-2.1400662	-0.2517725			
				d	4	0.2352941	0.0553633	-1.446919	-0.3404515			
				e	2	0.1176471	0.0138408	-2.1400662	-0.2517725			
				f	1	0.0588235	0.0034602	-2.8332133	-0.1666596			
				g	1	0.0588235	0.0034602	-2.8332133	-0.1666596			
				h	1	0.0588235	0.0034602	-2.8332133	-0.1666596			
				i	1	0.0588235	0.0034602	-2.8332133	-0.1666596			
				j	1	0.0588235	0.0034602	-2.8332133	-0.1666596			
				k	1	0.0588235	0.0034602	-2.8332133	-0.1666596			
				l	1	0.0588235	0.0034602	-2.8332133	-0.1666596			
					17		0.1141869		-2.343933			
Chiredzi	-20.932	31.718	6	a	3	0.2727273	0.0743802	-1.299283	-0.3543499	1.67	4.84	
				b	2	0.1818182	0.0330579	-1.7047481	-0.3099542			
				c	1	0.0909091	0.0082645	-2.3978953	-0.2179905			
				d	1	0.0909091	0.0082645	-2.3978953	-0.2179905			
				e	1	0.0909091	0.0082645	-2.3978953	-0.2179905			
				f	3	0.2727273	0.0743802	-1.299283	-0.3543499			
					11		0.2066116		-1.6726254			

Chiredzi	-20.936	31.651	4	a	1	0.1111111	0.0123457	-2.1972246	-0.2441361	1.15	2.61
				b	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
				c	5	0.5555556	0.308642	-0.5877867	-0.3265481		
				d	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
					9		0.382716		-1.1490597		
Chiredzi	-20.934	31.579	8	a	3	0.1875	0.0351563	-1.6739764	-0.3138706	1.89	5.57
				b	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				c	2	0.125	0.015625	-2.0794415	-0.2599302		
				d	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				e	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				f	2	0.125	0.015625	-2.0794415	-0.2599302		
				g	5	0.3125	0.0976563	-1.1631508	-0.3634846		
				h	1	0.0625	0.0039063	-2.7725887	-0.1732868		
					16		0.1796875		-1.8903628		
Chiredzi	-20.956	31.262	6	a	4	0.4	0.16	-0.9162907	-0.3665163	1.61	4.17
				b	2	0.2	0.04	-1.6094379	-0.3218876		
				c	1	0.1	0.01	-2.3025851	-0.2302585		
				d	1	0.1	0.01	-2.3025851	-0.2302585		
				e	1	0.1	0.01	-2.3025851	-0.2302585		
				f	1	0.1	0.01	-2.3025851	-0.2302585		
					10		0.24		-1.6094379		
Chiredzi	-21.07	31.233	11	a	5	0.2380952	0.0566893	-1.4350845	-0.3416868	2.24	8.02
				b	1	0.047619	0.0022676	-3.0445224	-0.1449773		
				c	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				d	1	0.047619	0.0022676	-3.0445224	-0.1449773		
				e	1	0.047619	0.0022676	-3.0445224	-0.1449773		
				f	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				g	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				h	1	0.047619	0.0022676	-3.0445224	-0.1449773		
				i	2	0.0952381	0.0090703	-2.3513753	-0.2239405		
				j	3	0.1428571	0.0204082	-1.9459101	-0.2779872		
				k	1	0.047619	0.0022676	-3.0445224	-0.1449773		
					21		0.1247166		-2.2403223		
Chiredzi	-21.012	31.219	4	a	1	0.1666667	0.0277778	-1.7917595	-0.2986266	1.24	3.00
				b	3	0.5	0.25	-0.6931472	-0.3465736		
				c	1	0.1666667	0.0277778	-1.7917595	-0.2986266		
				d	1	0.1666667	0.0277778	-1.7917595	-0.2986266		
					6		0.3333333		-1.2424533		
Chivi	-20.897	30.919	1	a	4	1	1	0	0	0.00	1.00
					4		1		0		
Chivi	-20.9239	30.912	8	a	3	0.1578947	0.0249307	-1.8458267	-0.2914463	1.75	4.25
				b	8	0.4210526	0.1772853	-0.8649974	-0.3642094		
				c	2	0.1052632	0.0110803	-2.2512918	-0.2369781		
				d	1	0.0526316	0.0027701	-2.944439	-0.1549705		
				e	1	0.0526316	0.0027701	-2.944439	-0.1549705		
				f	1	0.0526316	0.0027701	-2.944439	-0.1549705		

				g	2	0.1052632	0.0110803	-2.2512918	-0.2369781		
				h	1	0.0526316	0.0027701	-2.944439	-0.1549705		
					19		0.2354571		-1.7494938		
Chivi	-20.9487	30.965	6	a	4	0.3333333	0.1111111	-1.0986123	-0.3662041	1.68	4.80
				b	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				c	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				d	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				e	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				f	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
					12		0.2083333		-1.6762349		
Mwenezi	-21.067	30.854	8	a	2	0.125	0.015625	-2.0794415	-0.2599302	1.75	4.13
				b	7	0.4375	0.1914063	-0.8266786	-0.3616719		
				c	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				d	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				e	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				f	2	0.125	0.015625	-2.0794415	-0.2599302		
				g	1	0.0625	0.0039063	-2.7725887	-0.1732868		
				h	1	0.0625	0.0039063	-2.7725887	-0.1732868		
					16		0.2421875		-1.7479662		
Mwenezi	-21.1	30.798	7	a	3	0.3333333	0.1111111	-1.0986123	-0.3662041	1.83	5.40
				b	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				c	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				d	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				e	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				f	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				g	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
					9		0.1851852		-1.8310205		
Mwenezi	-21.114	30.854	6	a	1	0.1111111	0.0123457	-2.1972246	-0.2441361	1.68	4.76
				b	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				c	3	0.3333333	0.1111111	-1.0986123	-0.3662041		
				d	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
				e	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				f	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
					9		0.2098765		-1.6769878		
Chiredzi	-21.146	32.13	8	a	4	0.2666667	0.0711111	-1.3217558	-0.3524682	1.93	6.08
				b	3	0.2	0.04	-1.6094379	-0.3218876		
				c	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
				d	2	0.1333333	0.0177778	-2.014903	-0.2686537		
				e	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
				f	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
				h	2	0.1333333	0.0177778	-2.014903	-0.2686537		
				i	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
					15		0.1644444		-1.93381		
Chiredzi	-21.189	32.13	8	a	2	0.1666667	0.0277778	-1.7917595	-0.2986266	1.98	6.55
				b	3	0.25	0.0625	-1.3862944	-0.3465736		

				c	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				d	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				e	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				f	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				h	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				i	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
					12		0.1527778		-1.9792045		
Chiredzi	-21.16	32.071	6	a	1	0.1428571	0.0204082	-1.9459101	-0.2779872	1.75	5.44
				b	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
				c	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
				d	2	0.2857143	0.0816327	-1.252763	-0.3579323		
				e	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
				f	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
					7		0.1836735		-1.7478681		
Mwenezi	-21.104	30.385	2	a	5	0.7142857	0.5102041	-0.3364722	-0.2403373	0.60	1.69
				b	2	0.2857143	0.0816327	-1.252763	-0.3579323		
					7		0.5918367		-0.5982696		
Mwenezi	-21.102	30.441	6	a	4	0.4	0.16	-0.9162907	-0.3665163	1.61	4.17
				b	2	0.2	0.04	-1.6094379	-0.3218876		
				c	1	0.1	0.01	-2.3025851	-0.2302585		
				d	1	0.1	0.01	-2.3025851	-0.2302585		
				e	1	0.1	0.01	-2.3025851	-0.2302585		
				f	1	0.1	0.01	-2.3025851	-0.2302585		
					10		0.24		-1.6094379		
Mwenezi	-21.147	30.486	3	a	2	0.3333333	0.1111111	-1.0986123	-0.3662041	1.01	2.57
				b	3	0.5	0.25	-0.6931472	-0.3465736		
				c	1	0.1666667	0.0277778	-1.7917595	-0.2986266		
					6		0.3888889		-1.0114043		
Mwenezi	-21.062	29.957	5	a	5	0.3125	0.0976563	-1.1631508	-0.3634846	1.54	4.41
				b	3	0.1875	0.0351563	-1.6739764	-0.3138706		
				c	4	0.25	0.0625	-1.3862944	-0.3465736		
				d	2	0.125	0.015625	-2.0794415	-0.2599302		
				e	2	0.125	0.015625	-2.0794415	-0.2599302		
					16		0.2265625		-1.5437892		
Mwenezi	-21.114	29.944	4	a	3	0.4285714	0.1836735	-0.8472979	-0.3631277	1.28	3.27
				b	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
				c	2	0.2857143	0.0816327	-1.252763	-0.3579323		
				d	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
					7		0.3061224		-1.2770343		
Mwenezi	-21.158	29.924	5	a	2	0.2222222	0.0493827	-1.5040774	-0.3342394	1.58	4.76
				b	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				c	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
				d	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
				e	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
					9		0.2098765		-1.5810938		
Mwenezi	-21.317	30.079	6	a	1	0.125	0.015625	-2.0794415	-0.2599302	1.67	4.57

				b	1	0.125	0.015625	-2.0794415	-0.2599302		
				c	3	0.375	0.140625	-0.9808293	-0.367811		
				d	1	0.125	0.015625	-2.0794415	-0.2599302		
				e	1	0.125	0.015625	-2.0794415	-0.2599302		
				f	1	0.125	0.015625	-2.0794415	-0.2599302		
					8		0.21875		-1.6674619		
Mwenezi	-21.279	30.133	4	a	2	0.4	0.16	-0.9162907	-0.3665163	1.33	3.57
				b	1	0.2	0.04	-1.6094379	-0.3218876		
				c	1	0.2	0.04	-1.6094379	-0.3218876		
				d	1	0.2	0.04	-1.6094379	-0.3218876		
					5		0.28		-1.332179		
Mwenezi	-21.331	30.149	3	a	1	0.1111111	0.0123457	-2.1972246	-0.2441361	0.94	2.31
				b	5	0.5555556	0.308642	-0.5877867	-0.3265481		
				c	3	0.3333333	0.1111111	-1.0986123	-0.3662041		
					9		0.4320988		-0.9368883		
Mwenezi	-21.268	30.466	2	a	3	0.75	0.5625	-0.2876821	-0.2157616	0.56	1.60
				b	1	0.25	0.0625	-1.3862944	-0.3465736		
					4		0.625		-0.5623351		
Mwenezi	-21.324	30.482	4	a	2	0.25	0.0625	-1.3862944	-0.3465736	1.21	2.91
				b	1	0.125	0.015625	-2.0794415	-0.2599302		
				c	4	0.5	0.25	-0.6931472	-0.3465736		
				d	1	0.125	0.015625	-2.0794415	-0.2599302		
					8		0.34375		-1.2130076		
Mwenezi	-21.322	30.545	6	a	1	0.1111111	0.0123457	-2.1972246	-0.2441361	1.74	5.40
				b	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				c	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
				d	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				e	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
				f	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
					9		0.1851852		-1.7351265		
Mwenezi	-21.293	30.879	5	a	3	0.375	0.140625	-0.9808293	-0.367811	1.49	4.00
				b	1	0.125	0.015625	-2.0794415	-0.2599302		
				c	1	0.125	0.015625	-2.0794415	-0.2599302		
				d	2	0.25	0.0625	-1.3862944	-0.3465736		
				e	1	0.125	0.015625	-2.0794415	-0.2599302		
					8		0.25		-1.4941751		
Mwenezi	-21.262	30.862	2	a	5	0.8333333	0.6944444	-0.1823216	-0.1519346	0.45	1.38
				b	1	0.1666667	0.0277778	-1.7917595	-0.2986266		
					6		0.7222222		-0.4505612		
Mwenezi	-21.326	30.899	7	a	4	0.2352941	0.0553633	-1.446919	-0.3404515	1.82	5.67
				b	3	0.1764706	0.0311419	-1.7346011	-0.3061061		
				c	2	0.1176471	0.0138408	-2.1400662	-0.2517725		
				d	4	0.2352941	0.0553633	-1.446919	-0.3404515		
				e	2	0.1176471	0.0138408	-2.1400662	-0.2517725		
				f	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				g	1	0.0588235	0.0034602	-2.8332133	-0.1666596		

					17		0.1764706		-1.8238733		
Mwenezi	-21.487	30.231	1		3	1	1	0	0	0.00	1.00
					3		1		0		
Mwenezi	-21.465	30.194	2	a	2	0.4	0.16	-0.9162907	-0.3665163	0.67	1.92
				b	3	0.6	0.36	-0.5108256	-0.3064954		
					5		0.52		-0.6730117		
Mwenezi	-21.511	30.182	4	a	1	0.125	0.015625	-2.0794415	-0.2599302	1.07	2.29
				b	5	0.625	0.390625	-0.4700036	-0.2937523		
				c	1	0.125	0.015625	-2.0794415	-0.2599302		
				d	1	0.125	0.015625	-2.0794415	-0.2599302		
					8		0.4375		-1.0735428		
Mwenezi	-21.441	30.436	2	a	2	0.6666667	0.4444444	-0.4054651	-0.2703101	0.64	1.80
				b	1	0.3333333	0.1111111	-1.0986123	-0.3662041		
					3		0.5555556		-0.6365142		
Mwenezi	-21.462	30.46	4	a	4	0.5714286	0.3265306	-0.5596158	-0.3197805	1.15	2.58
				b	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
				c	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
				d	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
					7		0.3877551		-1.1537419		
Mwenezi	-21.504	30.466	1	a	1	1	1	0	0	0.00	1.00
					1		1		0		
Mwenezi	-21.638	30.553	5	a	2	0.25	0.0625	-1.3862944	-0.3465736	1.49	4.00
				b	3	0.375	0.140625	-0.9808293	-0.367811		
				c	1	0.125	0.015625	-2.0794415	-0.2599302		
				d	1	0.125	0.015625	-2.0794415	-0.2599302		
				e	1	0.125	0.015625	-2.0794415	-0.2599302		
					8		0.25		-1.4941751		
Mwenezi	-21.643	30.6	6	a	3	0.2	0.04	-1.6094379	-0.3218876	1.64	4.59
				b	5	0.3333333	0.1111111	-1.0986123	-0.3662041		
				c	3	0.2	0.04	-1.6094379	-0.3218876		
				d	2	0.1333333	0.0177778	-2.014903	-0.2686537		
				e	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
				f	1	0.0666667	0.0044444	-2.7080502	-0.1805367		
					15		0.2177778		-1.6397064		
Mwenezi	-21.653	30.639	7	a	3	0.3	0.09	-1.2039728	-0.3611918	1.83	5.56
				b	1	0.1	0.01	-2.3025851	-0.2302585		
				c	1	0.1	0.01	-2.3025851	-0.2302585		
				d	2	0.2	0.04	-1.6094379	-0.3218876		
				e	1	0.1	0.01	-2.3025851	-0.2302585		
				f	1	0.1	0.01	-2.3025851	-0.2302585		
				g	1	0.1	0.01	-2.3025851	-0.2302585		
					10		0.18		-1.834372		
Mwenezi	-21.483	30.742	4	a	1	0.1666667	0.0277778	-1.7917595	-0.2986266	1.24	3.00
				b	1	0.1666667	0.0277778	-1.7917595	-0.2986266		
				c	3	0.5	0.25	-0.6931472	-0.3465736		

				d	1	0.1666667	0.0277778	-1.7917595	-0.2986266		
					6		0.3333333		-1.2424533		
Mwenezi	-21.464	30.7	2	a	1	1	1	0	0	0.00	0.50
				b	1	1	1	0	0		
					2		2		0		
Mwenezi	-21.524	30.727	6	a	3	0.3333333	0.1111111	-1.0986123	-0.3662041	1.68	4.76
				b	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
				c	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				d	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				e	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				f	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
					9		0.2098765		-1.6769878		
Mwenezi	-21.788	30.733	2	a	2	0.4	0.16	-0.9162907	-0.3665163	0.67	1.92
					3	0.6	0.36	-0.5108256	-0.3064954		
					5		0.52		-0.6730117		
Mwenezi	-21.827	30.743	4	a	2	0.4	0.16	-0.9162907	-0.3665163	1.33	3.57
				b	1	0.2	0.04	-1.6094379	-0.3218876		
				c	1	0.2	0.04	-1.6094379	-0.3218876		
				d	1	0.2	0.04	-1.6094379	-0.3218876		
					5		0.28		-1.332179		
Mwenezi	-21.814	30.7	3	a	1	0.1111111	0.0123457	-2.1972246	-0.2441361	0.85	1.98
				b	6	0.6666667	0.4444444	-0.4054651	-0.2703101		
				c	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
					9		0.5061728		-0.8486856		
Mwenezi	-21.633	30.774	1	a	4	1	1	0	0	0.00	1.00
					4		1		0		
Mwenezi	-21.62	30.753	2	a	2	0.6666667	0.4444444	-0.4054651	-0.2703101	0.64	1.80
				b	1	0.3333333	0.1111111	-1.0986123	-0.3662041		
					3		0.5555556		-0.6365142		
Mwenezi	-21.589	30.821	4	a	4	0.3076923	0.0946746	-1.178655	-0.3626631	1.35	3.76
				b	3	0.2307692	0.0532544	-1.4663371	-0.3383855		
				c	4	0.3076923	0.0946746	-1.178655	-0.3626631		
				d	2	0.1538462	0.0236686	-1.8718022	-0.2879696		
					13		0.2662722		-1.3516812		
Mwenezi	-21.295	31.112	5	a	1	0.1666667	0.0277778	-1.7917595	-0.2986266	1.56	4.50
				b	1	0.1666667	0.0277778	-1.7917595	-0.2986266		
				c	2	0.3333333	0.1111111	-1.0986123	-0.3662041		
				d	1	0.1666667	0.0277778	-1.7917595	-0.2986266		
				e	1	0.1666667	0.0277778	-1.7917595	-0.2986266		
					6		0.2222222		-1.5607104		
Mwenezi	-21.336	31.096	3	a	2	0.5	0.25	-0.6931472	-0.3465736	1.04	2.67
				b	1	0.25	0.0625	-1.3862944	-0.3465736		
				c	1	0.25	0.0625	-1.3862944	-0.3465736		
					4		0.375		-1.0397208		

Mwenezi	-21.357	31.141	6	a	3	0.3333333	0.1111111	-1.0986123	-0.3662041	1.68	4.76
				b	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				c	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				d	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				e	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
				f	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
					9		0.2098765		-1.6769878		
Mwenezi	-21.27	31.381	2	a	3	0.75	0.5625	-0.2876821	-0.2157616	0.56	1.60
				b	1	0.25	0.0625	-1.3862944	-0.3465736		
					4		0.625		-0.5623351		
Mwenezi	-21.361	31.382	1	a	2	1	1	0	0	0.00	1.00
					2		1		0		
Mwenezi	-21.316	31.383	3	a	5	0.5555556	0.308642	-0.5877867	-0.3265481	1.00	2.45
				b	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
				c	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
					9		0.4074074		-0.995027		
Chiredzi	-21.274	31.538	5	a	1	0.1111111	0.0123457	-2.1972246	-0.2441361	1.43	3.52
				b	4	0.4444444	0.1975309	-0.8109302	-0.3604134		
				c	2	0.2222222	0.0493827	-1.5040774	-0.3342394		
				d	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
				e	1	0.1111111	0.0123457	-2.1972246	-0.2441361		
					9		0.2839506		-1.427061		
Chiredzi	-21.277	31.591	2	a	5	0.625	0.390625	-0.4700036	-0.2937523	0.66	1.88
				b	3	0.375	0.140625	-0.9808293	-0.367811		
					8		0.53125		-0.6615632		
Chiredzi	-21.312	31.559	3	a	2	0.4	0.16	-0.9162907	-0.3665163	1.05	2.78
				b	1	0.2	0.04	-1.6094379	-0.3218876		
				c	2	0.4	0.16	-0.9162907	-0.3665163		
					5		0.36		-1.0549202		
Chiredzi	-21.241	31.744	9	a	1	0.0588235	0.0034602	-2.8332133	-0.1666596	2.07	7.05
				b	2	0.1176471	0.0138408	-2.1400662	-0.2517725		
				c	2	0.1176471	0.0138408	-2.1400662	-0.2517725		
				d	2	0.1176471	0.0138408	-2.1400662	-0.2517725		
				e	4	0.2352941	0.0553633	-1.446919	-0.3404515		
				f	3	0.1764706	0.0311419	-1.7346011	-0.3061061		
				g	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				h	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
				i	1	0.0588235	0.0034602	-2.8332133	-0.1666596		
					17		0.1418685		-2.0685135		
Chiredzi	-21.185	31.755	5	a	2	0.25	0.0625	-1.3862944	-0.3465736	1.49	4.00
				b	1	0.125	0.015625	-2.0794415	-0.2599302		
				c	3	0.375	0.140625	-0.9808293	-0.367811		
				d	1	0.125	0.015625	-2.0794415	-0.2599302		
				e	1	0.125	0.015625	-2.0794415	-0.2599302		
					8		0.25		-1.4941751		

Chiredzi	-21.213	31.756	8	a	4	0.3076923	0.0946746	-1.178655	-0.3626631	1.93	5.83
				b	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				c	2	0.1538462	0.0236686	-1.8718022	-0.2879696		
				d	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				e	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				f	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				g	2	0.1538462	0.0236686	-1.8718022	-0.2879696		
				h	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
					13		0.1715976		-1.9251212		
Chiredzi	-21.099	31.773	2	a	1	0.3333333	0.1111111	-1.0986123	-0.3662041	0.64	1.80
				b	2	0.6666667	0.4444444	-0.4054651	-0.2703101		
					3		0.5555556		-0.6365142		
Chiredzi	-21.078	31.791	5	a	6	0.5454545	0.2975207	-0.6061358	-0.3306195	1.29	2.81
				b	2	0.1818182	0.0330579	-1.7047481	-0.3099542		
				c	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
				d	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
				e	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
					11		0.3553719		-1.2945452		
Chiredzi	-21.1	31.823	1	a	3	1	1	0	0	0.00	1.00
					3		1		0		
Mwenezi	-21.488	31.039	8	a	2	0.1666667	0.0277778	-1.7917595	-0.2986266	1.98	6.55
				b	3	0.25	0.0625	-1.3862944	-0.3465736		
				c	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				d	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				e	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				f	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				g	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				h	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
					12		0.1527778		-1.9792045		
Mwenezi	-21.495	31.097	9	a	1	0.0714286	0.005102	-2.6390573	-0.1885041	2.11	7.54
				b	1	0.0714286	0.005102	-2.6390573	-0.1885041		
				c	3	0.2142857	0.0459184	-1.540445	-0.3300954		
				d	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
				e	1	0.0714286	0.005102	-2.6390573	-0.1885041		
				f	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
				g	2	0.1428571	0.0204082	-1.9459101	-0.2779872		
				h	1	0.0714286	0.005102	-2.6390573	-0.1885041		
				i	1	0.0714286	0.005102	-2.6390573	-0.1885041		
					14		0.1326531		-2.1065773		
Mwenezi	-21.513	31.064	4	a	2	0.2857143	0.0816327	-1.252763	-0.3579323	1.35	3.77
				b	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
				c	2	0.2857143	0.0816327	-1.252763	-0.3579323		
				d	2	0.2857143	0.0816327	-1.252763	-0.3579323		
					7		0.2653061		-1.351784		
Mwenezi	-21.621	30.959	2	a	2	0.6666667	0.4444444	-0.4054651	-0.2703101	0.64	1.80
				b	1	0.3333333	0.1111111	-1.0986123	-0.3662041		

					3		0.5555556		-0.6365142		
Mwenezi	-21.602	31.015	6	a	1	0.0909091	0.0082645	-2.3978953	-0.2179905	1.54	3.67
				b	5	0.4545455	0.2066116	-0.7884574	-0.3583897		
				c	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
				d	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
				e	2	0.1818182	0.0330579	-1.7047481	-0.3099542		
				f	1	0.0909091	0.0082645	-2.3978953	-0.2179905		
					11		0.2727273		-1.5403058		
Mwenezi	-21.611	30.986	7	a	3	0.2307692	0.0532544	-1.4663371	-0.3383855	1.78	5.12
				b	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				c	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				d	2	0.1538462	0.0236686	-1.8718022	-0.2879696		
				e	4	0.3076923	0.0946746	-1.178655	-0.3626631		
				f	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				g	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
					13		0.1952663		-1.7782333		
Chiredzi	-21.476	31.359	3	a	2	0.4	0.16	-0.9162907	-0.3665163	1.05	2.78
				b	2	0.4	0.16	-0.9162907	-0.3665163		
				c	1	0.2	0.04	-1.6094379	-0.3218876		
					5		0.36		-1.0549202		
Chiredzi	-21.519	31.313	5	a	1	0.125	0.015625	-2.0794415	-0.2599302	1.49	4.00
				b	3	0.375	0.140625	-0.9808293	-0.367811		
				c	2	0.25	0.0625	-1.3862944	-0.3465736		
				d	1	0.125	0.015625	-2.0794415	-0.2599302		
				e	1	0.125	0.015625	-2.0794415	-0.2599302		
					8		0.25		-1.4941751		
Chiredzi	-21.521	31.363	2	a	1	0.5	0.25	-0.6931472	-0.3465736	0.69	2.00
				b	1	0.5	0.25	-0.6931472	-0.3465736		
					2		0.5		-0.6931472		
Mwenezi	-21.746	31.107	8	a	3	0.25	0.0625	-1.3862944	-0.3465736	1.98	6.55
				b	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				c	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				d	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				e	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				f	2	0.1666667	0.0277778	-1.7917595	-0.2986266		
				g	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				h	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
					12		0.1527778		-1.9792045		
Mwenezi	-21.782	31.127	2	a	2	0.5	0.25	-0.6931472	-0.3465736	0.69	2.00
				b	2	0.5	0.25	-0.6931472	-0.3465736		
					4		0.5		-0.6931472		
Mwenezi	-21.804	31.017	5	a	1	0.0833333	0.0069444	-2.4849066	-0.2070756	1.35	3.27
				b	4	0.3333333	0.1111111	-1.0986123	-0.3662041		
				c	5	0.4166667	0.1736111	-0.8754687	-0.3647786		
				d	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				e	1	0.0833333	0.0069444	-2.4849066	-0.2070756		

					12		0.3055556		-1.3522094		
Mwenezi	-21.944	30.89	3	a	1	0.2	0.04	-1.6094379	-0.3218876	0.95	2.27
				b	1	0.2	0.04	-1.6094379	-0.3218876		
				c	3	0.6	0.36	-0.5108256	-0.3064954		
					5		0.44		-0.9502705		
Mwenezi	-21.949	30.934	1	a	3	1	1	0	0	0.00	1.00
					3		1		0		
Mwenezi	-22.003	30.946	3	a	2	0.2857143	0.0816327	-1.252763	-0.3579323	0.96	2.33
				b	4	0.5714286	0.3265306	-0.5596158	-0.3197805		
				c	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
					7		0.4285714		-0.9556999		
Chiredzi	-21.678	31.465	5	a	6	0.5	0.25	-0.6931472	-0.3465736	1.31	3.00
				b	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				c	3	0.25	0.0625	-1.3862944	-0.3465736		
				d	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
				e	1	0.0833333	0.0069444	-2.4849066	-0.2070756		
					12		0.3333333		-1.3143738		
Chiredzi	-21.676	31.551	2	a	3	0.75	0.5625	-0.2876821	-0.2157616	0.56	1.60
				b	1	0.25	0.0625	-1.3862944	-0.3465736		
					4		0.625		-0.5623351		
Chiredzi	-21.711	31.513	4	a	5	0.5	0.25	-0.6931472	-0.3465736	1.22	2.94
				b	1	0.1	0.01	-2.3025851	-0.2302585		
				c	2	0.2	0.04	-1.6094379	-0.3218876		
				d	2	0.2	0.04	-1.6094379	-0.3218876		
					10		0.34		-1.2206073		
Chiredzi	-21.752	31.709	2	a	3	0.4285714	0.1836735	-0.8472979	-0.3631277	0.68	1.96
				b	4	0.5714286	0.3265306	-0.5596158	-0.3197805		
					7		0.5102041		-0.6829081		
Chiredzi	-21.769	31.663	5	a	1	0.0769231	0.0059172	-2.5649494	-0.1973038	1.46	3.93
				b	3	0.2307692	0.0532544	-1.4663371	-0.3383855		
				c	1	0.0769231	0.0059172	-2.5649494	-0.1973038		
				d	4	0.3076923	0.0946746	-1.178655	-0.3626631		
				e	4	0.3076923	0.0946746	-1.178655	-0.3626631		
					13		0.2544379		-1.4583192		
Chiredzi	-21.788	31.623	3	a	3	0.6	0.36	-0.5108256	-0.3064954	0.95	2.27
				b	1	0.2	0.04	-1.6094379	-0.3218876		
				c	1	0.2	0.04	-1.6094379	-0.3218876		
					5		0.44		-0.9502705		
Chiredzi	-21.393	31.778	4	a	1	0.1	0.01	-2.3025851	-0.2302585	1.09	2.38
				b	6	0.6	0.36	-0.5108256	-0.3064954		
				c	1	0.1	0.01	-2.3025851	-0.2302585		
				d	2	0.2	0.04	-1.6094379	-0.3218876		
					10		0.42		-1.0889		
Chiredzi	-21.393	31.843	2	a	4	0.8	0.64	-0.2231436	-0.1785148	0.50	1.47
				b	1	0.2	0.04	-1.6094379	-0.3218876		

					5		0.68		-0.5004024		
Chiredzi	-21.432	31.817	3	a	1	0.3333333	0.1111111	-1.0986123	-0.3662041	1.10	3.00
				b	1	0.3333333	0.1111111	-1.0986123	-0.3662041		
				c	1	0.3333333	0.1111111	-1.0986123	-0.3662041		
					3		0.3333333		-1.0986123		
Chiredzi	-21.335	32.096	1	a	2	1	1	0	0	0.00	1.00
					2		1		0		
Chiredzi	-21.388	32.081	3	a	2	0.4	0.16	-0.9162907	-0.3665163	1.05	2.78
				b	1	0.2	0.04	-1.6094379	-0.3218876		
				c	2	0.4	0.16	-0.9162907	-0.3665163		
					5		0.36		-1.0549202		
Chiredzi	-21.362	32.089	2	a	1	0.5	0.25	-0.6931472	-0.3465736	0.69	2.00
				b	1	0.5	0.25	-0.6931472	-0.3465736		
					2		0.5		-0.6931472		
Chiredzi	-21.529	31.927	4	a	2	0.2857143	0.0816327	-1.252763	-0.3579323	1.28	3.27
				b	3	0.4285714	0.1836735	-0.8472979	-0.3631277		
				c	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
				d	1	0.1428571	0.0204082	-1.9459101	-0.2779872		
					7		0.3061224		-1.2770343		
Chiredzi	-21.518	31.978	3	a	1	0.25	0.0625	-1.3862944	-0.3465736	1.04	2.67
				b	1	0.25	0.0625	-1.3862944	-0.3465736		
				c	2	0.5	0.25	-0.6931472	-0.3465736		
					4		0.375		-1.0397208		
Chiredzi	-21.559	31.916	2	a	4	0.6666667	0.4444444	-0.4054651	-0.2703101	0.64	1.80
				b	2	0.3333333	0.1111111	-1.0986123	-0.3662041		
					6		0.5555556		-0.6365142		
Chiredzi	-22.042	31.257	4	a	1	0.2	0.04	-1.6094379	-0.3218876	1.33	3.57
				b	2	0.4	0.16	-0.9162907	-0.3665163		
				c	1	0.2	0.04	-1.6094379	-0.3218876		
				d	1	0.2	0.04	-1.6094379	-0.3218876		
					5		0.28		-1.332179		
Chiredzi	-22.068	31.331	3	a	1	0.1666667	0.0277778	-1.7917595	-0.2986266	0.87	2.00
				b	1	0.1666667	0.0277778	-1.7917595	-0.2986266		
				c	4	0.6666667	0.4444444	-0.4054651	-0.2703101		
					6		0.5		-0.8675632		
Chiredzi	-22.091	31.266	2	a	2	0.4	0.16	-0.9162907	-0.3665163	0.67	1.92
				b	3	0.6	0.36	-0.5108256	-0.3064954		
					5		0.52		-0.6730117		
Chiredzi	-22.211	31.232	1		2	1	1	0	0	0.00	1.00
					2		1		0		
Chiredzi	-22.229	31.189	3	a	2	0.3333333	0.1111111	-1.0986123	-0.3662041	1.01	2.57
				b	3	0.5	0.25	-0.6931472	-0.3465736		
				c	1	0.1666667	0.0277778	-1.7917595	-0.2986266		
					6		0.3888889		-1.0114043		

Chiredzi	-22.262	31.212	2	a	3	0.4285714	0.1836735	-0.8472979	-0.3631277	0.68	1.96
				b	4	0.5714286	0.3265306	-0.5596158	-0.3197805		
					7		0.5102041		-0.6829081		

Appendix V: Key Stakeholder Interview Guide

INTERVIEW GUIDE FOR KEY STAKEHOLDERS: IMPACT OF CLIMATE CHANGE ON VEGETATIVE SPECIES DIVERSITY

Introduction

My name is Chapungu Lazarus, a student from the University of South Africa (UNISA). I am carrying out a research which is part of requirements towards the fulfilment of my studies for DPhil in Environmental Sciences. The research is purely academic but it is sincerely expected that the findings will sift to the local, national and regional policy makers as a body of knowledge that will help in decision making, planning and management of vegetative species diversity in the face of environmental modifications driven by climate change. The broad objective of the study is to assess the impact of climate change on vegetative species diversity in Masvingo province. The success of this study depends on your participation as an important source of data. In that regard, I kindly seek your support and cooperation through sparing part of your valuable time to respond to my questions. Kindly note that throughout the entire process, the responses you give are virtuously for academic purposes and will be treated with highest confidentiality to protect your rights and privacy.

GUIDING QUESTIONS

1. Define the concept of Climate Change as it is understood within your organisation.
2. What is your understanding of the term vegetative species diversity?
3. Has there been any change in the climate of Zimbabwe between the years 1974 and 2014? What about in Masvingo province? Specify patterns of climatic variables.
   a. Temperature
   b. Rainfall.
4. Are there any national studies that assessed the impact of climate change on vegetation diversity? Kindly specify. (*Probe for details if there is any*).
5. Do you think climate change affects vegetative species diversity? If so in what way?
6. Are there any reports of species that have invaded, migrated or gone extinct over the past 40 years in Masvingo province?
7. What is the role of your organisation with regards to climate change and vegetation diversity issues? What has been done so far? Any plan of Action? What is the progress so far against measured targets?

8. What do you think is the significance of biodiversity data, specifically vegetative species diversity data, to national development and policy making?
9. How does your organisation ensure availability of Climate data to researchers? How have you been making use of research outputs from researchers?
10. Do you have a repository for biodiversity data across agro-ecological regions? Any challenges and recommendations?
11. What strategies are in place to reduce impact of climate change on vegetative species diversity?
12. Does climate change influence the use of vegetative species by communities?

THANK YOU FOR YOUR PARTICIPATION

Appendix VI: Research Ethical Clearance

UNISA university of south africa

2014-04-14

Ref. Nr.: 2014/CAES/056

To:
Student: L Chapungu
Supervisor: Dr L Nhamo
Department of Environmental Sciences
College of Agriculture and Environmental Sciences

Student nr: 53262506

Dear Dr Nhamo and Mr Chapungu

Request for Ethical approval for the following research project:

Impact of climate change on vegetative species diversity in Masvingo Province, Zimbabwe

The application for ethical clearance in respect of the above mentioned research has been reviewed by the Research Ethics Review Committee of the College of Agriculture and Environmental Sciences, Unisa. Ethics clearance for the above mentioned project (Ref. Nr.: 2014/CAES/056) **is given** for the duration of the study.

Please be advised that should any part of the research methodology change in any way as outlined in the Ethics application (Ref. Nr.: 2014/CAES/056), it is the responsibility of the researcher to inform the CAES Ethics committee. In this instance a memo should be submitted to the Ethics Committee in which the changes are identified and fully explained.

The Ethics Committee wishes you all the best with this research undertaking.

Kind regards,

Prof E Kempen,
CAES Ethics Review Committee Chair

Good luck.

Prof MJ Linington
Executive Dean: College of Agriculture and Environmental Sciences

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 429 12 429 4150
www.unisa.ac.za

Appendix VII: Authority to carry out research in Masvingo province

Correspondence should not be addressed to individuals

Telephone: 263351/2/3
Fax : 265968
Email address: [illegible]

ZIMBABWE

Reference:
MINISTRY OF LOCAL GOVERNMENT, RURAL AND URBAN DEVELOPMENT
Provincial Administration
Benjamin Burombo House
P.O. Box 595
Masvingo

10 December 2013

To Mr Chapungu Lazarous
Great Zimbabwe University
Box 1235
Masvingo

RE: REQUEST FOR AUTHORITY TO CARRY OUT A RESEARCH ON IMPACTS OF CLIMATE CHANGE ON VEGETATIVE SPECIES DIVERSITY IN MASVINGO PROVINCE .

The above caption refers.

Please be informed that the head of Ministry in minute ref ADM/23/8 dated 19 November 2013 granted authority for your application to carryout research on impact of climate change on vegetative species diversity in Masvingo Province. In the same vein you are advsed that the information gathered is confidential and should not be divulged to any unauthorized members of the public.

The Ministry will be grateful to receive a copy of the end product.

May we wish you the best in your endeavors

Provincial Administrator
10 NOV 2013
P.O. Box 595
Masvingo

K. Manikwa
For: Provincial Administrator, Masvingo