



**SENSITIVITY OF INDIGENOUS PLANT SPECIES DIVERSITY TO CLIMATE
CHANGE IN A SEMI- ARID ENVIRONMENT: THE CASE OF CHEGUTU DISTRICT,
ZIMBABWE**

BY

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Declaration

I, Madzikatidze Wellington hereby proclaim that this thesis, which I hereby present for the degree of MPhil in Geography and Environmental Science at the Great Zimbabwe University, is my own piece of work and has not previously been presented by me for a degree at this or any other institution.

I declare that the dissertation is my own work in design and execution and that all reference materials therein have been dully acknowledged.

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Signature Date.....

Supervisor..... Date.....

Dedication

I, Madzikatidze Wellington, dedicate this dissertation to my family for the endless inspiration they gave me throughout my study journey. These are my wife Esnath and our children Kunashe Dylan, Kutenda Danielle and Kupakwashe Dyaliyn. May the Almighty God bless you all in abundance.

Acknowledgements

I wish to express my heartfelt appreciation to Dr L. Chapungu, my study supervisor and Dr H. Zinhiva, my co-supervisor, for their devoted, tireless and invaluable supervision, during the preparation of this dissertation. They constantly guided and supported me to pull through my study journey. I acknowledge with high regard their untiring constructive criticism as well as accessibility to my cause right through my study journey. My heartfelt thanks are also extended to the entire staff in the Department of Physics, Geography and Environmental Science at the Great Zimbabwe University, for all the contributions they made during my studies. Finally, study participants in Chegutu district are also acknowledged for setting aside their precious time and effort to truthfully provide responses to my questionnaires and interviews.

Abstract

The research examined the sensitivity of indigenous plant species diversity to climate change in a semi-arid environment over 36 years (1984–2020) in Chegutu district of Mashonaland West Province in Zimbabwe. This research was premised on the pragmatic research model and implemented the mixed-methods research design. Precipitation and temperature-related variables were first analysed to ascertain the climate system changes. Indigenous plant species diversity data were collected from 180 sampling plots identified using the nonaligned sampling framework. Correlations between observed indigenous plant species data along with the Normalised Difference Vegetation Index (NDVI) were determined, resulting in the use of NDVI as a proxy indicator for indigenous plant species diversity. Thus, NDVI was used in the determination of modifications in indigenous plant species over time. The indigenous plant species diversity data were regressed with climate variables data over the study period to establish the cause-effect relationships. Questionnaire surveys, interviews and direct field observations were used to understand further the climate-indigenous plant species dynamics from the perspective of local people in the area over the study period. Significant ($p < 0.05$; $\alpha = 0.05$) trends in climatic variables were observed over the period under study, signifying a changing climate in the district. Significant correlations between different bioclimatic elements (precipitation and temperature) and the Shannon index of diversity were also observed, indicating the sensitivity of plant species to climatic variables. The study concludes that the changing climate partly influences the trends and dynamics of indigenous plant species in Chegutu District. Thus, indigenous plant species are considerably sensitive to climate change. There is need to equip organisations responsible for managing ecosystems for effective monitoring of the impacts of climatic changes on indigenous plant species, given the importance of indigenous plants to humanity. Capacitating organisations responsible for managing ecosystems would go a long way in preventing the likely invasions, migrations, and extinctions of key indigenous plant species within and from local ecosystems.

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CHAPTER I: INTRODUCTION

1.0 Background to the study

Globally, plant species are being lost and increasingly threatened by the changing climate attributed to various anthropogenic activities (Aragao et al., 2016; Bhuyan et al., 2018; Sintayehu, 2019). Besides anthropogenic activities, it is believed that physical processes like ocean currents, solar radiation, albedo and water vapour are considerably contributing to climatic changes (Sandi et al., 2020). Models of climate for southern Africa, Australia, southeast Asia, southern Europe, and the Middle East predict an increase of aridness and continuous dry spells during the 21st century (Han et al., 2020). Climate change in semi-arid areas, particularly the occurrence and severity of dry spells, is expected to worsen biodiversity loss. Biodiversity in these semi-arid areas of the world will be heavily impacted when climate change seriously influences drought periods (Sandi et al., 2020).

The economy of the world (40%) as well as economies of less-developed countries (80%) depends on natural ecosystem services (Sintayehu, 2019; Yelwa et al., 2019; Han et al., 2020). Plant species abundance, richness, structure and composition are determined by environmental gradients, mainly rainfall and temperature (Chapungu, 2017; Odeny et al., 2019). The current changing climate is also likely to impact indigenous plant species' geographical distribution significantly, and this trend is visible globally (Palita, 2018; Dev et al., 2019; Han et al., 2020). Therefore, this calls for a further local level investigation that would enhance an understanding of climate change models in an endeavor to improve suitable management policies that reduce loss of ecosystem services at local levels (Parmesan & Hanley, 2015; Kosanic et al., 2018).

Africa has a rich biodiversity, including a diversity of indigenous plant species. However, it is predicted that this biodiversity is threatened by climate-induced environmental changes since Africa is regarded as a hotspot of climatic changes (Matata et al., 2019; Odeny et al., 2019). Projections of climate change in Africa point towards a warming pattern, as witnessed by relentless incidence of severe high temperatures, escalating dryness as well as precipitation shifts, accompanied by a marked decrease, mostly in Africa's southern region and a rise in the eastern part of Africa (Parmesan & Hanley, 2015; Kosanic et al., 2018). By the year 2050, in

Africa, in particular southern Africa, rainfall predictions indicate a decline of about 10% (Sintayehu, 2019). The savanna vegetation is among African ecosystems that have been recognised as exceptionally vulnerable to climate change impacts. However, across the western part of the Sahel region, about a 15 % decrease in the density of vegetation as well as a considerable reduction in the richness of plant species was noted over the twentieth century (Lawal et al., 2019). The changes in the Sahel region are ascribed to temperature changes as well as variations in precipitation (Lawal et al., 2019 and Sintayehu, 2019).

Typical impacts of climatic changes on species and ecosystems include modifications in phenology, decreases in plant populations and changes in the distribution of species. Flora responds to a changing climate in the following three ways:

1. Some species may adapt to climate change.
2. Some species may move to more suitable ecological conditions.
3. Other species may die.

These ways of how plants respond to climatic changes severely affect the diversity of species, particularly species evenness and richness.

In Africa's southern region, the average seasonal temperature and rainfall alterations are predicted to rise contributing to the occurrence of harsh climatic conditions (IPCC, 2019). A substantial body of literature has indicated that Africa's southern region has been subjected to extremely unpredictable and unreliable precipitation, rising temperature, as well as a rising pattern in extreme weather phenomena like recurrent dry spells, episodes of cyclones, flooding and heat waves. Extreme events related to climate, accompanied by human induced factors, work together to cause shifts in the spread and abundance of indigenous plant species. Grasping how climatic features influence the diversity of indigenous plant species becomes important when devising sustainable managing strategies and safe guarding of ecosystems (Kosanic et al., 2018). Even though there is plenty of literature on the sensitivity of vegetation to changing climate worldwide, fairness around the topic has yet to be done, particularly concerning indigenous plant species diversity in semi-arid environments in Africa's southern region.

Africa's southern region is recognised among the high-risk parts of the world regarding changes in climatic variables (Thuiller & Midgley, 2018; Yelwa et al., 2019; Han et al., 2020). A large body of scientific literature reiterates that climate change will likely alter plant species distribution, phenology, abundance, richness, structure and composition in different ecosystems (Chapungu & Nhamo, 2016; Thuiller & Midgley, 2018; Odeny et al., 2019). Indigenous plants remain essential to the structure and function of ecosystems, underpinning a wide range of products as well as services human beings draw from flora and fauna. The expected severity of the effects of a changing climate on indigenous plants in various Global Warming Levels (GWLs) is yet to be well researched in Africa's southern region (Ouma et al., 2018).

Flora in Africa's southern region is amongst the world's susceptible areas at levels of warming around 1.2°C to 1.5°C ahead of pre-industrial times (Arets et al., 2019, Lawal et al., 2019, and Sintayehu 2019). Several studies have predicted dramatic changes for southern African plant species in the next 50 years (Sintayehu, 2019; Yelwa et al., 2019). Severe challenges to sustainable development have been presented by a changing climate in Africa, as it is possibly a significant environmental challenge of our time (Ouma et al., 2018). As a result, there is phenomenal scientific confirmation of a changing climate. However, lack of scientific certainty, particularly in Africa's southern region, regarding the impacts of climate change on a variety of biological events, including the diversity of indigenous plant species still exists.

Zimbabwe is located in a semi-arid area characterised by inadequate as well as erratic rainfall trends and variations in temperature. Precipitation in Zimbabwe shows significant spatial and temporal variations associated with changes in the starting of the rain season, increase in the occurrence and amount of intense precipitation episodes, increase in the number of years of little rainwater. Also noted in Zimbabwe's climate is the reduction in rainfall events marked by low-intensity as well as increasing occurrences and intensity of dry spells during mid-seasons (Makova et al., 2019). Severe climatic conditions, including episodes of tropical storms, flooding as well as dry spells, are reported to have also increased their occurrence and severity (Manatsa et al., 2020). In addition, the Zimbabwe Meteorological Service Department, reported an increase in the daily minimum temperatures by roughly 1.5°C during the previous century, whilst daily maximum temperatures increased by approximately 2°C in the same time under assessment (Brown et al., 2012). Changes in climate have caused further dry environmental

conditions for productive agriculture as well as the growth of vegetation, which led to shifts in Zimbabwe's major natural farming and ecological regions. Rainfall trends in the country gradually decline from agro-ecological region 1 to 6. For instance, Chinhoyi, Mhondoro as well as Chibero including their surrounding areas moved from agro-ecological zone 2 to zone 3. In contrast, Kwekwe's surrounding areas moved from agro-ecological 3 to farming zone 4 (Manatsa et al., 2020). Overall, the climate of Zimbabwe is differentiated regionally but is in general getting hotter accompanied by further unreliable precipitation trends.

Zimbabwe's savannas represent a vital environment for people practising livestock breeding, crop farming, and collecting non-timber forest products for multiple purposes (Parmesan & Hanley, 2015; Sintayehu, 2019). However, the savannas are predicted to shrink in the next few centuries, as a result of largely temperature and precipitation changes (Sintayehu, 2019). The fact that the climate system is changing and influencing biological diversity is unequivocal. Several studies have examined the effects of a changing climate on various vegetation attributes (Upson et al., 2016; Chaitra et al., 2018; Kosanic et al., 2018). Others have focused on global, continental, and regional scales, leaving gaps in knowledge concerning localised changes in indigenous plant species attributes (Adhikari et al., 2018; Rinawati et al., 2018; Lawal et al., 2019). Climate change effects on indigenous plant species diversity are yet to be fully quantified and characterised. Specifically, little has been done so far to appreciate how native species in Zimbabwe respond to vagaries caused by climate system changes. Understanding the sensitivity of indigenous plant species to climatic variables is indispensable in an effort to deal with the mounting demands for the sustainable management of ecosystems in different climates in the future (Thuiller & Midgley, 2018; Dev et al., 2019). Thus, additional research is needed which focuses on indigenous plants response to a changing climate at a local scale (Kosanic et al., 2018). In view of the preceding gaps in scientific knowledge, this study examines the sensitivity of indigenous plant species diversity to climatic changes over a period of thirty-six-years in Chegutu district, Zimbabwe.

1.1 Statement of the problem

The future of indigenous plant species is uncertain in Chegutu district as they undergo structural, compositional and genetic changes. These changes affect the ability of indigenous plants to

provide provisioning, regulating, cultural and supporting services to humanity. What compounds the problem is that there remains a paucity of scientific perception of the driving forces causing these changes. Having a scientific perception of the driving forces causing the changes is critical in crafting relevant policy instruments and managing approaches to secure the sustainability of indigenous plants in the district. At biome scale, a changing climate is the main driver of ecosystem changes. At ecosystem level, in highly disturbed areas, climate change contribution is yet to be studied. In this regard, a study that interrogates the sensitivity of indigenous plant species diversity to climate change becomes necessary, especially if it leads to the identification of effective policy instruments, conservation strategies, and species-specific management approaches to maintain the capability of flora and fauna to offer goods and services to humanity. Given this necessity, this study examines the sensitivity of indigenous plant species to climatic changes, specifically rainfall and temperature variables to determine whether climate change contributes to species diversity changes in Chegutu district of Zimbabwe. The knowledge will provide a reasonable basis for understanding the distribution, structural, compositional and genetic changes of the diversity of indigenous plant species in Chegutu district. The information is also vital for having an appreciation of susceptible indigenous plant species as well as guiding the adjustment of plant species in the Chegutu district, Zimbabwe.

1.2 Main Objective

The main objective of this research is to examine the sensitivity of indigenous plant species diversity to changing climate in a semi-arid environment of Chegutu district in Zimbabwe over a thirty-six-year period (1984- 2020).

1.2.1 Specific objectives

1. To determine trends in bioclimatic variables in Chegutu district over 36 years (1984- 2020).
2. To determine trends of indigenous plant species diversity in Chegutu district between 1984 and 2020.
3. To assess factors influencing changes in indigenous plant species diversity in Chegutu district for the past 36 years (1984- 2020).

4. To examine the relationship between indigenous plant species diversity and bioclimatic variables.
5. To estimate the impact of changing climate on the diversity of indigenous plant species in Chegutu district between 1984 and 2020.

1.3 Research questions

1. What are the trends of bioclimatic elements in Chegutu district over 36 years? (1984-2020)?
2. What are the trends of indigenous plant species diversity in Chegutu district between 1984 and 2020?
3. What are the factors influencing changes in indigenous plant species diversity in Chegutu district for the past 36 years (1984-2020)?
4. What is the relationship between the diversity of indigenous plant species and bioclimatic variables?
5. What is the impact of changing climate on indigenous plant species diversity in Chegutu district over 36 years?

1.4 Significance of the Study

Policymakers

The research will significantly inform scientists as well as policymakers regarding the vagaries of climatic changes on indigenous plant species. Findings of this research will enlighten policymakers of probable forthcoming impacts, working as a tool in the management and protection of indigenous plants, especially in this time of changing climate. The results of this study will also guide policymakers to build resilience and adaptive ability to tackle severe threats of the changing climate, building a further sustainable socio-ecological structure. The study will further recommend ways to reinforce the credit of indigenous plant species modifications to climatic changes as well as supporting the crafting of sustainable environmental laws and practical plans that control climate change effects on the diversity of indigenous plant species.

Although research has predicted threats of the changing climate on ecosystem diversity, there is a lot that should be done to ascertain the degree of these impacts as well as the changes in indigenous plant species diversity, mainly in a semi-arid area such as Chegutu district in Zimbabwe. Therefore, this research will go further to find out how climatic changes have influenced the diversity of indigenous plant species in Chegutu district. In general, the results of this research will help policymakers at local, national and regional levels as a point of reference that will assist in making decisions, planning as well as the managing of indigenous plant species diversity in this era of ecological changes caused by climatic changes.

Academics

This research shall add weight to the existing body of literature on the sensitivity of indigenous plant species diversity to climatic changes in a semi-arid area at a global, regional, national, and local scale. Since this study emphasises the comprehension of the correlation involving indigenous plants and climatic changes in dry environments, it will enhance the formulation of policies that will improve ecosystem resilience by implementing adaption and mitigatory measures that are in favor of indigenous plant species. The research will, therefore, help the attainment of Sustainable Development Goal (SDG) number 15, which requires nations to take critical and considerable steps to stop biodiversity loss and guard against species extinction. The management and protection of indigenous plant species improve ecosystems' ability to defy climatic changes and builds resilience against climate related threats. Furthermore, findings of this research will contribute towards the achievement of SDG 13, which calls for urgent measures aimed at fighting the changing climate and the related consequences.

Environmental agencies

Environmental agencies must practice appropriate strategies for managing and conserving biodiversity, which is repeatedly described as the livelihood inheritance of humanity, hence the need to keep a record of indigenous plants occurring in their areas. The Environmental Management Agency (EMA), Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement and ARES Officers in Chegutu district will use the recommendations from this study to step up their efforts in the advocacy for sustainable use of the delicate indigenous plant species and encouraging local communal households to engage in environmentally friendly

activities. It is imperative for environmental agencies in Chegutu district to understand how indigenous plant species are being affected by the changing climate. Hence, the research findings will provide the much needed information regarding how indigenous plants are influenced by climatic changes in Chegutu district, Zimbabwe.

Local community

The study will assist local communities in considering climate change information in their livelihood projects, including scientific data about trends and changes in the local climate. The results from this study will encourage the improvement of agricultural methods, improved management of native plant species as well as improvement of livelihoods supported by ecosystems. In addition, the research will assist the local community to establish a green-economy focused on adaptive and mitigatory measures against the emission of greenhouse gases. This will capacitate farmers on the production of crops and livestock to improve food security and income at the same time managing indigenous plants sustainably aimed towards economic development as well as improvement of ecosystem services.

Environmental Non-Governmental Organisations (eNGOs)

While the findings of this research will be helpful in whichever community, the same is true for environmental NGOs. This research will be very significant to eNGOs with regards to improving climate change consciousness at local and national levels and also capacitating government sectors to prepare adaptive strategies. The research findings will also help eNGOs inform their activities, thereby improving the accomplishment of their planned actions, making informed decisions. The results of this study will offer scientific knowledge that environmental eNGOs can use to influence local communities and agencies to improve their environmental performance and bring critical environmental issues to the forefront. The research further allows eNGOs to design and develop their climate change and biodiversity awareness programmes according to the latest evidence. It further allows eNGOs to test, improve and scale up their programming and contribute to the broader knowledge base by integrating recent scientific research findings into their work. Through educational programmes at the local level, eNGOs create climate change and biodiversity awareness and motivate behavioural change among local communities; as a

result, the communities understand the scientific concept of climate change and the diversity of indigenous plant species within their locality.

1.5 Study Area

The study was conducted in the district of Chegutu in Mashonaland West province of Zimbabwe, shown in Figure 1.1. Chegutu district is found about 80 km to the southwestern part of the capital city Harare at 1180 meters above sea level (Makova et al., 2019). Chegutu district occupies an area of 38, 300km². The study area was chosen since it is one of the areas in Zimbabwe where the response of indigenous plants to climatic changes has yet to be well studied and documented.

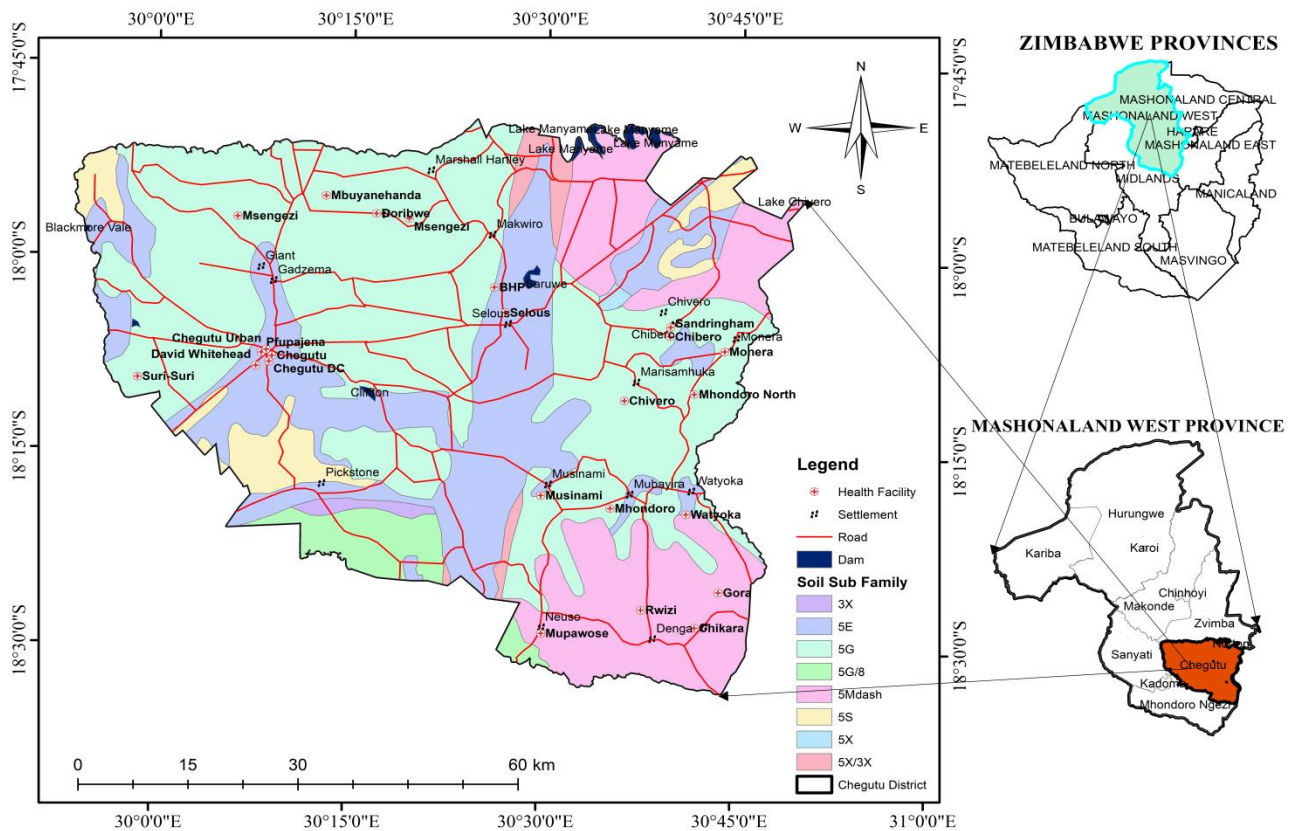


Figure 1. 1: Location of the study area (Chegutu district)

Climate

Chegutu district is in agro-ecological regions 2b and 3 (Makova et al., 2019; Manatsa et al., 2020). The annual rainfall received averages between 700–850mm per year. The rainfall is seasonal, erratic, and poorly distributed and falls mainly for a few months between November and April. The mean temperatures vary between 33°C in October, the hottest month, to 14°C in June, the coldest month (Makova et al., 2019). The categorization of climate was altered, and different physical variations took place due to the changing and uneven rainfall and temperatures experienced countrywide in general and particularly in Chegutu district (Makova et al., 2019; Manatsa et al., 2020). Therefore, there is a need to review the physical and socio-economic description of the district. The climatic conditions in the district are almost similar to those of nearby districts such as Kadoma, Sanyati, Zvimba and Makonde.

Soils

In any given area, the soil type and distribution are strongly associated with its geology, climate and topography (Nyamapfene, 1992; Manyevere et al., 2015). With reference to the Soil Classification System of Zimbabwe, soils in the study area are categorised in the Fersiallitic group of the Kaolinitic Order (Nyamapfene, 1992). Reddish-brown loams characterise Chegutu district with silty sandy and clay loams occurrences found in some places (Nyamapfene, 1992; Manyevere et al., 2015; Manatsa et al., 2020). Soils in Chegutu district are fertile for agriculture and appropriate for growing crops like cotton, tobacco and maize. Figure 1.2 shows the soil map of Chegutu district.

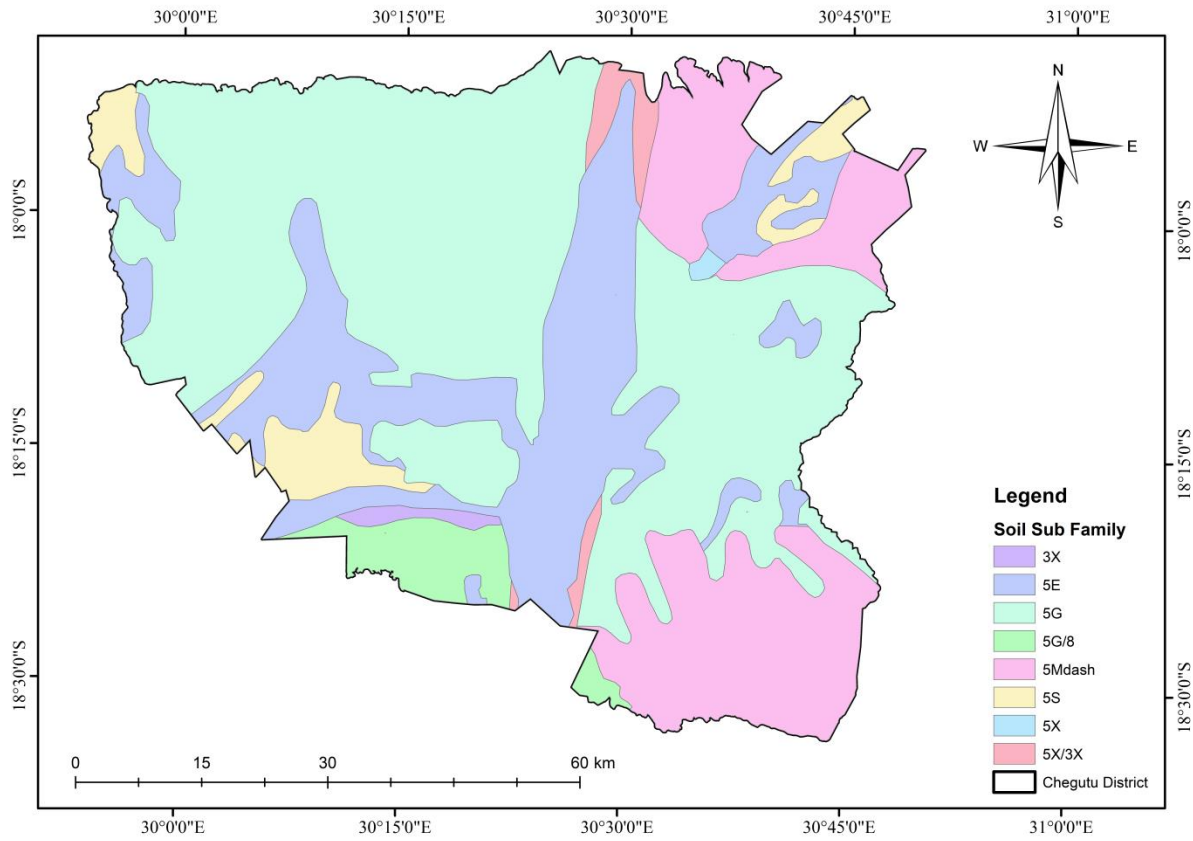


Figure 1. 2: Soil map of Chegutu district

Vegetation

Chegutu district is characterised by tree bush savanna, with miombo woodlands primarily being dominant. The miombo woodlands are associated with vegetation species like Musasa (*Brachystegia speciformis*), Munondo (*Julbernardia globiflora*) and Mutukutu (*Pliostigma thonningii*) (Nyamapfene, 1992; Manyevere et al., 2015; Manatsa et al., 2020). Also commonly found within study area are other indigenous tree species that include *Pseudolachnostylis maprouneifolia*, *Diplorhynchus condylocarpon*, *Acacia sp*, *Combretum sp*, *Uapaca kirkiana* (Ribeiro et al., 2008; Manyevere et al., 2015; Manatsa et al., 2020). Indigenous plants tend to be more abundant in regions of their particular environmental optima, and species composition differs along natural gradients (Zhou, 2004).

Population

The total population in Chegutu district is 63 779, comprising about 33 511 (52.5%) females and 30268 (47.5%) males (ZIMSTATS, 2022). The density of population in the study area is approximately 30 people per km².

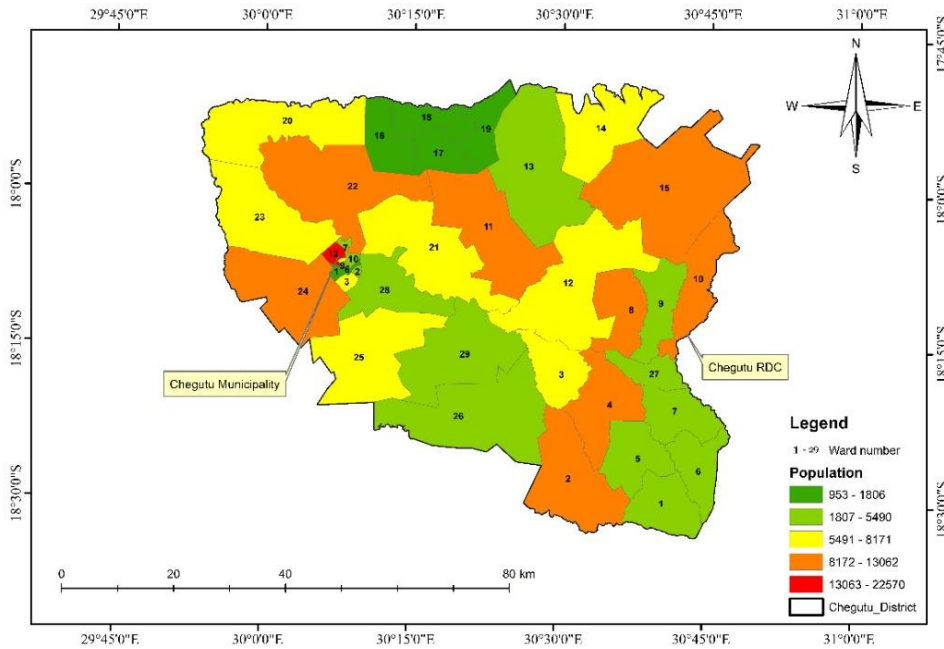


Figure 1. 4: Population map of Chegutu district

Most people in Chegutu district stay in rural areas. The composition and distribution of indigenous vegetation in Chegutu district might be mainly determined by the greater number of people who reside in rural areas. Chegutu district is dominated by the Shona-speaking tribe, mainly the Zezuru (ZIMSTATS, 2012).

Economic activities

Most households in Chegutu district depend on agricultural production of mainly maize and tobacco. Livestock rearing is also a significant economic activity in the district. A larger percentage of the population in Chegutu district is resettled communal farmers who rely on

rainfed agriculture. The farming area of Chegutu district falls under agro-ecological region 2b (Makova et al., 2019; Manatsa et al., 2020). The area which covers Mhondoro falls under agro-ecological region 3 and is dominated by semi-intensive farming. Subsistence mining of gold is also a significant economic activity carried out in Chegutu district. Gold is the main mineral produced in Chegutu district. The Great Dyke, which forms the main goldfield in Zimbabwe, also passes through the district.

1.6 Study delimitation

The study was limited to the whole of Chegutu district, Mashonaland West Province in Zimbabwe, located at 18.1380°S and 30.1474°E. Urban areas are excluded in this study, assuming indigenous plant species in Chegutu urban have been exposed to changes mainly attributed to urban people, not the changing climate. The study focused on precipitation, temperature and indigenous plant species characteristics within Chegutu district. Based on previous scientific studies that have confirmed a positive correlation between diversity indices and vegetation indices, indigenous plant indices from satellite images between the years 1984 and 2020 were used as a proxy indicator for the diversity of indigenous plant species (Hashemi et al., 2013; Madonsela, 2018.; Onyia & Balzter, 2018; Chapungu et al., 2020). Remote sensing was the main instrument employed for the assessment of changes in indigenous plant species during the review period. Downloaded and processed satellite images were analysed from 1984 to 2020 for the wet and dry seasons.

1.7 Study limitations

This study had planned to sample 180 plots. However, seven (7) plots were inaccessible; as a result, questionnaires were distributed to 173 plots. Inaccessibility of some randomly selected plots was a barrier against the collection of data from all the 180 sampled plots. In some instances, the sampled points were positioned at highland areas with dense vegetation that were difficult to work in. A 95% response rate for the questionnaire surveys was achieved. In addition, lack of a 100% response rate was not achieved due to hectic programs, absenteeism, and general truancy among the respondents. Some respondents were hesitant to respond to questions, some gave excuses that they were busy. In some instances, respondents were not cooperative especially when interviewed. It was only after length persuasion explaining the importance of the

study that they accepted to be interviewed. Accessing adequate climate data from the Zimbabwe Meteorological Service Department (ZMSD) was a challenge caused by the exorbitant prices to which the data was sold by the department. However, the data acquired from the ZMSD were complemented by a dataset downloaded from the internet. The researcher also encountered financial constraints during data collection. A lot of money was required for travelling and subsistence, accessing information from the internet among other costs.

1.8 Definition of terms

Climate change

"Climate change is the long-term change in the Earth's climate caused by the release of greenhouse gases which capture heat in the atmosphere, causing the planet to become hotter," (Brazier, 2015, p. 67). Climate change is the significant change of climatic conditions caused either directly or indirectly by human activities that alter the global atmospheric composition and is observed after a long period of time (UNFCCC, 2014). According to the Intergovernmental Panel for Climate Change (IPCC), (2019), "climate change is the change in the state of the climate that can be identified by changes in the mean and the variability of its properties and that persists for an extended period, typically decades or longer". Therefore, climate change refers to significant changes of climatic conditions experienced after a long period of time as a result both natural variability and human activities.

Indigenous woody plant species

The term indigenous woody plant refers to a plant which occurs naturally in a particular geographical area (Rankoana, 2016; Thuiller & Midgley, 2018). Indigenous plants also occur in other areas, either nearby or elsewhere in the state or country. Many studies have revealed that plants that are indigenous to an area thrive better and sustain a wider variety of other species, such as animals and insects since they have adapted to the specific conditions of that area, such as soil and climate, over many thousands of years (Rankoana, 2016; Thuiller & Midgley, 2018; Manatsa et al., 2020). Chegutu district is largely characterised by indigenous plants such as the tree bush savanna, with miombo woodlands primarily being dominant. The miombo woodlands are associated with vegetation species like musasa (*Brachystegia speciformis*), munondo

(*Julbernardia globiflora*) and mutukutu (*Pliostigma thonningii*) (Ribeiro et al., 2008; Manyevere et al., 2015; Manatsa et al., 2020). Also commonly found in Chegutu district are other indigenous plant species that include *Pseudolachnostylis maprouneifolia*, *Diplorhynchus condylocarpon*, *Acacia sp*, *Combretum sp*, *Uapaca kirkiana*. Indigenous plants are endowed with forest goods and services that supply food, medicines, shelter and energy to rural communities.

Plant species diversity,

Plant species diversity measures the number of plant types within a given area (Rankoana, 2016; Thuiller & Midgley, 2018). In Zimbabwe, plant species diversity is described within the context of the five woodland types of the *Zambeziaca phyto-region* (Miombo, Mopane, Teak, *Acacia*, and *Terminalia/Combretum*), the four vegetation types of the Afromontane phyto-region; and the exotic plantations (*Pinus and Eucalyptus*, and several ornamentally important species) (Nyamapfene, 1992; Manyevere et al., 2015; Manatsa et al., 2020).

1.9 Structure of the Thesis

This research is made up of five chapters.

Chapter 1: It is the introductory part, which grounds the project. This chapter describes the project background; bringing to light the research gaps that prompted the need to carry out the research from broad to specific and worldwide to local perspectives. The problem statement, main objective, specific objectives, research questions as well as the significance of the research are highlighted in this chapter. The chapter further describes the study area's background with reference to its location, physical and climatic conditions, population and demography characteristics, among other issues that contextualize the project area.

Chapter 2: This chapter reviews the literature on the changing climate, its trends and influence on the diversity of indigenous plant species. Also reviewed is literature that relates to objectives and research questions outlined in chapter 1.

Chapter 3: This chapter highlights the methods employed to achieve the objectives of the study. The research paradigm, design, data collection instruments and procedures are described in this

chapter. Also presented in this chapter are techniques of analysing data that led to the production of study results.

Chapter 4: Results of the study and discussions to ascertain whether the study has achieved the objectives are presented in this chapter

Chapter 5: This chapter summarises the project and draws conclusions and recommendations for sustainable management of indigenous plant species under the hostile climatic changes in the area of study, considering reflections given to the literature review use.

CHAPTER II: LITERATURE REVIEW

2.1 Introduction

The chapter presents literature to give an academic frame and experiential setting to enlighten the research. The reviewed literature includes the real as well as expected climatic changes and how they affect indigenous plant species diversity globally, regionally, and locally. Changing climatic trends at global, regional, and local levels in dry areas are presented taken from different researchers. Also reviewed in this chapter are present and anticipated biodiversity changes, particularly indigenous plant species diversity, as pointed out in scientific research and theories to put this research into perspective. Additionally, literature on remote sensing tools, particularly flora indices, in approximating the diversity of indigenous plant species was reviewed taken from research conducted by different scholars.

2.2 Climate change trends at global level

The primary determinant of plant species diversity is climate, mainly precipitation and temperature (Chaitra et al., 2018; Sintayehu, 2019; Yelwa et al., 2019). "Climate change is the long-term change in the Earth's climate caused by the release of greenhouse gases which capture heat in the atmosphere, causing the planet to become hotter" (Brazier, 2015, p. 67). These changes can occur over a few decades or millions of years. For the past 100 years, global mean temperature increased by 0.5°C and is projected to keep increasing (Thuiller & Midgley, 2018; Lawal et al., 2019). The IPCC forecasts that at the end of the twenty-first century, temperatures are set to rise by 1.6 - 6.4°C relative to projections made between 1980 and 1999 (IPCC, 2019, Ouma et al., 2018). As a result, scientists are currently concerned about the rate at which the climate changes since it has exceeded changes previously experienced during the past 800 000 years (Parmesan & Hanley, 2015; Rinawati et al., 2018; Arets et al., 2019; Matata et al., 2019). Climatic changes alter the whole ecosystem including all flora and fauna that survive in that ecosystem. Climate change is occurring at a fast pace which has caused numerous challenges affecting nearly every aspect of life on Earth, including indigenous plant species on which human beings depend for survival (Engelbrecht et al., 2007; Jasrai, 2013; Rinawati et al., 2018; Han et al., 2020).

2.3 Climate Change in Southern Africa

Africa's southern region consist of arid to semi-arid areas with different biomes including woodland savannas, grassland savannas, tropical deserts, wetlands, and freshwater biomes. Various levels of assessments have significantly shown that in southern Africa there is increasing confirmation of climatic changes (Lawal et al., 2019; Mpandeli et al., 2019; Sintayehu, 2019). Changing climate in Africa's southern region is associated with change in the occurrence of severe climatic phenomena like El Nino- Southern Oscillation (ENSO), that is, El Nino and La Nina (Ouma et al., 2018; Matata et al., 2019; Mpandeli et al., 2019). Because of southern Africa's unpredictable climatic changes including actual and anticipated climatic threats, the region is among the hot spots of climatic changes (Madonsela et al., 2021; Urich et al., 2021).

Trend analysis of long-term climatic parameters like temperature and precipitation as climate surrogates have revealed that climatic changes occurred in southern Africa (Kupika et al., 2018). Previous records of precipitation in southern Africa show a decreasing trend of precipitation during the past century in the region (Odeny et al., 2019; Sintayehu, 2019). Data from remote sensing as well as available records of precipitation and temperature in Africa's southern region confirm that these climatic variables have been decreasing and warming respectively during the previous ten years (Chapungu et al., 2020). The warming patterns experienced in southern Africa match the worldwide rising temperatures recorded during the past ten years (Kusangaya et al., 2014; Bentley et al., 2019; Id et al., 2020). Namibia, for example, is experiencing a temperature increase at a rate of 0.023°C annually. Furthermore, the Indian Ocean, which influences many of southern Africa's climatic events, was reported to have recorded increasing temperature of above 1°C as of 1950 (Rankoana, 2016; Thuiller & Midgley, 2018; Kapuka, 2021).

The increase in temperature is closely related to decreasing trends in precipitation, which has become extremely low, resulting in very little rainfall being received (Id et al., 2020). Sintayehu (2019) confirms that more than 16 serious drought events were experienced in southern Africa between 1972 and 1992. Mayet & Centre (2020) and Kapuka (2021) confirmed the same emotions claiming that southern Africa received precipitation that was 20% lesser than that experienced in the 1970s, and severe dry spells were recorded during recent decades. In addition, southern Africa in the recent past experienced extremely low rainfalls in 2014/2015, 2015/2016, and 2018/2019 rain seasons (Bombi, 2018) and destructive tropical storms during the 2019 rain

season (tropical cyclones Idai and Kenneth), devastating mostly parts of Malawi, Mozambique, and Zimbabwe (Kamara et al., 2020; Kapuka, 2021). In many areas of southern Africa where persistent dry spells have been recorded, indigenous plant species diversity has also been seriously affected (Kamara et al., 2020). Severe recurrent dry spells recorded in Africa's southern region caused the mortality of vegetation, triggered the degradation of habitats, and decreased the richness of plant species diversity as well as placing management plans of ecosystems in jeopardy (Sintayehu, 2019). The 2015/16 El Niño Southern Oscillation (ENSO) triggered dry spell, is among the most destructive drought that affected southern Africa in living memory and has seriously devastated the region's water, food and energy security (Lawal et al., 2019).

Besides warming temperatures and falling precipitation, southern Africa is also faced with climate variability. Annual to annual variability of climate in southern Africa varies from 25% to 30% (Ndlala & Dube; 2021). Southern Africa's present-day climate is mainly semi-arid, characterised by increased inter and intra-seasonal rainfall unpredictability (Urich et al.; 2021). Chersich et al. (2018) claim that Africa's southern region has recorded severe and recurrent climatic phenomena that has become a characteristic feature of the early warning systems. Madonsela et al. (2018) assert that precipitation in southern Africa is characterised by seasonal uniqueness, where most significant areas experience summer rainfall, which usually starts around end of October to mid November and ending around end of March to mid April. Also noted by some authors in southern Africa is the spatial and temporary variability that characterise the beginning and ending of seasons as well as frequency of droughts (Chapungu & Nhamo, 2016; Al, 2017; Manatsa et al., 2020).

2.4 Climate Change in Zimbabwe

Generally, Zimbabwe is a semi-arid country characterised by inadequate and unpredictable precipitation trends accompanied by variations of temperature (Mudzengi et al., 2017). Precipitation shows significant spatial and temporal unevenness associated with variations in the starting of rain season, occurrences of heavy rainfall storms as well as the incidences of mid rain season dry spells (Mudzengi et al., 2017; Chapungu et al., 2020). Severe climatic conditions such as tropical storms, flooding and incessant dry spells are reported to have increased their

occurrence and severity in Zimbabwe. The Zimbabwe Meteorological Service Department, reported an increase in the daily minimum temperatures by roughly 1.5°C during the previous century, whilst daily maximum temperatures increased by approximately 2°C in the same time under assessment (Brown et al., 2012; Mpandeli et al., 2019). Climatic changes in Zimbabwe have led to more arid environments for biodiversity in general and indigenous plant species in particular.

The recurrence of drought events is intensifying dryness in nearly all provinces in Zimbabwe, leading to the changing of boundaries of natural farming regions (Mpandeli et al., 2019). A marked downward change of precipitation trends and yield of crops from agro-ecological regions 1 to 5 has been noted. Some parts of Mashonaland's western province are reported to have moved from agro-ecological 2 to 3 (Mpandeli et al., 2019). Furthermore, some areas have shifted from natural farming zone 3 to 4 in the Midlands province of Zimbabwe. On the same note, there is a marked reduction in the size of natural farming zone 1, where the highest precipitation is received (Chapungu et al., 2020). Natural region 2 has shifted eastwards with region 3 shifting northwards. Generally, the climate of Zimbabwe has become regionally distinguished, but warmer conditions and unreliable precipitation trends are experienced in all agro-ecological zones (Mudzengi et al., 2017; Mpandeli et al., 2019; Chapungu et al., 2020).

The Zimbabwean government signed and ratified the UNFCCC to recognise that climate change threatens the nation. Taking into consideration the multifaceted characteristics of climate change, it has remained a challenge for the nation to develop effective sector-specific adaptation and mitigation strategies (Mpandeli et al., 2019). The government of Zimbabwe's failure to devise strategies of curbing the calamities of climate change could be emanating from limited practical appreciation of the relationship between sector-specific variables and climate change. Many scholars have confirmed the influence of climate change on some sectors including farming, energy and power generation, water as well as human health (Mapaura & Zimudzi, 2013). However, only a few steps have been taken to grasp how indigenous plant species are impacted. As a result, this created a gap concerning effective strategies meant to enhance the adaptive ability of indigenous plants in a changing climate setting. Despite the incorporation of the climate change issue into the Environmental Management Act 20:27, climate change threats to the diversity indigenous plant species need to be addressed sufficiently.

2.5 Climate change in Chegutu district

Since climatic changes occur at global, regional and national levels, local districts such as Chegutu are not spared from the same vagaries posed by the climate change phenomenon (Manatsa et al., 2020). Real climate change in Chegutu district is marked by increases in the occurrence of dry spells, unpredictable rainfall among other climatic calamities. This implies that Chegutu district has not been spared from declining precipitation accompanied by uncertain starting and ending of rain seasons, increasing average temperatures, the occurrence of pests and diseases, as well as increases in the occurrence and severity dry spells. Although historical records of some studies in the district focused on the influence of climatic changes concerning biodiversity in general, more needs to be done on the sensitivity of indigenous plant species to climatic parameters of precipitation and temperature. Modifications on the diversity of plant species in ecosystems is significantly attributed to climatic changes mainly climate related variables such as temperature and precipitation together with increases in their unpredictability during and between seasons (Chapungu, 2017).

2.6 Plant species diversity

Plant species diversity in Zimbabwe is a characteristic function of ecosystems attributed to spatial and temporal variations in precipitation, temperature, geological as well as soil conditions in agro-ecological regions (Nyamapfene, 1992; Manyevere et al., 2015; Manatsa et al., 2020). The central part and Zambezi Valley of Zimbabwe have the richest diversity of plant species, seconded by the Eastern Highlands, and lastly the Save- Limpopo low lying areas (Mapaura & Zimudzi, 2013). Forests, woodlands and grasslands dominate plant species diversity in Zimbabwe with Montane forests dominating the Eastern Highlands. In contrast, grasslands are found mainly in high-altitude areas in the same region and meandering formations along the Great Dyke. Woodlands comprise *Acacia*, *Biakiaea*, *Terminalia/ Combretum*, Miombo and Mopane (Mapaura & Zimudzi, 2013). Plant species diversity across Zimbabwe's landscape has drastically decreased as a result of human activities including agricultural expansion, increased demand for fuel wood, development of infrastructure, proliferation of persistent foreign species and human induced climatic change among others (Manatsa et al., 2020).

Plant species diversity has an important function of determining both the aesthetic and societal significance of ecosystems as well as the importance of supplying forest products and services (Oran, 2016; Tomback et al., 2016 cited in Chapungu, 2017). Nearly all environmental roles and processes of ecosystems are determined by indigenous plant species' conditions; therefore, plant species diversity plays the most critical role. Indigenous plant species affect nearly every constituent of the environment, hence are regarded as the bedrock of global ecosystems functioning (Oran, 2016; Runting et al., 2016). In light of this recognition, preserving and conserving indigenous plant species diversity contribute considerably to mitigating climate change.

2.7 Significance of indigenous plant species diversity in semi-arid environments.

Indigenous plant species diversity is regarded significant in the shaping of societal values, influencing the aesthetic value of the environment and the value of products and services provided (Scholes, 2020; Afuye & Kalumba, 2021). The conservation of ecological functions, processes and disturbance regimes are as important as preserving indigenous plant species, their populations, genetic structure, biotic communities and landscapes (Runting et al., 2016; Pecl et al., 2017). Plant species diversity is usually considered as the foundation of biodiversity due to its influence on almost all aspects of any ecosystem (Odeny et al., 2019). Nearly all the biophysical processes and functions are dependent on the condition of indigenous plants, of which the variety plays the most important role. In fact, the key determinant of terrestrial biodiversity is indigenous plant species diversity (Scholes, 2020). Indigenous plant species diversity can be regarded as the variety of native plant species; the genetic variety among the species, communities, ecosystems and the landscapes in which they occur (Li et al., 2016; Peng et al., 2018; Scholes, 2020). Indigenous plant species diversity is an important constituent of ecosystems because of its function as the main reservoir of terrestrial biodiversity. In this regard, the management of indigenous plant species diversity contributes significantly to the mitigation of climatic changes in semi- arid environments.

2.8 Factors influencing changes in indigenous plant species diversity.

2.8.1 Land fragmentation

The leading threat to changes in indigenous plant species diversity, particularly in semi-arid areas, is land fragmentation resulting in habitat loss. The alteration of indigenous forests in semi-arid areas to grazing lands and commercial agriculture has replaced small-scale cultivation by communal farmers as the primary driver of forest loss (Peel et al., 2017). Whether fragmented or not, vast areas of the remaining indigenous forests are degraded by logging, fuel wood harvesting and human-induced fires (Runting et al., 2016). In addition, other factors such as overgrazing, urbanisation and road construction influence changes in indigenous plant species and other ecosystem services (Tshwene-mauchaza and Aguirre-Gutiérrez, 2019). Furthermore, the fragmentation of the landscapes relates to the effects of climatic changes. The fragmentation of landscapes have all the time influenced indigenous plants that require spacious environments, disturbed the functioning of small isolated floral ecological units caused by lack of cross breeding and this has resulted in some indigenous plant species becoming extinct (Boutaj et al., 2019). Furthermore, shifting of range caused by climatic changes, particularly of indigenous plant species, is slowed down and sometimes not possible due to low mobility (Scholes, 2020; Afuye & Kalumba, 2021). Fragmentation of land was discovered to further lessen the rate of movement, for example, of indigenous plants, lower than the expected rates of movement to remain above the rate at which climatic changes are taking place (Rampheri et al., 2020).

2.8.2 Climate change

The changing climate remains the leading contemporary as well as expected threat to indigenous plant species diversity changes since it directly affects species and their habitats. Climatic factors, such as rainfall and temperature, influence environmental conditions for the growth of indigenous plant species (Li et al., 2016). Usually, changes in climatic parameters are considered among significant factors influencing indigenous plant species growth since warming temperatures have encouraged the increase of vegetation greening (Li et al., 2016). Climatic changes favour plant species with particular uniqueness, for instance, favouring light-colored insects, while other plant species possibly will be reduced in their abundance or disappear.

Usually, changes in climate result in species moving towards elevated altitudes and latitudes as they try to remain within range of temperatures they can keep surviving. With plant species, the movement is impossible due to their low speed of migration (Scholes, 2020; Afuye & Kalumba, 2021). In this regard, it is impossible for the range and habitat of indigenous plants to shift freely across the land. For instance, as temperature increases, plant species located in low elevations of mountains cannot shift to higher elevations (Harrison et al., 2020). In the long run, climatic changes will cause compositional changes of indigenous plants species (Rampheri et al., 2020). Inevitably, plant species will be recombined with the emergence of new ecosystems, amid little certainty of fresh relationships for specific plants. Therefore, climatic changes create harsh environmental settings for indigenous plant species to keep thriving (Odeny et al., 2019). Climate change, directly and indirectly, remains the leading factor behind the extinction of indigenous plant species in savanna ecosystems of southern Africa despite the influence of other anthropogenic factors (Chapungu et al., 2020).

2.8.3 Invasive alien species

Another possible threat to the thriving of indigenous plant species diversity is invasive alien species. Literature has revealed that the declining rainfall, in conjunction with increased warming climate encourage persistent plant species to flourish and results in some indigenous plant species becoming extinct (Harrison et al., 2020). As a result, increased temperatures have a tendency to promote the multiplication of alien plant species. A recent research by Chersich et al. (2018) revealed that more than 13000 species, 39% vascular plant species worldwide, have become naturalised in external ranges due to invasive alien species. Globally, the loss of biodiversity including indigenous plant species has been reported to be driven primarily by the influence of invasive alien species (Siyum, 2020). The proliferation of invasive plant species causes harm to indigenous plant species, due to parasitism, competition, biophysical modifications of the environmental settings, as well as the outbreak of diseases (Rampheri et al., 2020). The rapid spread of invasive alien species is attributed to the increased travelling of people across international boundaries and the globalisation of trade (Madonsela et al., 2021). Certain woody and herbal persistent foreign species, such as Black locust (*Robinia pseudoacacia*), Boxelder maple (*Acer negundo*), Tree of Heaven (*Ailanthus altissima*), or wattles (*Acacia sp.*), have a negative effect on indigenous plant species since they compete with local

species, change food webs, spread pathogens and sustain the multiplication of indigenous plant eaters (Li et al., 2016; Peng et al., 2018; Scholes, 2020).

Chapungu (2017) observe the significant multiplication of the Cherry pie (*Lantana Camara*) species in Masvingo province of Zimbabwe. In addition, intermittent emergence of Cactus Rosea (*Opuntia fulgida*) and wild Oats (*Avenafatua*) have as well been noted in Masvingo (Chapungu & Nhamo, 2016). These invasive plants have become a threat since they are rapidly multiplying, leading to the disappearance of indigenous plants. Climatic changes provide a conducive environment for invasive plant species to thrive. Certain invasive plant species tend to alter soil chemical characteristics, creating unfavourable conditions for the growth of other plant species (Chidumayo, 2019). The *Lantana Camara* has a tendency to increase the pH of soil above ranges that discourage particular plants to survive and consequently reduce plant species diversity (Kupika et al., 2018). The reduction of plant species has been widespread in the Chiredzi and Chivi districts of Masvingo province in Zimbabwe, in which the *Lantana Camara* has conquered many parts of the communal as well as restricted places (Chapungu, 2017). Confirmed reduction of indigenous plant species validates results of a study by Mudzengi et al. (2017) which noted that invasive species' proliferation decreases plant species' diversity, including indigenous herbaceous plants. According to a research that examined the influence of *Lantana Camara* on ecosystems, Ndlala & Dube (2021) conclude that the diversity of indigenous plants declined in ecosystems invaded by *Lantana Camara*. Therefore, climatic changes, directly and indirectly affect indigenous plant species diversity. Climatic changes directly promote the increase in persistent alien plant species and indirectly encourage the extinction of indigenous plant species.

Climate change, as evidenced by prolonged droughts and extreme heat waves, is reducing the available water resources leading to the multiplication of plant species sensitive to climate, resulting in their death and extinction (Chapungu et al., 2014; Chapungu, 2017; Bombi, 2018; Chidumayo, 2019). The expansion of dry environments in the region (Botswana, Namibia and southern parts of Zimbabwe) favour the spread of persistent foreign plants, worsening the disappearance of certain indigenous plant varieties (Bombi, 2018; Chidumayo, 2019). The most affected species have been herbal and grass species, and consequently loss of indigenous plant species diversity (Rampheri et al., 2020).

2.8.4 Agricultural activities

The distribution of plant species on the land is determined by several reasons, and land use usually affects agricultural land. Globally, it has been discovered that agricultural activities cause a decrease in indigenous plant species because natural ecosystems are converted into farmland since the discovery of agriculture (Zheljazkov, 2020). Generally, the change of natural ecosystems into agricultural land leads to shortage of carbon in the soil and consequently a reduction of plant species (Chersich et al., 2018; Zheljazkov, 2020). During the pre-industrial era, practicing small-scale traditional agriculture allowed natural ecosystems to co-exist with agriculture. However, the rapid growth of the human population and the expansion of agricultural activities led to the dramatic change of the co-existence between agriculture and natural ecosystems (Siyum, 2020). Clearing vegetation for agricultural land and using heavy machines, application of pesticides and rigorous tillage negatively affect natural ecosystems leading to the removal of indigenous plant species. Consequently, agricultural lands at present are significantly different from the natural ones and this has resulted in marked changes in the diversity of indigenous plant species (Jewitt et al., 2015).

2.9 Relationship between the diversity of indigenous plant species and bioclimatic variables

Globally, bioclimatic variables, mainly rainfall and temperature significantly control the spatial spread of flora (Geremew & Jebessa, 2018; Byrne et al., 2019; Afuye & Kalumba, 2021). In turn, flora cover influences climate through the modification of natural properties of the land's surface, such as the conductivity of water, roughness, albedo and the composition of atmospheric gases, like carbon dioxide (Afuye & Kalumba, 2021). In this context, bioclimatic variables, defined as the seasonal temperature and rainfall, ultimately determine the primary type of terrestrial plants and the biogeochemical characteristics of the landscape (Moncrieff et al., 2015; Wheatley, 2018; Sandi et al., 2020). Low rainfall leads to limited plant growth, with exposed grounds, with a higher albedo, largely caused by the surface albedo (Banze et al., 2018; Malhi et al., 2020). This positive feedback supports an arid or semi-arid area that can sustain itself. Conversely, where high precipitation is available, plenty of vegetation can thrive and the surface becomes darker than bare soils, hence lower albedo. Temperature on the surface becomes higher, and the temperature gradient between the sand surface and water bodies goes up, intensifying the

distribution and vertical movement on the land surface (Macrice, 2017; Maljean-Dubois et al., 2018). This results in the region experiencing an increase in precipitation. In addition, the capability of vegetation to release moisture from the soil, increasing water vapour into the atmosphere compared to uncovered land surfaces is yet another precipitation -vegetation positive feedback (Tomback et al., 2016). This hydrological feedback concluded that rainfall increases in any given environment improve the growth of floral cover, water vapour into the atmosphere and eventually precipitation (Townsend & Masters, 2015; Zegeye, 2018; Lawal et al., 2019).

Vegetation growth in arid and semi-deserts is dependent on climate, particularly rainfall since the growth of vegetation is strongly restricted by the availability of little moisture (Weiskopf et al., 2020). Since vegetation does not cover the land surface, it implies that in dry climates there is scarce vegetation as well as a significant fraction of bare soils (Adhikari et al., 2018). Natural properties of the land's surface, such as the conductivity of water, roughness and albedo are different from vegetation cover properties (Kosanic et al., 2018), hence creating the argument that vegetation cover influences climate (Matata et al., 2019).

Bioclimatic variables significantly influence indigenous plant diversity spatially and temporarily compared to other factors (Yelwa et al., 2019). High dependence of plant species diversity on climatic conditions is most evident if the richness of plants is considered on broader landscapes (Ouma et al., 2018). Globally, areas with humid climates tend to encourage the growth of a variety of plants as compared to areas with cold and arid climatic conditions. This global scale climatic effect is more important than any other predictor of plant species diversity (Aragao et al., 2016; Lovejoy, 2019; Han et al., 2020). In light of recent climatic changes, the understanding of climate- plant diversity relationships remains very critical. It has been confirmed that about 50% of the global land surface, tropical and arid climatic conditions are fast shifting toward hotter temperatures, which is projected to result in the reduction of moisture available during the wet period (Han et al., 2020). Simple extrapolation of current bioclimatic trends into projected climate can be used to predict the reduction of indigenous plant species diversity, more significantly in parts of the earth where precipitation is strongly limited (Rinawati et al., 2018; Sintayehu, 2019).

Several studies have confirmed that precipitation remains the most hindering factor over global terrestrial drier ecological units, where the abundance of precipitation influences the diversity of plant species, primarily plant development (Palita, 2018; Lovejoy, 2019; Mayet & Centre, 2020, Muluneh, 2021). In the 21st century, arid and semi arid biomes are expected to become drier as influenced by a combination of warmer climates and rainfall changes (Arets et al., 2019). A spatial and temporal investigation of plant species diversity in California, one of the ecosystem hotspots, concluded that indigenous plant species diversity shrinks with the decrease in available moisture (Mayet & Centre, 2020; Muluneh, 2021).

Trends of indigenous woody species diversity in Africa's southern region have shown remarkable uniformity with regards to their spatial relationships with bioclimatic variables (Bombi, 2018; Chidumayo, 2019). Taxonomic diversity, such as plant species richness improved as rainfall increased, regardless of the decrease in mean temperatures, confirming worldwide patterns of climatic conditions and plant species richness relationships (Harper et al., 2021). Also noted is the increase of functions of plant species diversity, with an increase in precipitation, as predicted by the assumption of tolerance, which suggested that further combinations of functional characteristics can occupy kind rather than harsh climates (Harper et al., 2021, Ndlala & Dube, 2021).

2.10 The impact of changing climate on the diversity of indigenous plant species

The rate of photosynthesis and respiration is primarily influenced by climate, mainly temperature and rainfall (Malanson et al., 2017; Chifurira, 2018; Han et al., 2020). In addition climatic changes control temporary functions, leading to changes on the diversity of plant species. An example is the influence of climatic conditions on the frequency of temporary processes such as forest fires, herbivory and species migration. These climatic impacts affect plant species diversity because when the world climate shifts, flora in different biomes is modified as well due to exceeded physiological tolerances (Parmesan & Hanley, 2015; Dev et al., 2019). Multifaceted floral ecosystems, like forests, grassland and shrub land, have excess biophysical processes that react independently to inside as well as outside influences. With reference to climatic changes, when the rainfall decreases, the presence of moisture turns out to be a restrictive feature which can probably influence vegetation growth (Thuiller & Midgley, 2018; Yelwa et al., 2019;

Weiskopf et al., 2020). Considerable climatic changes, especially temperature and rainfall, result in natural changes in plant species diversity including hereditary changes. Certain plants, for example, can get to a stage where their structure may remain unchanged. Severe climate changes may substitute forests for savannas or grasslands (Parmesan & Hanley, 2015; Dev et al., 2019).

Phenological changes

Plant species can respond to climate change through shifts in time which results in phenological changes. Phenological changes have been observed in southern Africa's plant species in response to variation in temperature and precipitation (Ribeiro et al., 2008; Brazier, 2015; Moncrieff et al., 2015; Banze et al., 2018). In plant species, shifts in phenological events include leaf growth changes, flowering, blooming and fruiting (Engelbrecht et al., 2007; Parmesan & Hanley, 2015; Aragão et al., 2016; Han et al., 2020). Extreme weather events can also have an effect on plant species diversity in multifaceted ways. Consequently, changes in the intensity or duration of the rainy and drought seasons may possibly alter the genetic structures of plant species (Jasrai, 2013; Thuiller & Midgley, 2018; Lovejoy, 2019; Harrison et al., 2020). Some plant species tend to have low phenological flexibility, for instance, they are less able to alter their time of flowering in response to increase or decrease in temperature (Kupika et al., 2018; Sintayehu, 2019; Chapungu et al., 2020; Malhi et al., 2020; Afuye & Kalumba, 2021). As a result, such plant species fail to follow the changing climate whilst their rivals that cope with climate change positively thrive. This affects the abundance of particular plant species within ecosystems and as a result influences plant species diversity (Arets et al., 2019; Dev et al., 2019).

Kamara et al., (2020) observe a change in essential phenological events of 5.1 days earlier per decade over the past 50 years after a meta-analysis of a multitude of plant species. The phenological changes can raise the plant species ability to keep synchrony with recurring climatic factors but they can also be disruptive leading to extinction (Moncrieff et al., 2015; Sintayehu, 2019).

Changes in plant species distribution

The changing climate in Southern Africa has greatly affected the distribution of plant species in different habitats in different ways (Sintayehu, 2019; Byrne et al., 2019; Harrison et al., 2020; Sandi et al., 2020), and possibly will force lots of plant species to become extinct (IPCC, 2019;

Lovejoy, 2019; Tshwene-Mauchaza & Aguirre-Gutiérrez, 2019). Extensive literature outcomes reveal that many plant species have changed their geographic ranges, usually pole ward, toward higher elevations, due to rapid changes in temperature and precipitation (Parmesan & Hanley, 2015 ; Chaitra et al., 2018; Ouma et al., 2018; Odeny et al., 2019). Climate change resulted in the retreat of montane woody vegetation toward higher elevations in the Great Escarpment of South Africa and Lesotho (Bentley et al., 2019). This is anticipated to result in the general reduction of the distribution of the essential plant species. Ndlala & Dube, (2021) found possible range decrease of plant species such as the Wild syringa (*Burkea Africana*), Wild Plum (*Ochna pulchra*), and Kalahari podberry (*Dialium englerianum*) in the woodlands of the Kavango-Zambezi Transfrontier Conservation Area (KAZA TFCA) in Namibia and Angola. The range reduction was possibly driven by climate change, mainly rising temperatures and droughts.

A number of woody species of the Namibian savanna, such as the African teak (*Biakiaea plurijuga*), Wild syringa (*Burkea Africana*), African rosewood (*Guibourtia coleosperma*), and Wild teak (*Pterocarpus angolensis*) were experiencing a decrease in their physiological performances, leading to the decline of their distribution (Bombi, 2018). The decrease in the distribution of woody species was driven by reduced rainfall and increased temperature, and the related water shortage (Rankoana, 2016; Weiskopf et al., 2020). The severe reduction in perennial grasses, causing the decline in the carrying capacity of the grassland ecosystem, was expected to take place in the central Kalahari savanna, Namibia. The major drivers of the reduction were decreased precipitation, higher temperature and increased interannual climatic variations (Parmesan & Hanley, 2015; Chaitra et al., 2018; Ouma et al., 2018; Odeny et al., 2019).

Observed in the Miombo woodlands in central parts of Zimbabwe was a decline in the distribution range of the evergreen tree *Julbernardia paniculata* (Chidumayo, 2019). The contraction in the range was largely driven by high mean annual maximum temperatures and increased evapotranspiration. The increasing temperatures were found to favor the co-occurring *J.globiflora* at the expense of the *J.paniculata* (Chidumayo, 2019). Climate change was also expected to cause a range contraction of the *Welwitschia mirabilis* in the northern part of the Namib Desert (Bombi, 2018).

In terrestrial ecosystems, plant species shifted toward higher elevations at the rate of 0.011 km per decade and to higher latitudes at the rate of 16.9 km per decade (Adhikari et al., 2018, Sintayehu, 2019). Climate change has resulted in significant change in the geographical distributions of southern Africa's plant species. The changing climate is drastically shifting southern Africa's plant species diversity. The miombo tree species in Zimbabwe are stressed to adjust to the longer dry episodes and dwindling availability of water (Mudzengi et al., 2017). In South Africa, the unique environments that support plant species are more at risk to the effects of climate change (Kamara et al., 2020). Finally, a temperature increase by 1.5°C –2°C was anticipated to drive the productivity decline of southern African plant species, for the most parts of Mozambique, Namibia, Botswana, Zimbabwe, and Zambia (Lawal et al., 2019).

CHAPTER III: METHODOLOGY

3.1 Introduction

This chapter aims to present the research paradigm, research design, sampling methods and specific field data collection methods as well as procedures employed to accomplish this research's objectives. Further, the chapter examines methods used in data analysis and presentation. The methodology of this research is presented following the order in which the main objective, specific objectives, research questions and conceptual framework are presented in the preceding sections. The study's critical aspects were presented, considering the strength and consistency of the techniques employed.

3.2 Research paradigm

This research was premised on the pragmatic research paradigm. The pragmatic research paradigm advocates using quantitative and qualitative research methods (Maarouf, 2019). Some researchers consider pragmatism as the most common theoretical rationalisation for the mixed method research design (Trochim, 2015, Khaldi, 2017, Maarouf, 2019). Therefore, the pragmatic research paradigm is a theory that can be collaborated with the mixed method research design since its fundamental postulations offer the quintessence for integrating research methods. Pragmatism is an advanced theory that provides the epistemology and reason for integrating quantitative and qualitative techniques (Kivunja et al. (2017). This research adopted the pragmatic research paradigm on the basis that it utilises the advantages and resemblances of both qualitative and quantitative strategies. The adoption of the pragmatic research paradigm in this study reduces the limitations of each research model through taking advantage of the strengths of both. A case in point is the positivist paradigm which assumes any change may be alleged to be due to the correlation involving two elements, for example, climate-species diversity relationship, could not be perfect since the relationship is not all the time causality. The fissure therefore, may be filled by a model that attempts to comprehend perceptions and responses of inhabitants who have interacted with the surroundings for an extended time frame concerning the sensitivity of indigenous plants to climatic changes in a semi-arid environment.

Kivunja et al. (2017) believe that pragmatism is a philosophy which permits the incorporation of paradigms, hypotheses, techniques as well as processes of collecting and analysing data. The pragmatic research theory is oriented towards resolving realistic issues around the actual world unlike relying on suppositions regarding the nature of facts (Trochim, 2015). It means that pragmatism encourages action-oriented methods of enquiry. Pragmatism was developed by theorists who disagreed on the possibility of accessing reality regarding the natural world using a single scientific technique as supported by the positivist model (Trochim, 2015; Khaldi, 2017), hence a mono-paradigmatic orientation of study desired to be better. There was need for a broader perspective that could offer research techniques regarded as the most suitable for researching the current problem. This idea saw the prominence of a paradigm that advocated for the use of integrated research techniques as a pragmatic means to comprehend world phenomena, thus the adoption of the pragmatic research model.

3.3 Research design

The research employed the mixed-methods research blueprint as its approach of inquest. This research design originates from the pragmatic perception and many scholars drawn from different disciplines are using it over and over again (Daniel, 2016; Kivunja et al., 2017). The mixed-methods technique entails collection, analysis as well as integration of qualitative and quantitative data (Daniel, 2016; Ishtiaq, 2019). The quantitative methodology is premised on the positivist paradigm, whilst the qualitative methodology is rooted in the interpretivist model (Chapungu et al., 2020). The quantitative research's focal point is hypothesis testing, thus it follows the confirmatory scientific method whilst the qualitative research primarily follows the experimental scientific method. Qualitative research describes what is seen locally to appreciate experiences of human beings and communicate their viewpoints. Figure 3 .1 illustrates the mixed-methods research design as practically used in this research.

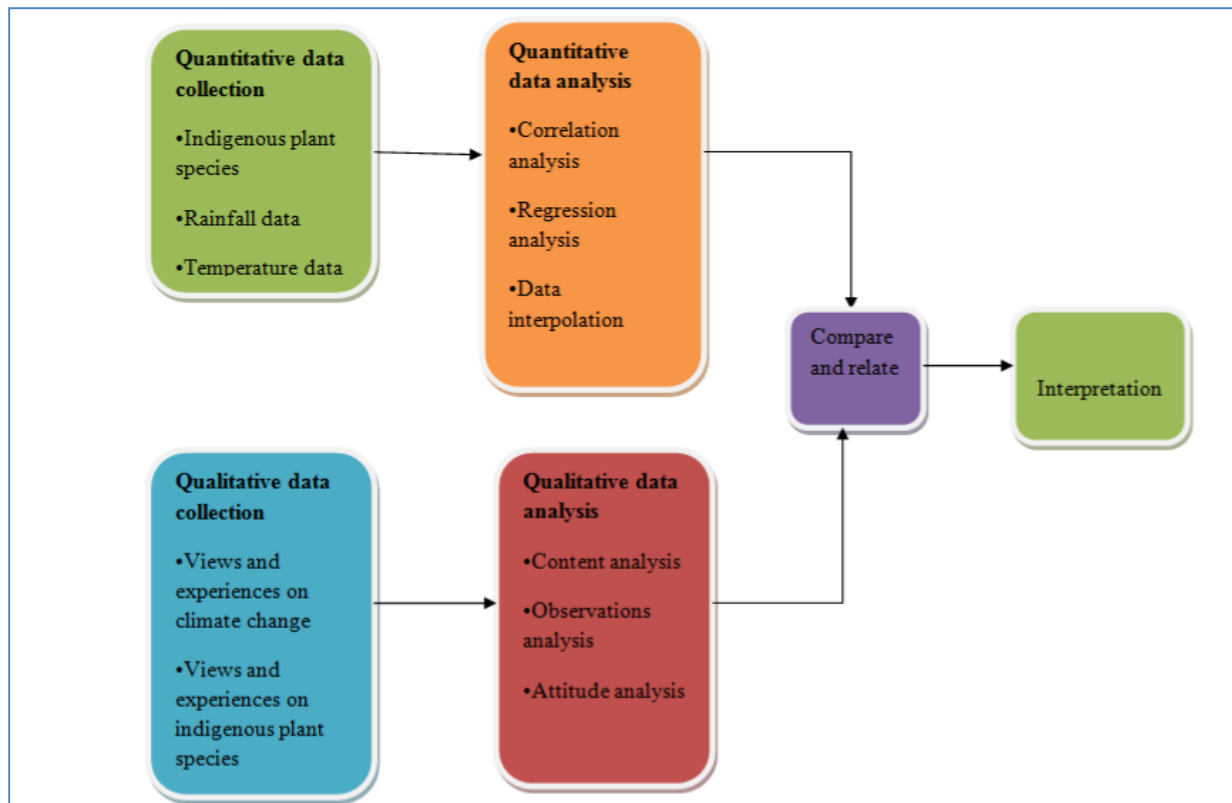


Figure 3. 1: The Mixed method research design as practically used in this research

Source: Adapted from Chapungu, (2017)

The idea of integrating quantitative and qualitative approaches allowed the study to expand its extent of grasping and validation whilst neutralising the limitations of each method of enquiry. Among the advantages of the mixed-method research includes its probability to triangulate many techniques and sources of data to study and get to the bottom of the same problem (Daniel, 2016; Ishtiaq, 2019). Triangulation facilitates the accurate identification of a problem through getting closer to it from various angles employing varied methodologies. The mixed-methods research also has the advantage of providing a full and inclusive understanding of the study problem as compared to using either the quantitative or qualitative approaches separately (Daniel, 2016; Ishtiaq, 2019).

This research used the mixed methods approach to integrate qualitative and quantitative statistics to build up a full understanding of the influence of the changing climate on the diversity of

indigenous plant species. Furthermore, the use of the mixed method research design validates results derived from the analysis of imagery. However, the mixed method research design can be difficult to apply since it is time consuming and requires more resources in terms of planning and implementation. Besides, it becomes a mammoth task to plan and put into practice one technique by drawing on the results the other (Daniel, 2016; Ishtiaq, 2019).

3.4 Population

This research's main target population was older people in communal households in Chegutu district. Older people have information about the environmental changes in the study area. From this population, 10 percent of the communal households were chosen at random from final selected plots to complete questionnaires. However, key informants from the stated institutions and traditional leaders were also targeted for interviews. Individual types of indigenous plant species in the entire district were documented, and this was carried out on sampled plots regarded as representative of the whole district.

3.5 Sampling

A geographic information system (GIS) called the non-aligned block sampling technique was employed to study the distribution, abundance, richness and diversity of indigenous plant species between 1984 and 2020 throughout the district. The system makes use of the grid as a guide, which involves the nesting of sampling plots randomly. The grid system comprises perfect squares that divide space into parts of the same dimensions. The non-aligned sampling block technique allows the measurement of parameters at various levels. Using a step-by-step procedure, the nesting of sampling plots was executed on the digital map of Chegutu district following the three stages outlined below.

•**First stage:** Equal grids with same dimensions were superimposed over the study area's map. The grids divided the map of Chegutu district in such a manner that sampled plots were drawn from all parts of geographic difference. Every grid represented points where plot samples were obtained. The method ensured that the sampling was more representative of the study area covering the entire map of Chegutu district. Twenty grids were sampled.

•**Second stage:** Grids chosen in the first stage were split further into smaller equal grids. Three sampled grids were randomly picked using the random point generator in ArcGIS. As a result, sampled plots increased in number to 60.

•**Third stage:** Grids in the second stage were split further into smaller grids of equal size. Three smaller sampled grids were randomly picked from every bigger grid created in stage two. Hence, sampled grids rose to 180. These constituted the sampling plots where data was obtained.

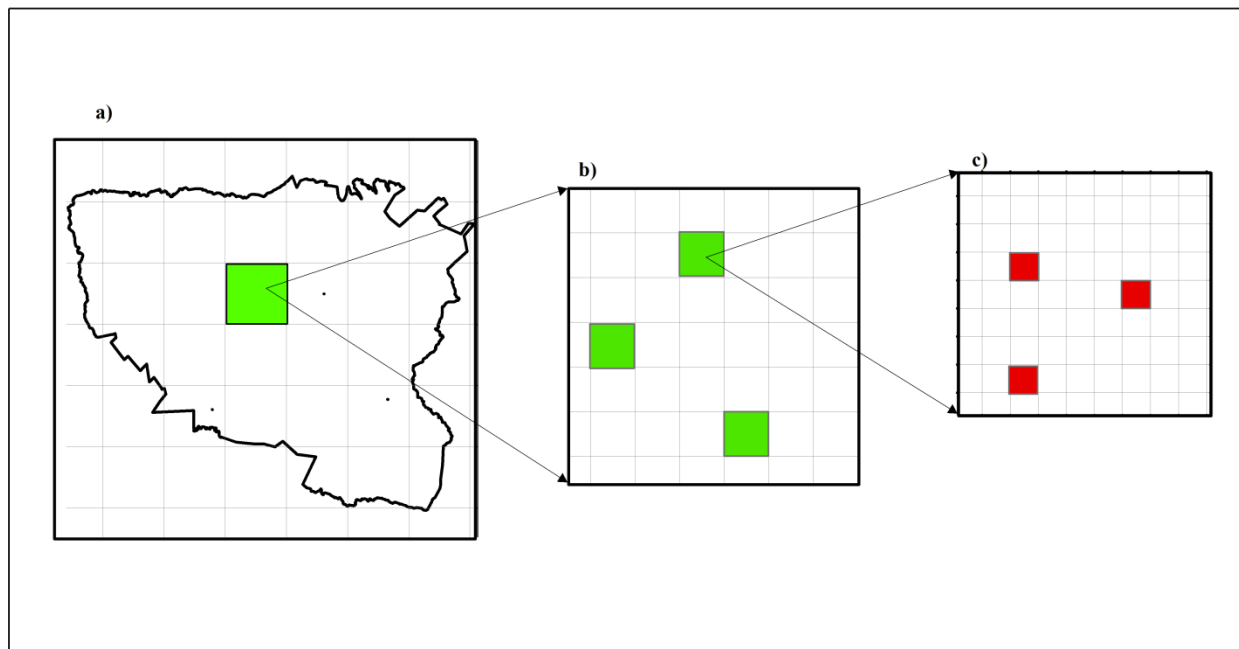


Figure 3. 2: The non-aligned sampling method as used in the study

(a) The study map was split into large equal grids of the same dimensions; (b) the grids were divided again with same dimensions where 3 plots were selected at random; and (c) last sampled plots after further split and selection of 3 grids at random

3.6 Determination of the optimum plot size

Sampled plot sizes can affect the quality of data gathered when representation is affected. In this research, plot sizes were determined by the use of the species-area technique. The species-area system entails plotting the number of species identified in plots of a sequentially bigger part such

that the part enfolded by each one surrounded the part enclosed by the smaller one. To minimise sampling bias, the species-area method considered areas with varying species since samples were taken from each area of geographical difference.

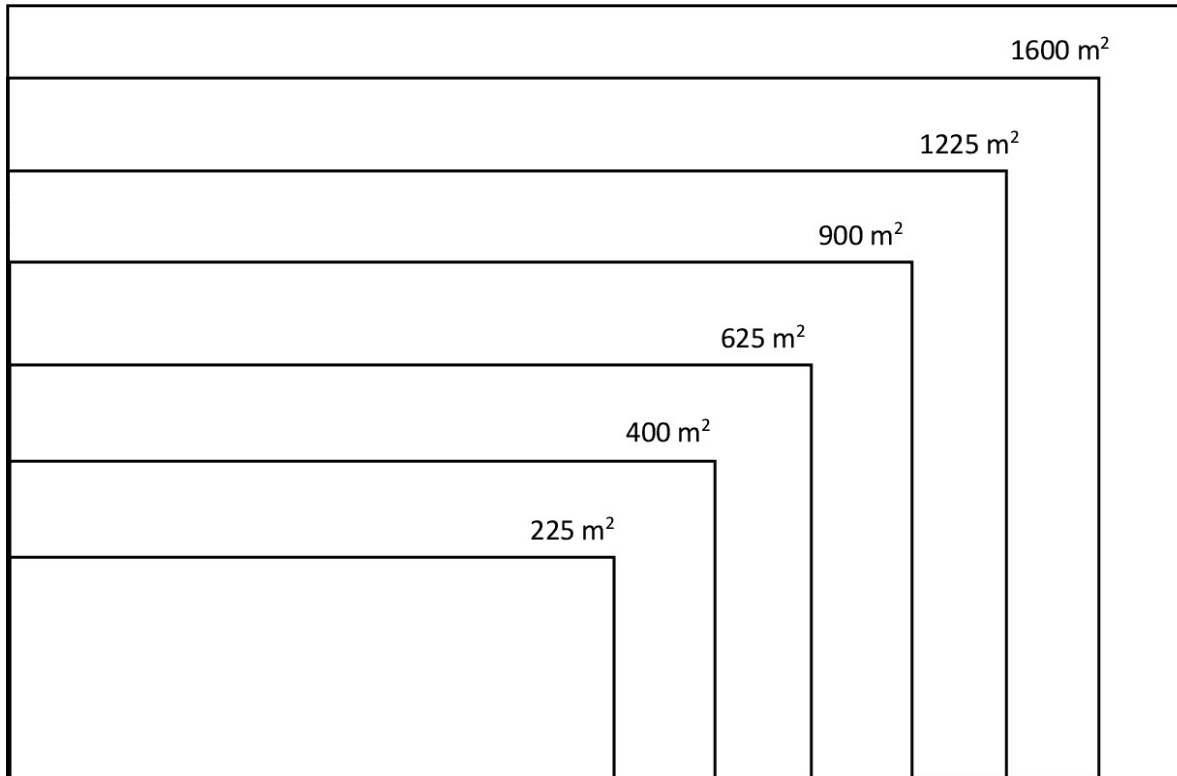


Figure 3. 3: Plots used to determine the optimal plot dimensions in the research.

As a result, 225m², 400m², 625 m², 900 m², 1225 m² and 1600 m² plots were sequentially created to establish the optimal plot dimensions (Figure 3.3). Species richness was documented for each plot. The best possible plot with optimal dimensions was the one in which the number of species recorded remained constant with an increase in the size of plots.

3.7 Satellite image downloading and processing

Remote sensing was the main instrument employed to assess indigenous plant species diversity changes during the study period. The use of remote sensing was possible after establishing a positive correlation between indigenous plant species diversity and a satellite derived vegetation

index (NDVI). Downloaded satellite images covering a period from 1984 to 2020 for both the wet and dry seasons were analysed. Images for the study area were obtained from the online Landsat archive via the GloVis web link (<http://glovis.usgs.gov/>). Consideration of the year for the first images was arrived as a result of the accessibility of images with bands essential to work out NDVI. Accessibility of free images from the GloVis web link also determined the selection of years. The study guaranteed that the chosen images spread over particular decades, for example, between 1990 and 2000, 2000 and 2010, and 2010 and 2020. Also considered was an interval of 10 years between the years considered. The Landsat images were acquired in digital number (DN) format and calibrated to spectral radiance units. Landsat 7 Thematic Mapper (TM) imagery for 1990 and 2000 and Landsat 8 Thematic Mapper (TM) imagery for 2010 and 2020 with a spatial resolution of 30 m were used for analysing NDVI. NDVI is a mathematical pointer usually used as a proxy for plant biomass from remotely sensed data (Onyia & Balzter, 2018; Rampheri et al., 2020). 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 (Onyia & Balzter, 2018) in the analysis of remotely sensed information. The correlation involving NDVI and indigenous plant species richness was scrutinised to substantiate the usefulness of remote sensing in foretelling the diversity of indigenous plant species.

3.8 Precipitation and temperature data

Precipitation and temperature data were acquired from the Zimbabwe Meteorological Services Department (ZMSD). The data acquired from the ZMSD were complemented by a dataset downloaded from the internet. The most important bioclimatic variables that can be used as surrogates for detecting climate changes are precipitation and temperature (Yelwa et al.; 2019, Weiskopf et al.; 2020).

3.9 Data collection methods

a) Questionnaire surveys

A questionnaire survey was conducted with local household communities where indigenous plant species are found. People in the local community are more knowledgeable about the changes in their local areas concerning both climatic changes and indigenous plant species

diversity changes. Therefore, the research used the questionnaire survey to gather data on indigenous plant species sensitivity to climate change. The data collected through questionnaire surveys complemented data gathered through remote sensing, field observations and key informant interviews.

The use of questionnaire surveys as an instrument for collecting data was due to their effectiveness in gathering quantitative and qualitative data from respondents knowledgeable about changes during the study period. Ishtiaq (2019) believe that questionnaire surveys give information on environmental conditions in exact areas and remain among the economical method to bring together data that can be helpful in different areas (Kivunja et al., 2017). Questionnaires may include questions that are close-ended and open-ended. Close-ended questions solicit for responses that are objective from a list given, whilst open-ended questions allow free expression of answers by participants (Khaldi, 2017).

The administration of questionnaires was done in similar criteria used for assessing indigenous plant species diversity. This implies that participants who took part in the questionnaire survey were only those whose households were located in the final sampled plots and were selected at random to participate. This study had planned to sample 180 plots. However, seven (7) plots were inaccessible; as a result, questionnaires were distributed to 173 plots. A 95% response rate for the questionnaire surveys was achieved. Lack of 100% response rate was not achieved due to hectic programs and absenteeism. The researcher personally administered questionnaires to selected households, delivering the questionnaires to the participants and collecting them soon after completion.

d) Field observations

Field observations were conducted from the same sampled plots at least four times during the year covering all the seasons (summer, post-summer, winter and post-winter). During field visits, observations were made on indigenous plant species composition. Observations were done in the surrounding environments.

c) Key informants' interview

Key informant interviews involve asking open-ended questions to key stakeholders (Muhammad & Kabir, 2018). This study used the semi-structured type of interview whereby the procedure for collecting data was flexed whilst retaining the structure of issues meant for discussion. In an interview guide, a collection of predetermined problem questions are utilised to steer the interrogation procedure (Muhammad & Kabir, 2018). The interview procedure permitted conversations between the interviewer and the interviewees. Key informant interviewees were selected using purposive sampling. Through the use of the purposive sampling, the interviewer had the chance to get hold of respondents who could give comprehensive data as this guaranteed answers for all the research questions. Among the key informants were personnel from the Environmental Management Agency (EMA), Meteorological Service Department (MSD), the Ministry of Environment, Climate Change, Tourism and International Trade, ARES Officers and local traditional leaders.

The information collected from key informants was used to cross-check participants' views. The interview focused on the local area's climate pattern and indigenous plant species diversity. Conducting key informant questioning was meant to gather information from key organisations as well as persons involved in the management of indigenous plant species and climatic changes-linked effects. Accordingly, the Ministry of Environment, Climate Change, Tourism and International Trade was considered to be a key player in climatic changes - indigenous plant species diversity matters. The Meteorological Services Department (MSD) was considered necessary pertaining to climatic patterns in the district. The Environmental Management Agency (EMA) was taken on board to share insights pertaining to the diversity of indigenous plant species changes during the study period. Local traditional leaders were considered key informants at the community level because of the role they play as overseers with respect to the utilization of indigenous plants.

3.10 Data collection procedures

The researcher visited the District Administrator's Office in possession of an introductory letter and research ethics approval from Great Zimbabwe University granting permission to go for data collection (See appendix iv for the introductory letter provided by Great Zimbabwe University).

The District Administrator's Office issued a clearance letter to the researcher authorising data collection to commence in Chegutu district (See appendix v for authority granted to collect data in Chegutu district). After acquiring the letter of consent from the District Administrator, the researcher then proceeded to traditional leaders and all the institutions concerned for data collection and also the sampling of plots kick started. Questionnaires were managed personally, and right away interviews were also carried out.

Reliability, validity and trustworthiness issues

Reliability and validity concerns are important to the research and were taken into consideration by the researcher. A discussion of reliability and validity issues is given in the paragraphs underneath.

Reliability

Reliability is the extent to which methods of collecting and analysing data are expected to bring out similar results when different investigators conduct the same study (Muhammad & Kabir, 2018; Roshaidai & Arifin, 2018). Reliability, therefore, is the degree of consistency of research findings over time and how they precisely characterise the total population of the research. The researcher collected data from respondents at their homes and farms to ensure reliability and minimise errors caused by participants. These errors arise if data is collected from respondents in surroundings and setups inconsistent with their standard behaviour patterns. To enhance the consistency of the collected data, the investigator observed recommended principles and practices of conducting research. The researcher emphasised strongly the issue of secrecy before the completion of questionnaires, to encourage respondents to give correct information. Prior to data collection from respondents, the investigator clarified the purpose of the study to minimise respondent prejudice.

Validity

Validity refers to the extent to which the explanations and concepts hold common implications among respondents and the investigator. To ensure the validity of the study, the researcher employed complementary data collection methods and tools, and in that regard used many methods of collecting data. In this study, four methods of collecting data were used. This

increased the capability of the researcher to triangulate different data collection methods. This powerful technique facilitates data validation through cross- verifying from multiple methods of collecting data whilst studying the same event (Trochim, 2015). Before the commencement of data, a pilot study was carried out in two wards to test research instruments for possible errors. A pre-survey study was carried out to pre-test data and ascertains the practicability of the research instruments using questionnaires before they are distributed to the sampled plots (Teijlingen, 2014, Trochim, 2015, Teijlingen, 2018). A pilot study may provide warning in advance of possible failure of the main study or show either data collection tools are suitable or too complex. Authenticity of the results of this study was improved since data collection techniques complemented each other.

Trustworthiness of data collection procedure

The issue of trustworthiness was also of concern to the study and was considered by the researcher. The following procedures were used in this research to increase trustworthiness.

Prolonged engagement: This involves learning the way of life of the respondents in an effort to build faith (Trochim, 2015). Researchers must spare a reasonable amount of time at the study site and learn some alterations, including perceptual, discriminatory as well as misunderstanding of the researcher's question.

Persistent observation: This involves examining credibility by looking deeply at what the investigators are probing and studying in detail.

Triangulation: It was used since it examines a significant number of sources, that is, interviewing and observation methods. Contextual validation plays a role in triangulation because it examines the validity of a piece of a study by comparing it with other kinds of evidence on the same points to find similar characteristics.

Ethical considerations

In research, ethics are considered necessary, and investigators need to always take ethical issues seriously that come into sight during the study. The researcher observed the research ethics given below.

Confidentiality

The researcher ensured that the participants' right to confidentiality and privacy was upheld during the study. Respondents were ensured that data collected from them was going to be used only for academic purposes and that their real names were not to be used.

Informed Consent

Getting approval from participants involves the following: approval must be given willingly, respondents need to comprehend the issues they are asked to do, and involve respondents taking part must give consent. It implies that to take part in a study, respondents must be sufficiently informed about the study, understand the information required from them, and must freely choose to partake or not (Roshaidai& Arifin, 2018). The agreement by respondents to take part in this research was reached after the researcher had precisely explained the research process. Respondents were informed about the purpose of the study before they participated in the study. Participants were also assured that their involvement was at will and might pull out any time, decide not to answer certain questions they sense can jeopardize their privacy, and also pulling out from the study has no prejudice.

3.11 Data analysis

Normality tests

The time series data for temperature, precipitation as well as indigenous plant species were checked using the Kolmogorov-Smirnov test to determine if they diverge from normal distribution or not. The checking of data for normality assisted in determining whether the data satisfy the hypothesis of parametric or non-parametric statistical analysis methods (Pohlert, 2020). The analysis of data using parametric tests is appropriate if the data infers a normal distribution; if not, the use of non- parametric tests it is usually reasonable (Omayio & Mzungu, 2019, Pohlert, 2020). Non-parametric statistical analysis techniques were employed in this research.

Trend Testing

A trend analysis of precipitation and temperature records was acquired from meteorological stations in Chegutu district and the surrounding areas using Ms – Excel 2007. The Mann-Kendall trend test was used to check for significant changes in precipitation, temperature as well as the diversity of indigenous plant species during 36 years (1984–2020). The Mann-Kendall trend test is a non-parametric technique usually used for checking out for monotonic patterns in a series of environmental data such as climate (Pohlert, 2020). The unacceptable proposition, H_0 , means the data has no trend. The alternative theory, H_1 , means there is a trend in the data set. Therefore, the data series follow a monotonic trend. The Mann-Kendall test statistic is calculated as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(X_j - X_k)$$

In which S is the Kendall score. $\text{Sgn}(x) = (1 \text{ if } x > 0, 0 \text{ if } x = 0, -1 \text{ if } x < 0)$

Interpolation

Data on indigenous plant species gathered from sampling plots and meteorological data from the surrounding weather stations were interpolated first using the Thiessen polygons technique in a GIS to make sure that indigenous plant species, temperature as well as precipitation data represent all areas. The Thiessen Polygon method is among the most commonly employed approaches in hydrometeorology when establishing mean rainfall in a given region comprising more dimensions. Chegutu district was split into numerous polygons, each around a measurement point. A weighted average of the measurements was taken based on the size of each one's polygon. The weighted average was calculated using the equation:

$$P = \frac{P_1A_1 + P_2A_2 + P_3A_3 + \dots + P_nA_n}{A_1 + A_2 + A_3 + \dots + A_n} = \sum_{i=1}^n \frac{P_iA_i}{A_i}$$

Where 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 indigenous plant species and climate data to determine the correlation involving climatic variables and the diversity indigenous plant species.

Shannon Wiener Index (H)

The Shannon Wiener diversity index (H) was employed to determine the diversity of indigenous plant species from the species abundance data collected from the sampled plots. The Shannon-Wiener Index combines features of evenness and richness. The Shannon-Wiener index is an information statistics index which measures the average degree of doubt in establishing the diversity of randomly selected species from a collection of S species and N individuals (Omayio & Mzungu, 2019). The Shannon index is calculated using the equation:

$$H = - \sum_{i=1}^s P_i \ln P_i$$

Where P_i is the proportion (n/N) of individuals of one species found (n) divided by the total number of individuals found (N), \ln is the natural log, S is the sum of the calculations, and S is the number of species.

CHAPTER IV: RESULTS AND DISCUSSIONS

4.1 Introduction

The findings and discussions of the study are presented in this chapter. To achieve the study's objectives, data collection and data analysis followed the mixed- methods research design. The presentation of the research findings and discussions follows the arrangement of specific objectives and research questions in Chapter One. First to be presented in this chapter is the evidence of a changing climate in Chegutu district between 1984 and 2020, followed by factors influencing changes in indigenous plant species diversity covering the same period. The presentation and discussion of the evidence of climate change, focusing on variables related to rainfall and temperature helps to realize the state of climate change in the district. Results of the study substantiate the rationale for the study of the sensitivity of indigenous plant species diversity to a changing climate. Although several researchers, such as (Makova et al., 2019; Chapungu & Nhamo, 2016), have already established the incidence of climatic changes in other areas of the countryside, this research focuses on climatic changes at the district level employing different climatic elements to confirm its existence.

4.2 Evidence of climate change in Chegutu district between 1984 and 2020.

Results indicate that climate change occurred in Chegutu district, as shown by the statistically significant change in variables related to temperature and precipitation (Table 4.1). A statistically significant increase in bioclimatic variables linked to temperature demonstrates that the atmosphere is getting warmer over time. Likewise, bioclimatic variables linked to precipitation have shown a decreasing trend, suggesting a reduction of the total quantity of rainfall received in the district during the study time. The study assessed seven bioclimatic elements. Table 4.1 illustrates the assessed bioclimatic elements, trend equation, p-value and also the trend descriptions. Six (85.7%) bioclimatic elements of the seven analysed climatic elements confirm a significant trend signifying climatic changes (Table 4.1).

Table 4.1: Bioclimatic elements showing climatic changes in Chegutu district from 1984 to 2020

| Climatic element | Trend equation | P- Value | Trend description |
|--------------------------------|---------------------|----------|--------------------------------------|
| Mean monthly maximum temp | $y=0,031x-35,326$ | 0,005 | Increasing trend/significant change |
| Mean monthly temp | $y=0,0149x-17,398$ | 0,026 | Increasing trend/ significant change |
| Max temp : warmest month | $y=0,0477x-58,444$ | 0,008 | Increasing trend/ significant change |
| Min temp : coldest month | $y= 0,0089x+18,327$ | 0,006 | Decreasing trend/ significant change |
| Total annual precipitation | $y= 5,6078x+11836$ | 0,040 | Decreasing trend/significant change |
| Precipitation: warmest quarter | $y= 1,4652x+3065,1$ | 0,048 | Decreasing trend/significant change |
| Mean monthly precipitation | $y= 0,3101x+671,18$ | 0,029 | Decreasing trend/significant change |

4.2.1 Temperature-related variables

Figure 4. 1: Illustrates linear models for bioclimatic temperature-related variables from 1984 to 2020.

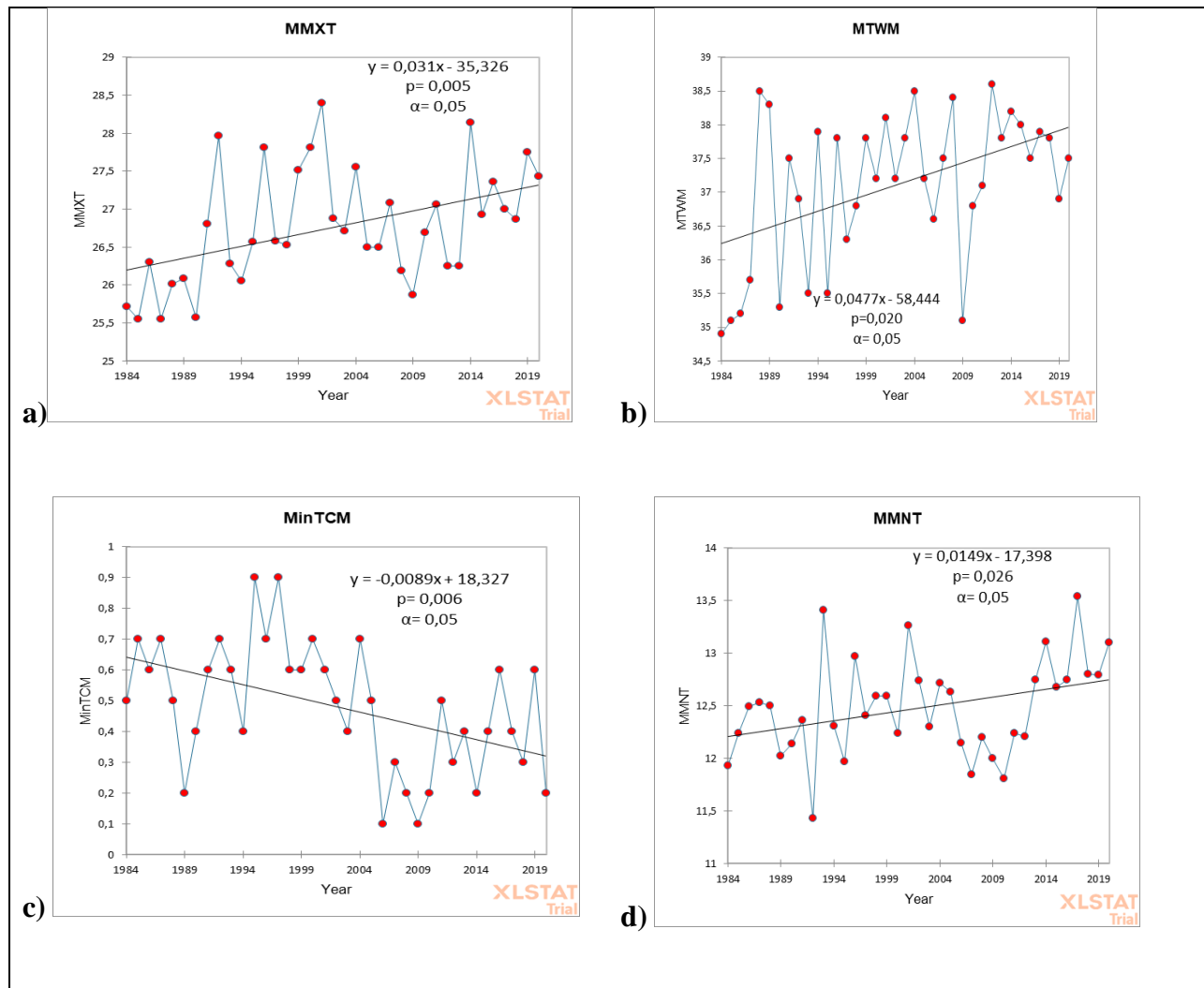


Figure 4.1: Linear models for bioclimatic variables related to temperature from 1984 to 2020:

(a) Mean monthly maximum temperatures, (b) Maximum temperature of the warmest, (c) Minimum temperatures of the coldest month, and (d) Mean monthly temperature

Results of the Mann- Kendall trend test confirm a rise in the mean monthly maximum temperatures (MMXT) (Figure 4.1a) from 1984 to 2020. There is a statistically significant change ($p= 0.005$, $\alpha = 0.05$) in mean monthly maximum temperature in Chegutu district. The unacceptable theory projected to check if a trend subsists states that there is no trend in the mean monthly maximum temperature statistics, whilst the other assumption proposes that there is a trend in the data. Previously confirmed:

H_0 : A trend do not exists in the mean monthly maximum temperatures between 1984 and 2020.

H_1 : A trend exists in the mean monthly maximum temperatures between 1984 and 2020.

In which H_0 is the unacceptable theory, and H_1 is the alternative theory.

Since the calculated p-value (0.001) is less than the level of significance (alpha 0.05), the unacceptable theory, which states that a trend do not exist in the mean monthly maximum temperatures, was rejected whilst accepting the other theory (0.005).

Illustrated in Figure 4.1b is the linear model for the maximum temperature of the warmest month (MTWM). Results of the Mann-Kendall trend test confirms a significant change ($p=0.020$; $\alpha=0.05$) in the maximum temperatures of the warmest month. In this study, the month of October is regarded as the warmest month based on the study of the temperature characteristics of all the months during the period under review. From the trend line model above (Figure 4.1b), the unacceptable theory stated that a trend do not exists in the maximum temperatures of the warmest month during the study time. It was formerly stated in the alternative theory that a trend existed in the maximum temperatures of the warmest month. Hence, the unacceptable suggestion is rejected since the calculated p-value (0.020) is less than the level of significance (alpha 0.05).

The trend line (Figure 4.1c) reveals a considerable decrease ($p= 0.006$; $\alpha= 0.05$) in the minimum temperatures of the coldest month (MinTCM) in the study area during the period under review. The study regarded variations in the minimum temperatures of the coldest month as the suitable surrogate pointer for climatic changes. Han et al. (2020) argue that the minimum temperature of

the coldest month is an excellent forecaster of the richness of plant species in a changing climate. The coldest month of the study area was determined by analysing the minimum temperatures of all the months during the study period of 36 years.

The unacceptable theory indicated a nonexistent pattern in the minimum temperatures of the coldest month, at the same time as the other assumption stated that a trend existed in the temperatures. The unacceptable theory is rejected since the calculated p-value (0.006) is less than the level of significance, alpha 0.05.

Linear model results of the Mann-Kendal show a significant ($\alpha=0.05$, $p=0.026$) trend in the mean monthly temperatures (MMNT) from 1984 to 2020. The trend line graph (Figure 4.1d) indicates an increase in the mean monthly temperatures in Chegutu district throughout the study time. The unacceptable assumption stated the nonexistence of a trend in the mean monthly temperatures, and the other assumption indicated the existence of a trend in the temperatures. It was previously stated as follows:

H_0 : A trend does not exist in the mean monthly temperatures between 1984 and 2020.

H_1 : A trend exists in the mean monthly temperatures between 1984 and 2020.

In which H_0 is the unacceptable assumption, whilst H_1 is the other assumption.

Given that the p-value (0.026) of the linear model is less than the level of significance ($\alpha = 0.05$), it, therefore, implies that the unacceptable assumption must be rejected since a trend does not exist in the mean monthly temperatures from 1984 and 2020.

These bioclimatic elements are considered significant since they determine the main changes in climate over an extended time frame (Gwitira et al.; 2013, Han et al.; 2020). Hence, these bioclimatic variables are essential, particularly when analysing the sensitivity of indigenous plant species diversity to climate change.

4.2.2 Views of local people on temperature changes between 1984 and 2020

A qualitative analysis of temperature changes in Chegutu district between 1984 and 2020 was done to verify the validity of quantitative assertions presented in this chapter. The analysis was based on perceptions that were collected through qualitative instruments like questionnaires and key informant interviews. The perceptions of local people and the respective percentages of participants for each perception concerning temperature changes in the district are shown in Table 4.2. Most respondents testified that bioclimatic variables related to temperature in the district have changed over the period under study.

Table 4. 2: Perceptions of local people regarding temperature indicator elements related to climatic changes

| Descriptions of temperature element | Strongly Agree | Agree | Not Sure | Total |
|---|----------------|-------|----------|-------|
| Increase in mean monthly temperatures | 60 | 27 | 13 | 100 |
| Increase in max temperatures of the warmest month | 95 | 3 | 2 | 100 |
| Decrease in min temperatures of the coldest month | 62 | 25 | 13 | 100 |
| Increase in summer temperatures | 80 | 20 | 0 | 100 |
| Increase in winter temperatures | 75 | 15 | 10 | 100 |

Participants could either strongly agree or agree to observed increases in temperature with reference to temperature related variables given in Table 4.2. Out of a total of 180 people interviewed, it is observed that 60% of participants agreed strongly to the view that there is a rise in the monthly mean temperatures in the district, whilst 27% of the participants agree with the same observation. The percentage of participants who confirmed that they were not sure of an increase in the mean monthly temperatures in the district was 13%. The participants' views concur with the results of statistical trend tests that give evidence of considerable changes of the monthly mean temperatures in the district. Regarding monthly mean maximum temperatures, the percentage of participants who strongly agree that it has increased is 75%. About 25% of the participants agree with the same view based on their experiences. Only 10% were not sure of this view.

In addition, as revealed in Table 4.2, the local community confirmed the rise in summer and winter temperatures in the district. The view that there is an increase in summer temperatures

was confirmed by approximately 80 % of the participants, whilst 20% agreed with the same thought. Concerning winter temperatures, the percentage of participants who strongly agreed that there was an increase was 75%, with 15% agreeing to the same perception based on their past experiences and observations. The remaining 10% was not sure of the increase in winter temperatures. Furthermore, the local community noted a rise in the maximum temperatures of the warmest month from 1984 to 2020. More than 95 % of the participants interviewed strongly agree with the view, while only 3% agree with the same observation. Just 2% of the participants were not sure of the increase in the maximum temperatures of the warmest month in the district.

Still, on temperature-related bioclimatic variables, the study examined the views of local people on the changes observed and experienced concerning minimum temperatures of the coldest month between 1984 and 2020. Also confirmed by most of the participants, was a decline in the minimum temperatures of the coldest month, who either agreed strongly or agreed to the view. The proportion of participants who agreed strongly to the decline in the minimum temperatures of the coldest month was 52%, while 25% only agreed with the same perception. On the other hand, 13% hinted that they neither agree nor prove false to this perception.

Generally, the findings have revealed that no one among the participants has consistently observed and experienced static trends of bioclimatic elements related to temperature in the district during the study period. The views of local people substantiate statistical results found in this research by analysing quantitative statistics gathered from internet websites as well as the Zimbabwe Meteorological Services Department.

4.2.3 Precipitation-related variables

Figure 4.2 shows linear models for precipitation-related bioclimatic variables from 1984 to 2020. The findings of this study confirm a statistically significant trend ($\alpha=0.05$ $p=0.040$) in the total annual precipitation (TPCP), as illustrated in Figure 4.2a. The linear model indicates a declining pattern in the total annual precipitation for the district over the study period. From Figure 4.2a, the unacceptable assumption states that a trend does not exist in the total yearly precipitation from 1984 to 2020, while the other assumption indicates the existence of a trend in the pattern of precipitation. The assumptions are previously stated as follows:

H_0 = A trend does not exist in the total annual precipitation during the period 1984 and 2020

H_1 =A trend exists in the total annual precipitation during the period 1984 and 2020

In which H_0 represents the unacceptable assumption, and H_1 is the alternative assumption. The trend line results reveal a lower p-value (0.040) compared to the level of significance ($\alpha=0.05$); hence the unacceptable assumption must not be considered.

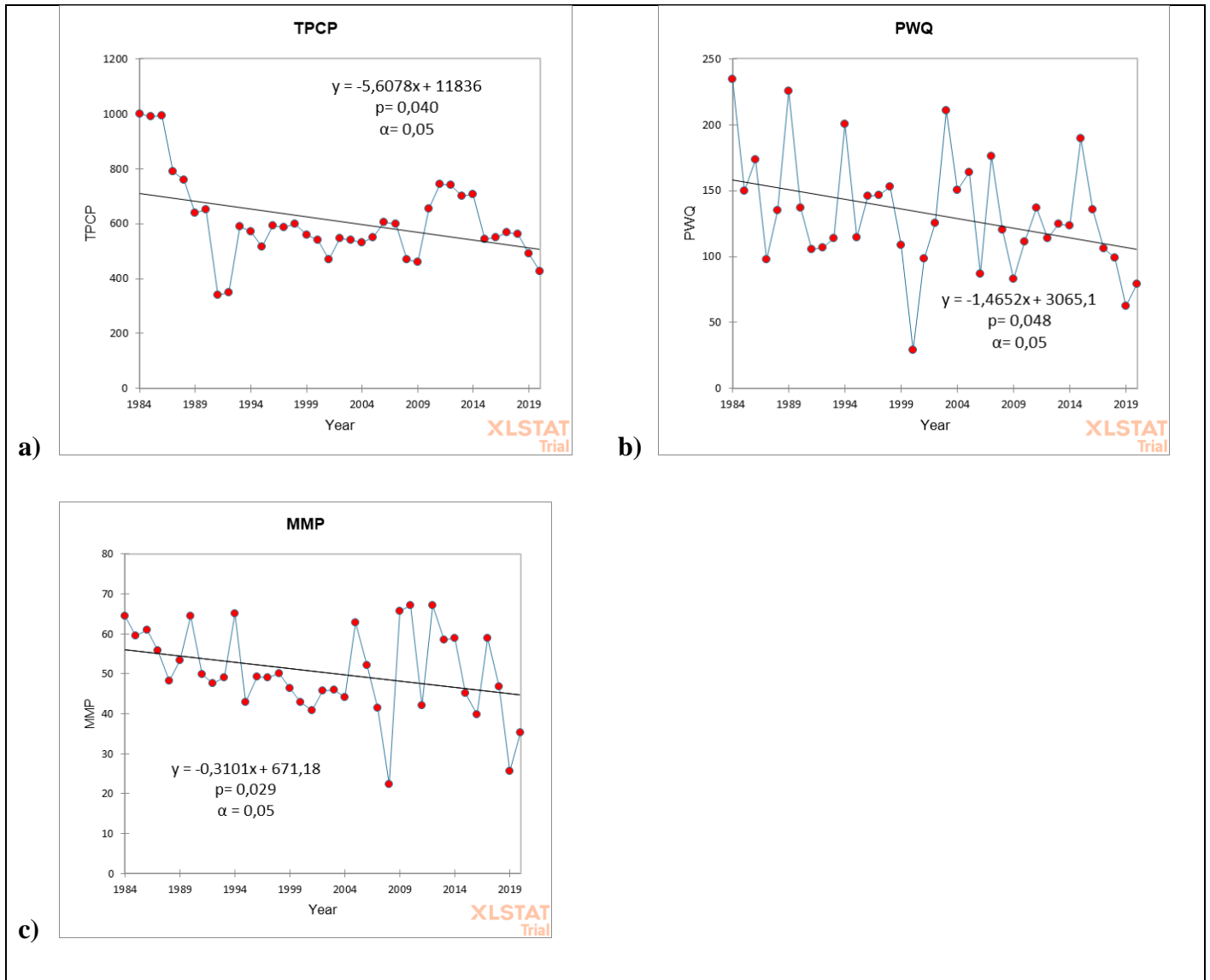


Figure 4. 2: Linear models for precipitation-related bioclimatic variables from 1984 to 2020

(a) Total annual precipitation, (b) Precipitation of the warmest quarter, (c) Mean monthly precipitation

With regards to precipitation of the warmest quarter (PWQ), results of the Mann-Kendall linear model (Figure 4.2b) illustrate a trend that is statistically significant during the study period ($\alpha = 0.05$, $p=0.048$). The linear trend model results in Figure 4.2b show a decline in the total annual precipitation for the warmest quarter of over the years. The annual three months period that experiences the maximum heat energy is regarded as the warmest quarter. Generally, in Zimbabwe and Chegutu, the warmest quarter falls between October and December (Gwitira et al., 2013).

The unacceptable assumption from the linear trend model (Figure 4.2b) states that a pattern does not exist from 1984 to 2020, while the alternative assumption states that there is a pattern in the sequence. The assumptions are previously stated as follows:

H_0 : A pattern does not exist in the precipitation of the warmest quarter between 1984 and 2020

H_1 : A pattern exists in the precipitation of the warmest quarter between 1984 and 2020

H_0 represents the unacceptable assumption, whilst H_1 stands for the alternative assumption.

Using the estimation technique, the Mann-Kendall linear model results indicate a lower p-value (0.048) compared to the level of significance ($\alpha = 0.05$). In this statistical test, the unacceptable proposition must not be considered whilst accepting the other assumption.

Shown in (Figure 4.2c) are results that confirm a significant trend ($\alpha= 0.05$, $p = 0.029$) in the mean monthly precipitation (MMP) during the period under review. The linear model shows a considerable decreasing trend line in the mean monthly precipitation for the district between 1984 and 2020. The unacceptable assumption states that a trend does not exist in the series from 1984 to 2020, while the other assumption indicates the existence of a trend in the precipitation statistics. The assumptions are previously stated as follows:

H_0 : A trend line does not exist in the mean monthly precipitation for Chegutu district

H_1 : A trend line exists in the mean monthly precipitation for Chegutu district.

H_0 represents the unacceptable assumption, whilst H_1 stands for the alternative assumption. The worked-out p-value (0.029) is less than the level of significance ($\alpha= 0.05$), and the unacceptable assumption is discarded. Therefore, the mean monthly precipitation significantly changed during the period under review. Gwitira et al. (2013) note that these bioclimatic elements related to precipitation are essential mainly when establishing the impacts of a changing climate on plant species diversity. The commonly used indicator for climate change is precipitation (Mapaura & Zimudzi, 2016, Mpandeli et al.; 2019, Chapungu et al.; 2020).

4.2.4 Perceptions of local people on precipitation changes

The study corroborated the scientific precipitation data by perceptions of rainfall changes from the surveyed local people. Illustrated in Table 4.3 are descriptions of variables related to rainfall by the local people. Approximately 75% of the participants strongly agree that total annual precipitation declined during the study period. Also supporting this view is 20% who agreed that the total annual precipitation was falling. In comparison, merely 5% of the participants could not confirm the decrease in the total annual precipitation. Table 4.3 shows that most participants either strongly agree or agree that all precipitation-related elements are declining over time. Only a tiny percentage of participants were neutral in all the situations.

Table 4. 3: Perceptions of local residents on precipitation variables from 1984 to 2020

| Description of variable | Strongly Agree | Agree | Not sure | Total |
|---|----------------|-------|----------|-------|
| Decrease in annual precipitation | 75 | 20 | 5 | 100 |
| Decline in precipitation of the warmest quarter | 80 | 17 | 3 | 100 |
| Decreasing seasonal total rainfall | 70 | 20 | 10 | 100 |
| Increasing frequency of drought | 90 | 8 | 2 | 100 |
| Reduced length of rainy season | 85 | 13 | 2 | 100 |
| Increasing severity of drought | 95 | 5 | 0 | 100 |

Participants in the study testified to a rise in the occurrence and severity of droughts. Generally, descriptions of variables by the locals confirmed a change in climate as evidenced by long-term variations in particular variables associated with precipitation. These opinions by local people coincide with statistical findings shown by many precipitation-related variables indicating a decreasing rainfall pattern over time.

4.3 The trends of indigenous plant species diversity in Chegutu district between 1984 and 2020

The Normalised Difference Vegetation Index (NDVI), adopted as a proxy indicator for plant species diversity, is decreasing over time. Illustrated in Figure 4.3 are changes in (NDVI) at intervals of ten years over 36 years. The average NDVI during the study period fluctuated between -1. and 1. However, the overall trend shows decreasing NDVI values, indicating decreasing indigenous plant species diversity. Low NDVI values of around 0.1 recorded in the study coincide with 1982, 1992, 2001 and 2016 droughts.

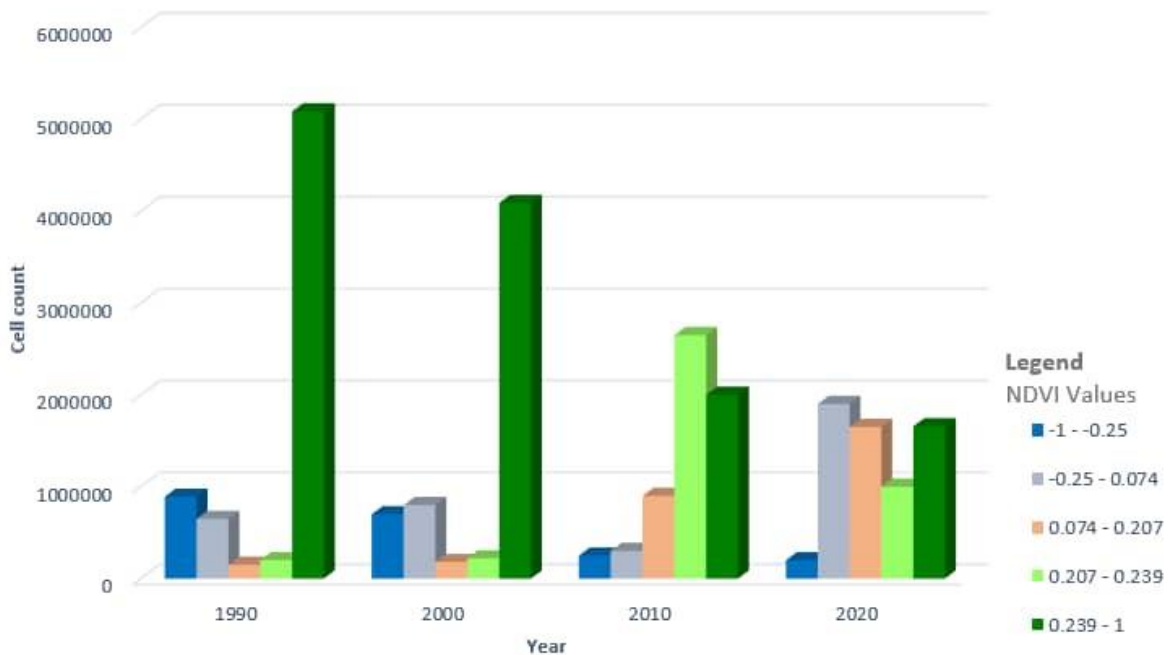


Figure 4. 3: NDVI dynamics in Chegutu district between 1984 and 2020

4.3.1 Indigenous plant species diversity changes in Chegutu district between 1984 and 2020

The Landsat images shown in Figure 4.4 for the years under study indicate spatial and temporal changes in NDVI, a proxy for plant species diversity, with time. Marked reduction of indigenous plant species diversity is noted in places that used to have rich plant species diversity. For example, in 1984, approximately 50% of the district had NDVI that was more than 0.1;

compared to 1994, the NDVI for the same place decreased to approximately less than 50%. In 2020, the decreasing pattern persisted, with places of negative NDVI values increasing compared to positive NDVI values. As a result, changes in NDVI are inevitable due to changes in climatic parameters. There appears to be a co-occurrence of indigenous plant species diversity decrease and changes in bioclimatic variables. As shown in Figure 4.4, generally, a reduction in the overall plant species diversity was observed during the period under study. A decline of the NDVI entails a reduction of the diversity of indigenous plant species, as discovered by this research. Accordingly, NDVI is used as a proxy indicator of modifications of indigenous plant species diversity.

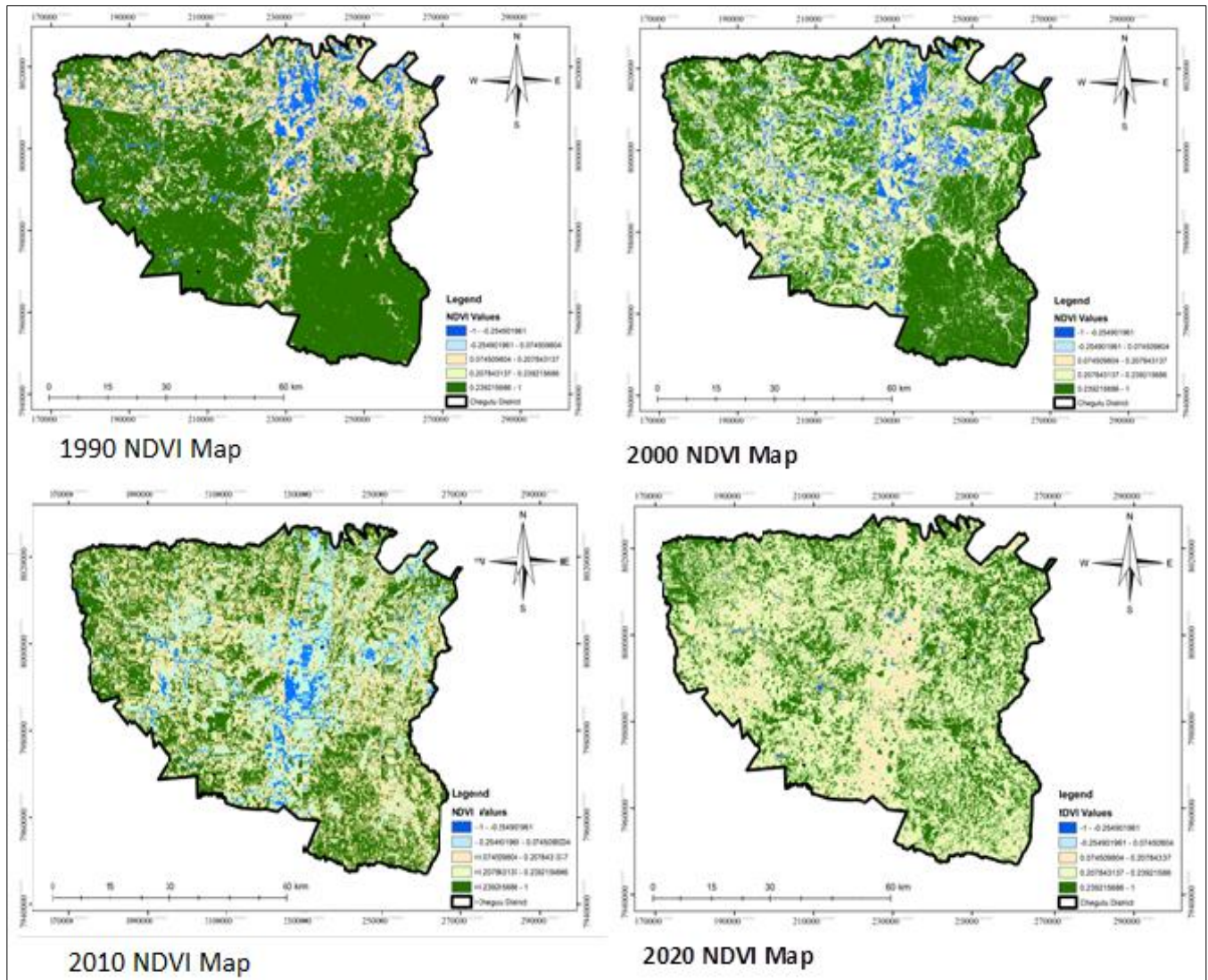


Figure 4. 4: NDVI for December showing plant species diversity changes for different years

Regardless of the evidence shown through remote sensing, local people in Chegutu district (80%) confirmed a decline in indigenous plant species diversity during the study period. The local people witnessed a significant reduction in the population of particular indigenous plant species, whilst some plant species have disappeared due to the changing climate fueled by land use activities in the district. The most affected indigenous plant species were the *Colophospermum Mopane*, *Burkea Africana*, *Brachystegia spiciformis*, *Parinari curatellifolia*, *Julbernardia globiflora*, and *Terminalia sericea*, among others. Logging of indigenous trees by local people was reported to have contributed to the decrease in tree species. Logging of indigenous trees indirectly affects environments controlled by climate change since participants acknowledged that cutting down trees is usually a means of adapting to a changing climate. In addition, Rampheri et al. (2020) concur that anthropogenic activities and changes in climate interact to speed up changes in vegetation. Since income-generating activities related to rainfed agriculture are no longer viable due to the severe climatic state increased by changes in climate, indigenous trees are logged to generate money.

4.4 Factors influencing changes in indigenous plant species diversity in Chegutu District

Figure 4.5 shows the opinions of locals concerning the factors influencing changes in indigenous plant species diversity in Chegutu district. Participants in Chegutu district have confirmed a decline in indigenous plant species diversity during the study period. It is shown that 80% of the participants think that agricultural activities in Chegutu district have contributed to changes in indigenous plant species diversity. Harvesting indigenous trees for selling was reported by 78% percent of the participants to have significantly contributed to the fall in indigenous plant species diversity. Additionally, 69% of the participants believe that harvesting indigenous trees for domestic use significantly changed indigenous plant species diversity.

Also, the respondents (68%) consider changes in climatic patterns responsible for modifications in the diversity of indigenous plant species in Chegutu district. The reduction in the diversity of indigenous plant species in Chegutu district is believed to have been influenced by the occurrence of invasive alien species, as opined by 78% of the respondents.

Generally, the respondents observed a considerable decrease in the population of some indigenous plant species whilst other trees have disappeared owing to changing climatic conditions also driven by land use activities in the district.

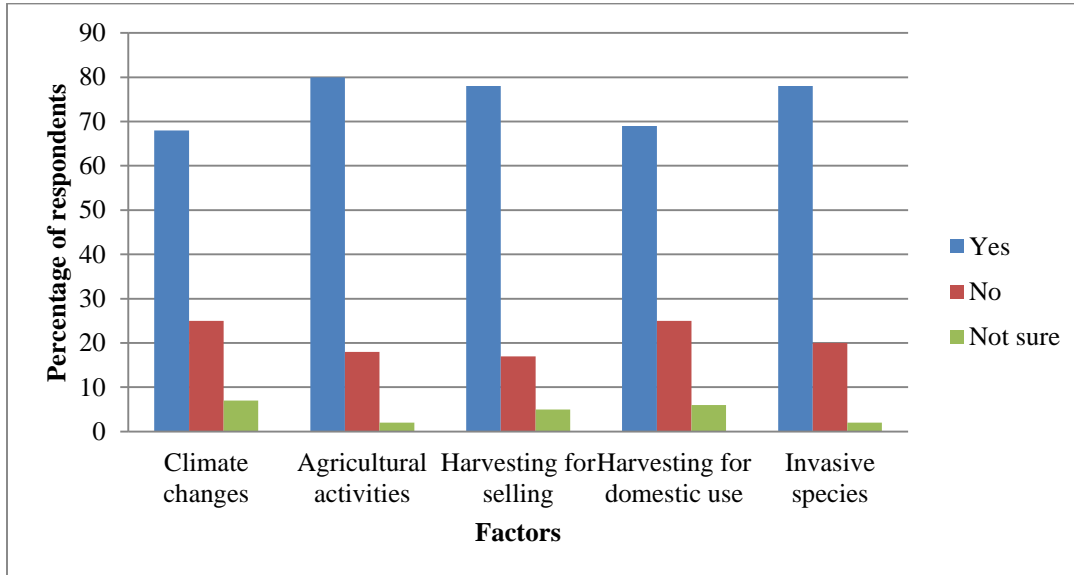


Figure 4. 5: Local people’s views on factors influencing modifications in indigenous plant species diversity

The most affected indigenous plant species were the *Colophospermum Mopane*, *Burkea Africana*, *Brachystegia spiciformis*, *Parinari curatellifolia*, *Julbernardia globiflora*, and *Terminalia sericea*, among others. Logging of indigenous trees by local people was reported to have contributed to the decrease in tree species. Logging of indigenous trees is considered to have indirectly affected environments controlled by climate change since participants acknowledged that cutting down trees is usually a means of adapting to a changing climate. In addition, Rampheri et al. (2020) concur that anthropogenic activities and changes in climate interact to speed up changes in vegetation. Since income-generating activities related to rainfed agriculture are no longer viable due to the severe climatic state increased by changes in climate, indigenous trees are logged to generate money.

4.4.1 Responses of local people on changes observed in indigenous tree cover

Figure 4.6 shows local people's perceptions concerning the changes they have witnessed in indigenous plant species diversity in Chegutu district. The respondents reported seeing changes in the study area's structure, composition, cover and distribution of indigenous plants. It is shown that 64% of the respondents witnessed changes in indigenous plant species structure. About 58% of the respondents reported that they had seen compositional changes of indigenous plant species. In addition, 74% of the respondents observed changes in the cover of indigenous plant species diversity, whilst 69 % reported distribution changes of indigenous plant species.

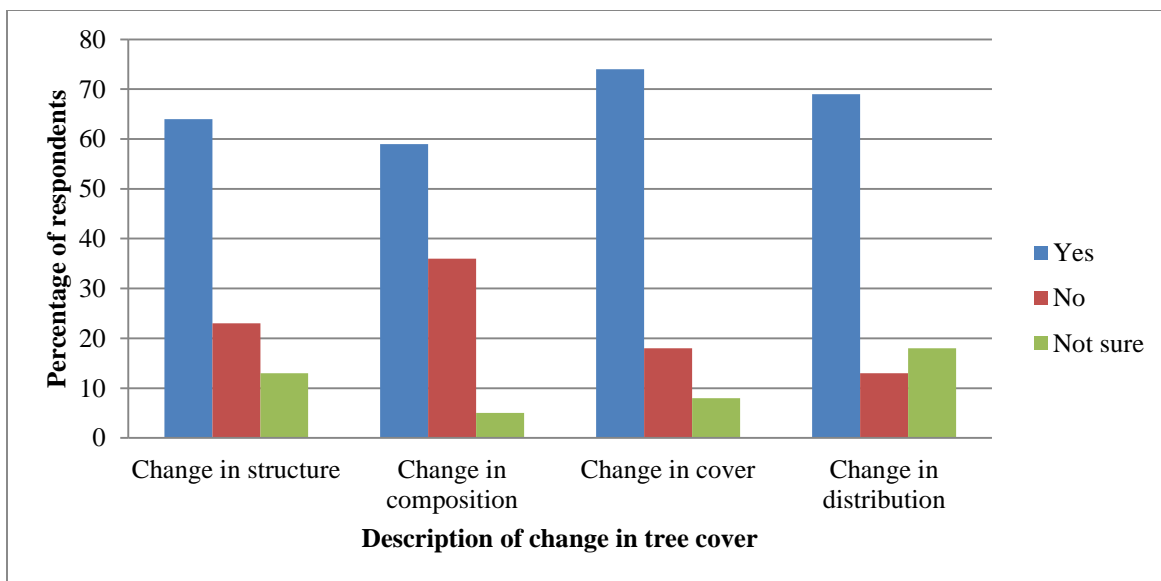


Figure 4. 6: Responses of local people on changes observed in indigenous tree cover

Study results also confirm a fall in rainfall in juxtaposition with a rise in temperatures is related to the increase in invasive alien species and the disappearance of other native plant trees. Therefore, the increasing temperatures support the proliferation of foreign tree species. Figure 4.7 indicates the rating of indigenous plant species richness, invasive plant species as well as the species diversity between 1984 and 2020.

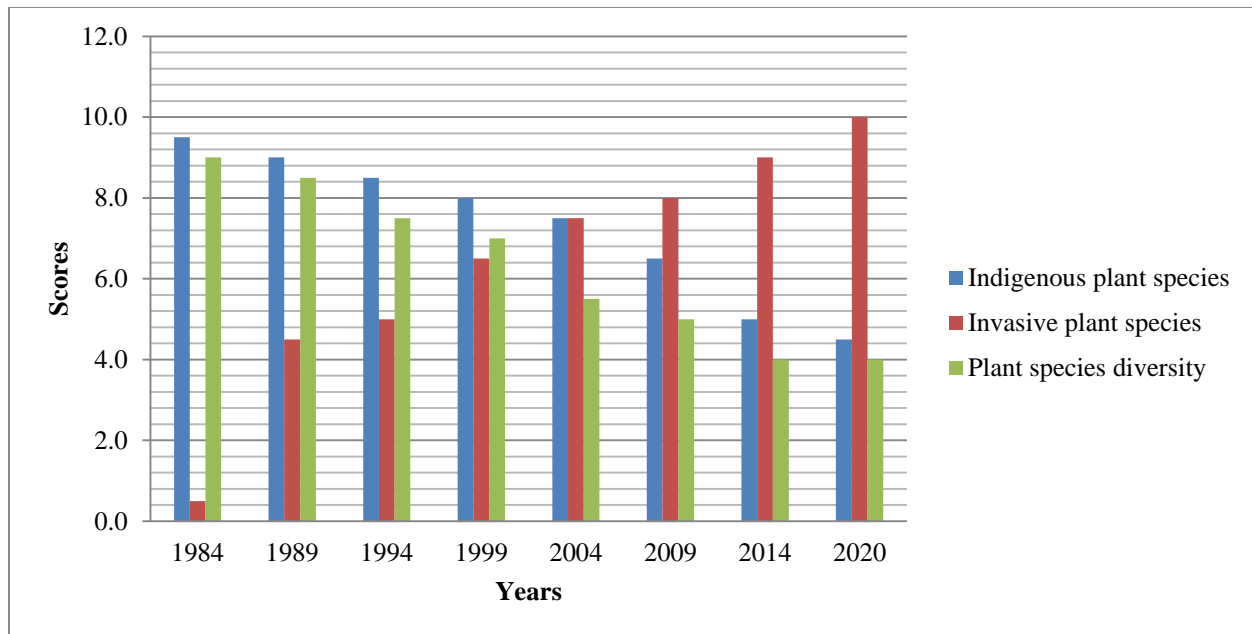


Figure 4. 7: Richness of indigenous plant species, invasive plant species, and species diversity

The views shared by participants have revealed that indigenous plant species diversity in the district is declining, influenced by climate-related elements. Noted by this research is a considerable rise in the population of the *Lantana camara* species in wards 8,9,10, 12 and 27 of the district and among other wards where it existed as isolated tree species. Also, the erratic existence of *Cactus Rosea* and wild Oats was witnessed in Chegutu district. The decline in indigenous plant species diversity over time has resulted in the extinction caused by invasive foreign trees that adapt to changes in climate. The invasion by foreign species chokes populations of indigenous plant species, and they eventually become extinct.

The spreading of invasive species like the *Eicchornia Crassipes*, *Dichrostachys*, *Cinerea*, and *Lantana camara* in the district results from climate change since invasive species proliferate in warm climatic conditions. This study established that participants agree with the numerical outcome of this research that climatic changes contribute to modifications of indigenous plant species diversity over time.

4.5 Relationship among climatic elements and diversity of indigenous plant species in Chegutu district

Table 4. 4: Regression results of the diversity of indigenous plant species by climatic elements in Chegutu district

| Regression variables | Regression equation | Correlation coefficient (r) | P Value | R2 | Description |
|--|---|-----------------------------|---------|--------|---|
| Monthly mean precipitation and SWI [H] | $Y = -4E-05x^3 + 0.006x^2 - 0.2093x + 2.3454$ | 0.785 | <0.001 | 0.9726 | The monthly mean precipitation explains the variability of indigenous plant species diversity |
| Precipitation of the warmest quarter and SWI [H] | $Y = 2E-05x^2 + 0.0176x - 1.1619$ | 0.744 | <0.001 | 0.9379 | The precipitation of the warmest month explains the unevenness in the diversity of indigenous plant species |
| Total annual precipitation and SWI [H] | $Y = -7E-09x^3 + 9E-06x^2 + 0.0003x + 0.0736$ | 0.708 | <0.001 | 0.7617 | The total annual precipitation explains the variability of indigenous plant species diversity |
| Minimum temperature of the coldest month and SWI [H] | $Y = 0.7697x - 2.6655$ | 0.704 | <0.001 | 0.8848 | The minimum temperature of the coldest month explains the unevenness of indigenous plant species diversity |
| Maximum temperature of the warmest month and SWI [H] | $Y = -0.0812x^2 + 5.3574x - 84.661$ | -0.788 | <0.001 | 0.8916 | The maximum temperature of the warmest month explains the variability of indigenous plant species diversity |
| Mean monthly maximum temperatures and SWI [H] | $Y = -0.014x^2 + 0.453x - 0.7567$ | -0.768 | <0.001 | 0.9774 | The mean monthly maximum temperatures explain the unevenness of the diversity indigenous plant species |
| Mean monthly temperatures and SWI [H] | $Y = -0.02x^3 + 1.184x^3 - 57.342x^2 - 1475.9x^3 - 21291x^2 + 163217x - 519480$ | -0.124 | <0.001 | 0.9455 | The mean monthly temperatures explain the unevenness in the diversity of indigenous plant species |

NB: SWI=Shannon Weaver Index (H) Source: Fieldwork data

The mean monthly temperatures explain the unevenness of indigenous plant species diversity. Generally, the regression analysis outcome (Table 4.4) confirms positive associations among

indigenous plant species and all climate-related elements. The SWI represents the species diversity of indigenous plants. The indigenous plant species diversity for climatic variables correlated to precipitation is best explained by the monthly mean rainfall. In contrast, for climate, monthly temperatures give an excellent determination coefficient.

4.5.1 Diversity of indigenous plant species and bioclimatic elements related to rainfall

Illustrated in Figure 4.8 are the regression analysis results of the Shannon-Weaver Index by climatic elements correlated to precipitation. A positive correlation ($r=0.785$) between the Shannon-Weaver Index and mean monthly precipitation is indicated by the result analysis. The three climatic elements related to precipitation used in the study positively explain indigenous plant species diversity in Chegutu district. The study concludes that 97% of the diversity of indigenous plant species is predicted significantly ($p<0.001$) using the mean monthly rainfall.

Indigenous plant species diversity increases with a rise in the mean monthly rainfall, as observed from the regression analysis of the two elements. Conversely, a rise that exceeds 77 mm mean precipitation will not match an increase of the diversity of indigenous plant species. Likewise, the diversity of indigenous plant species in Chegutu district is explained by the precipitation of the warmest quarter (Figure 4.8c). There existed a positive correlation ($r=0.744$) between the precipitation of the warmest quarter and the SWI between October and December. Precipitation of the warmest quarter can significantly ($p<0.001$) be used to predict approximately 94% of indigenous plant species diversity in the study area. Findings of the study demonstrate that an increase in the precipitation of the warmest quarter matches with a rise in indigenous plant species diversity. On the contrary, a rise that exceeds 460mm will not be correlated to a rise in indigenous plant species diversity

Furthermore, the regression equation has shown that indigenous plant species diversity is influenced by the total annual precipitation since there is a positively strong correlation ($r=0.708$) involving the two elements. Approximately 76% of indigenous plant species diversity in Chegutu district can be significantly ($p< 0.001$) explained using the total annual rainfall, as demonstrated in Figure 4.8a. A rise in the total annual rainfall matches with a rise in indigenous

plant species diversity, as illustrated by the regression analysis of the two variables. On the other hand, a rise beyond 780mm is not correlated to a rise in indigenous plant species diversity.

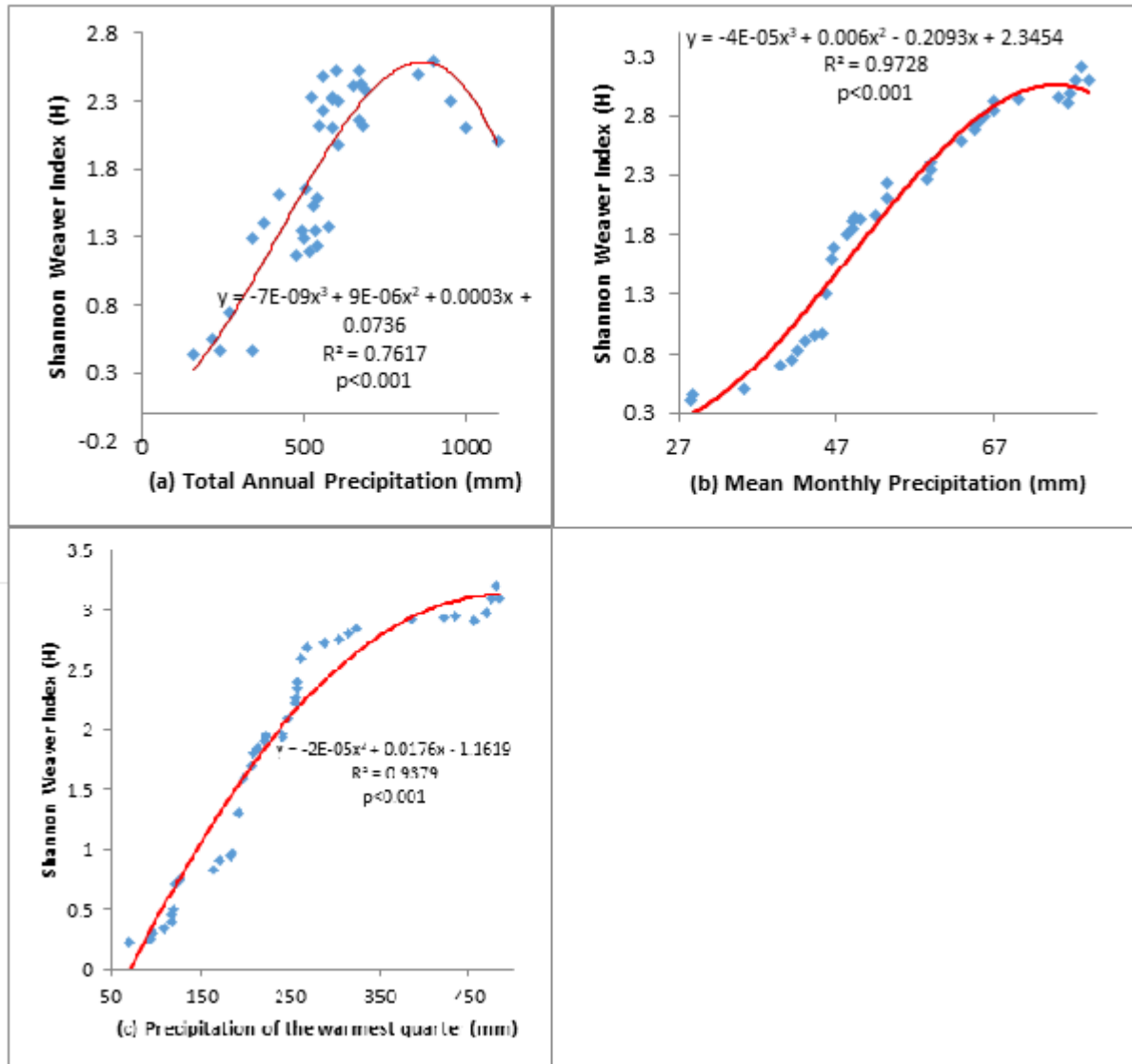


Figure 4. 8: Regression of the SWI (H) by climatic elements related to precipitation

(a) Total annual rainfall, (b) Mean monthly rainfall, and (c) Precipitation of the warmest quarter

4.5.2 Diversity of indigenous plant species and bioclimatic elements related to temperature

Figure 4.9 shows regression analysis results of the Shannon-Weaver Index by bioclimatic temperature-related elements. Results demonstrate a strong negative association (-0.788) between the SWI (H) and the highest temperature of the hottest month. About 89% of indigenous plant species diversity is considerably ($p < 0.001$) described using the highest temperature of the hottest month, as illustrated in Figure 4.9a. A rise in the maximum temperature of the warmest month is correlated to a decline in indigenous plant species diversity. However, at temperatures exceeding 38.4°C, indigenous plant species diversity is significantly low. During the period under study, the highest temperatures for the hottest month in Chegutú district averaged between 30°C to 39°C.

Results of the regression equation suggest that indigenous plant species diversity is described by the minimum temperatures of the coldest month. There is a positive association ($r = 0.704$) between indigenous plant species diversity and the minimum temperatures of the coldest month in Chegutú district as shown in Figure 4.9b. The linear regression model shows that approximately 88% of indigenous plant species diversity in the study area is significantly ($p < 0.001$) explained using the minimum temperatures of the coldest month. In the district, the minimum temperatures of the coldest month range between 4°C and about 8°C. A rise in the minimum temperatures of the coldest month is correlated to a rise in indigenous plant species diversity.

In the same way, the diversity of indigenous plant species in Chegutú district is also described by the mean monthly maximum temperatures (Figure 4.9c). Study results confirm that the mean monthly maximum temperatures in the district are between 17, 2°C to 29°C. A negatively strong relationship ($r = -0.768$) exists between the mean monthly maximum temperatures and indigenous plant species diversity. Figure 4.9c shows that approximately 98 % of indigenous plant species diversity in the district is described by the mean monthly maximum temperatures. As a result, a rise in the mean monthly maximum temperatures is correlated to a decline in the diversity of indigenous plant species.

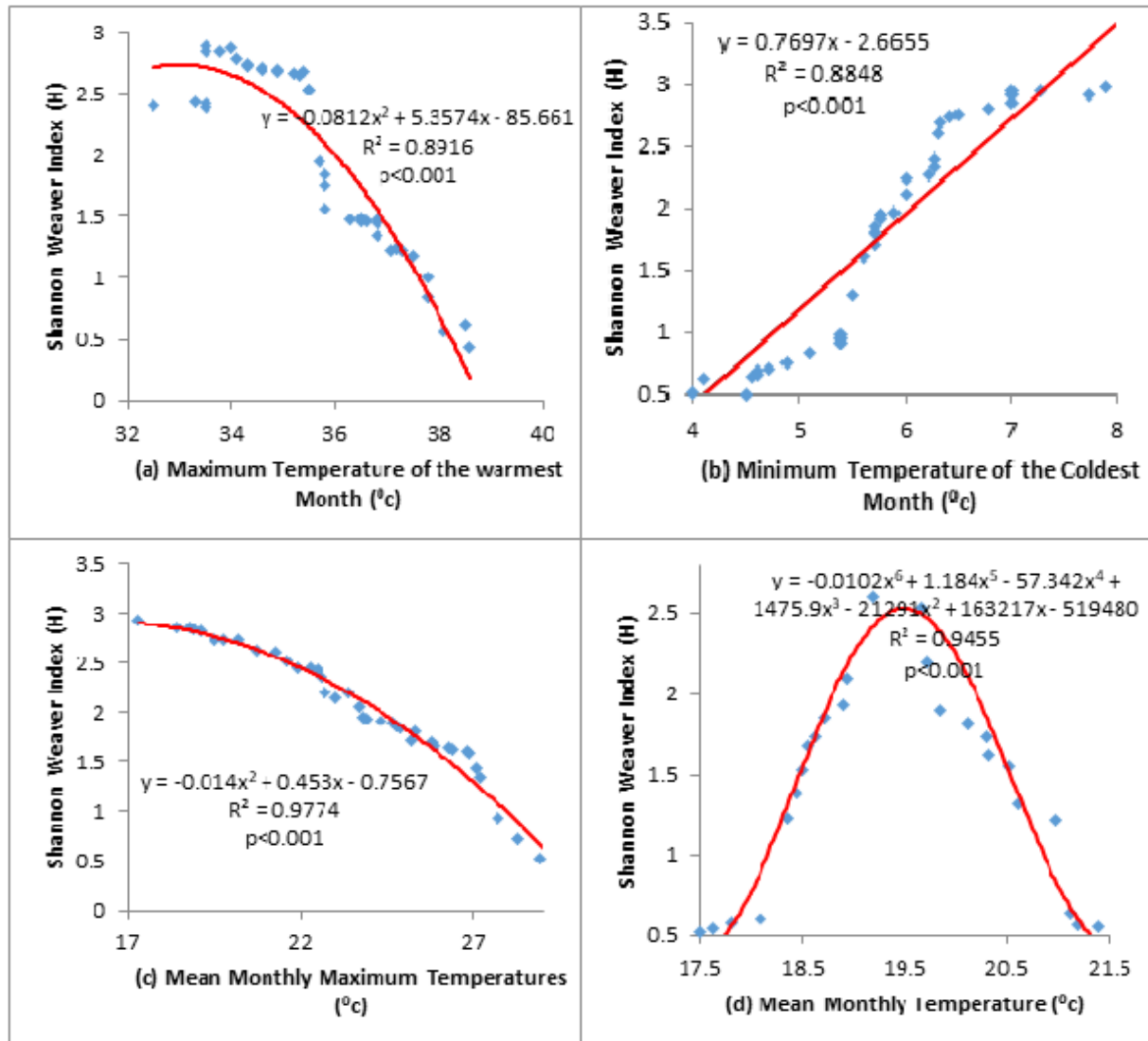


Figure 4. 9: Relationship between the diversity of indigenous plant species (SWI) and bioclimatic elements related to temperature.

Additionally, regression analysis results have proven that the diversity of indigenous plant species is considerably ($p < 0.001$) influenced by the mean monthly temperatures in the warming climatic surroundings of Chegutu district. Therefore, it can be deduced from the linear regression model that arise in the mean monthly temperatures matches with a rise in indigenous plant species diversity, hence a positively strong correlation between the two elements. On the other hand, further temperature increases beyond 18.8°C negatively affect indigenous plant species diversity. Generally, the temperature-related variables explain indigenous plant species diversity.

Also evaluated by this research were the views of locals concerning modifications of indigenous plant species diversity in the district during the period under review. Figure 4.10 shows indigenous plant species diversity changes in Chegutu district as opined by the locals. The level of an event, as perceived by the residents in the district, is shown by the scores. A high score reflects a high incidence of a specific observable event.

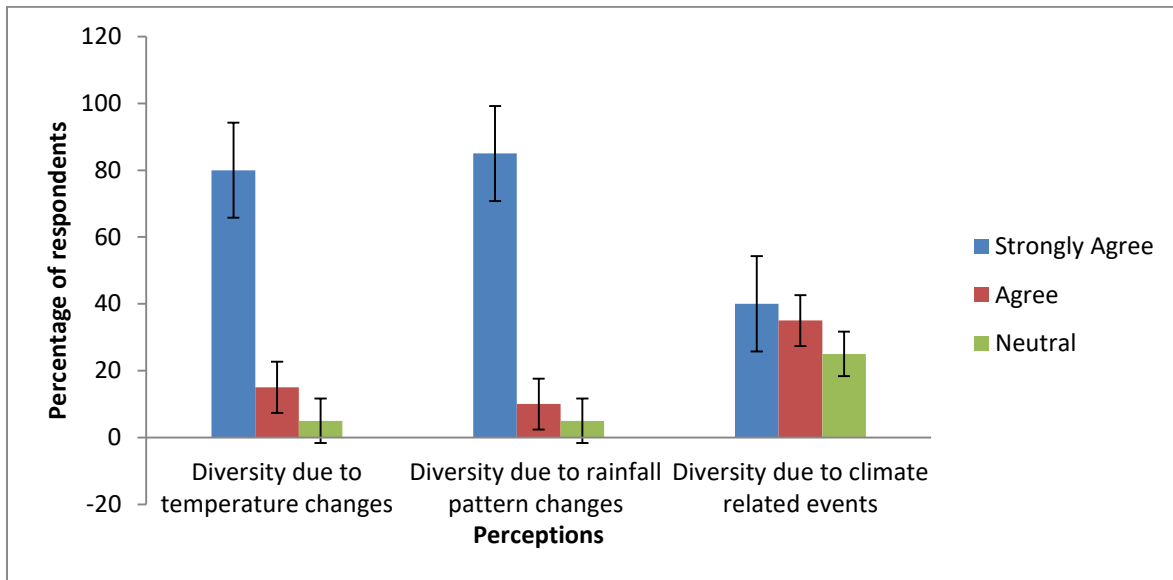


Figure 4. 10: Views of local people regarding the relationship between bioclimatic elements and changes in indigenous plant species diversity.

Generally, it is indicated that indigenous plant species diversity has been decreasing during the study time. Changes in bioclimatic elements in Chegutu district are related to a decline in the diversity of indigenous plant species. Participants have witnessed changes in indigenous plant species diversity. The change is associated with variations in rainfall and temperature systems accompanied by severe phenomena like solid and unpredictable winds and droughts.

In Figure 4.10 are residents' views concerning the bioclimatic elements' impacts that influenced changes in indigenous plant species diversity. The model shows that above 90% of the participants agree that the rise in temperature in the Chegutu district has contributed to alterations in indigenous plant species diversity. The reduction in rainfall during the study time has been reported by 90 % of the participants to be liable for the marked decrease in the diversity of indigenous plant species. Additionally, phenomena related to climates, such as recurrent dry

spells and solid and erratic winds, have been reported by more than 70% of the participants to be responsible for significant changes in indigenous plant species diversity in Chegutu district. The opinions of locals concur with numerical information that has revealed significant associations between indigenous plant species diversity and the majority of bioclimatic elements.

4.6 Estimating the impact of climatic changes on indigenous plant species diversity

Estimated by the study was the impact of climatic changes on indigenous plant species diversity in Chegutu district.

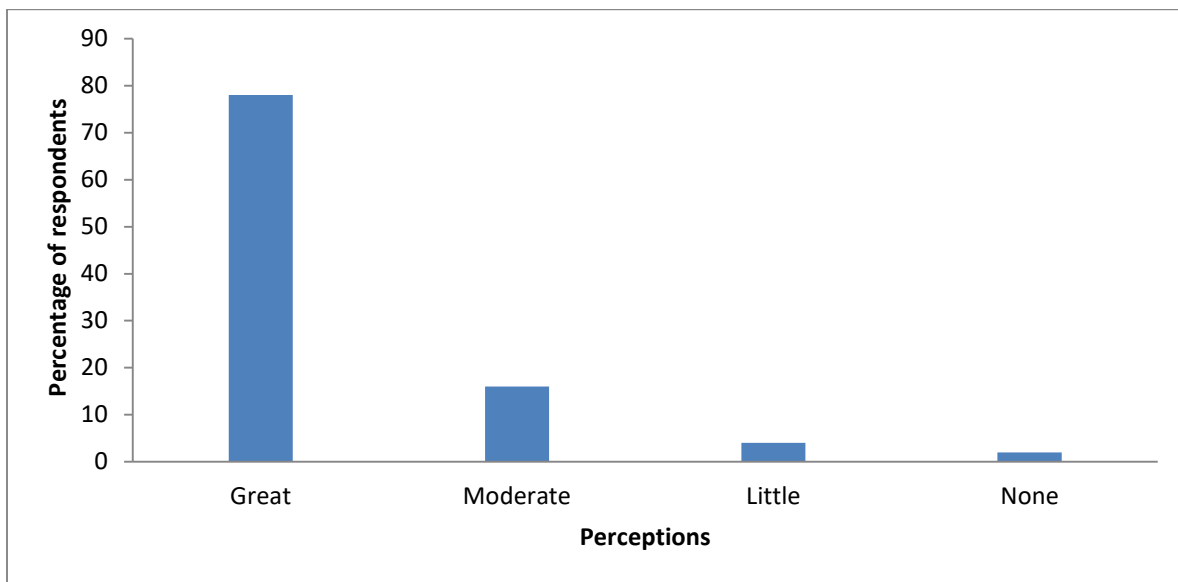


Figure 4. 11: Perceptions of local people on the degree to which climatic changes have impacted on indigenous plant species diversity

Results indicate that most respondents (78%) agree climate change has dramatically affected indigenous plant species diversity in Chegutu district (Figure 4.11). About 16% of the participants reported that the impact of climatic changes on the diversity of indigenous plant species is moderate. Only 4% of the participants believe climate change has caused a little impact on indigenous plant species, whilst 2% think climatic changes have no impact on indigenous plant species. People's perceptions in the study area agree with statistical facts that have exposed significant relationships involving indigenous plant species diversity and most climatic variables.

4.7. Discussion

4.7.1 Climate change trends in Chegutu district between 1984 and 2020

The human perceived and statistically significant rise in bioclimatic variables related to temperature from 1984 to 2020 entails that climatic conditions in Chegutu district have become warmer. Results of this research confirm remarks put forward by Tomback et al. (2016) cited in (Chapungu, 2017) that a substantial rise in temperatures of southern Africa's interior was observed. Findings of this research further confirm the general conclusions made by many different studies, Mapaura & Zimudzi., (2013, Chapungu., (2017), Kapuka., (2021) that the climate in Zimbabwe is getting warmer as indicated by a substantial increase in bioclimatic variables related to temperatures as well as protracted episodes of dry spells. For instance, Chidumayo (2019) put forward that several assessments made through remote sensing data and temperature observation reports agree that southern Africa, where Chegutu district is located, is becoming warmer and warmer. Lawal et al. (2019), Urich et al. (2021), Ndlala & Dube (2021) made investigations of pragmatic meteorological statistics bring to a close that the increase is influencing southern Africa in temperature, causing ramifications on ecosystems. In research that assessed temperature records from 1952 to 2011, Chidumayo (2019) noted a rise in the majority of temperature-related bioclimatic elements. These remarks are in sync with the worldwide increase in temperature believed to be a consequence of a changing climate Chidumayo, (2019); Urich et al., (2021). The changing temperature systems are expected to be linked to environmental consequences, including indigenous plant species diversity changes.

Furthermore, the results of this study support Chapungu (2017)'s allegations of a changing climate in the province of Masvingo in Zimbabwe, which has recorded a significant rise in both temperatures in winter and summer. The increased occurrence and severity of heat waves have heightened temperature changes. These temperature changes affect the phenology and physiology of indigenous plant diversity. The conditions, in some scenarios, become intolerable among certain indigenous plant species to such an extent that they disappear. Rising temperatures experienced in Chegutu district during the study time may result in increased evapotranspiration, resulting in water unavailability, affecting certain indigenous plants and leading to their death or reduced yield. Thuiller and Midgley, (2018) observed that temperature

increase stimulates the evaporation demand which raises the loss of moisture either direct or indirectly resulting in significant ecological changes. Kamara et al. (2020) concur that a high rate of evapotranspiration caused by temperature increases stress on plant species.

Changes in indigenous plant species diversity can result from both direct and indirect consequences of temperature changes. To that end, Kamara et al. (2020) forecast a 30-40 percent speed of biodiversity extinction due to hot environmental conditions. The results from this study, both quantitative and qualitative, have also revealed a decline in minimum temperatures of the coldest month. The decline represents a change in climatic conditions, raising the unpredictability of seasonal temperatures. Climate literature also confirmed that a changing climate leads to extreme climatic conditions. As such, the very low temperatures experienced in the coldest period indicate this climatic event's occurrence. This research also revealed significant decreases in most bioclimatic elements related to precipitation, including the total annual precipitation, precipitation of the warmest quarter and mean monthly rainfall. To that extent, the trend of precipitation-related bioclimatic elements shows that the district is becoming arid in the long run. The aridness led to a marked change of indigenous plant species diversity since water plays a crucial part in the functioning of ecosystems.

Remarks made by participants concerning a decreasing rainfall pattern experienced in the district validate the assertion that changing climatic conditions in the entire country is expected to make Zimbabwe an arid environment (Mpandeli et al., 2019). The participants have recognised a reduction of the total rainfall during the study time. The participants repeatedly confirm the occurrence of extreme climatic phenomena like recurring dry periods and destructive wind storms, which used to be less harsh before and nonexistent. The assertion by Mudzengi et al. (2017) also confirms that Zimbabwe faces the menace of a changing climate demonstrated by changes in precipitation trends and severe and periodic weather phenomena. Mudzengi et al. (2017) also observed increased events of drought and a decline in precipitation in Zimbabwe across all seasons.

Precipitation and temperature trends observed in this research follow regional and global patterns. A rising trend in regional and global temperatures has been confirmed (Kusangaya et al., 2014). Bentley et al. (2019) and Id et al. (2020) reveal that temperatures have risen globally

and are also anticipated to keep increasing. The temperature changes trigger changes in precipitation caused by variations in the atmospheric circulations (Bentley et al., 2019; Id et al., 2020). Research in Europe by Yelwa et al. (2019) confirms an increase in the average temperatures by about 2 - 4°C during the next 5 decades, resulting in significant changes in regional and seasonal rainfall trends. Hence, there are observed rainfall changes at the regional level in southern Africa, experiencing a decline in precipitation by about 5 – 20 % (Yelwa et al., 2019) and generally a 3% reduction in precipitation (IPCC, 2019). The changes in precipitation highlighted above are anticipated to affect all ecosystem levels across the continent (Yelwa et al., 2019).

The declining rainfall trend, either statistically significant or not, revealed by this research and also shared by some scholars, suggests that rainfall trends are shifting, representing a change in climatic conditions over a long period. This change can alter a number of environmental conditions because water is among the significant factors influencing ecosystem growth. To that extent, this research confirms that changes in precipitation and temperature have occurred in Chegutu district, suggesting that climate has, without a doubt, changed during the study period. Climate change gives merit to examining the sensitivity of indigenous plant species diversity to climatic changes in Chegutu district.

4.7.2 The trends of indigenous plant species diversity in Chegutu district between 1984 and 2020

Climate change-induced decrease in NDVI followed by the diversity of indigenous plant species witnessed in this research coincides with the negatively tilted occurrence distribution of flora indicators established by Malhi et al. (2020) in a research carried out in the Mongolian highlands that assessed the impact of vegetation on a changing climate during ten years. Indigenous plant species can adjust, drift or become extinct due to changing climatic conditions (Bentley et al., 2019; Id et al., 2020). These three ways in which indigenous plants react to a changing climate have a noticeable impact on the variety of species. The decline of indigenous plant species diversity confirmed in this research may be due to the relocation of certain species due to drying environmental settings or the disappearance of other species. Many scholars have revealed that plants relocate widely due to changes in climatic conditions (Boutaj et al., 2019; Scholes, 2020;

Afuye & Kalumba, 2021). Consequently, such migrations result in changes in the composition of indigenous plant species and other characteristics related to diversity.

Over time, the reduction of indigenous plant species diversity might be due to their disappearance caused by the invasion by alien species that can adapt to climate change. The invasion by alien plant species chokes the indigenous plant species, and eventually, they become extinct. The spreading of persistent foreign species like the *Dichrostachys Cinerea*, *Eichhornia Crassipes* and *Lantana Camara* across the district is linked to changes in climate in the district because persistent foreign species thrive in hot climatic surroundings. A case in point is the water hyacinth which can re-emerge and occupy water surfaces within two weeks under hot conditions when cleared. In support of the finding of this research, Pecl et al. (2017) claim that the cheat grass, stimulated by the changing climate, invaded more than 200 000 km² in about four decades, replacing indigenous plant species. Increased indigenous plant species relocations will be witnessed in future as a reaction to increased speed of climatic changes (Byrne et al., 2019; Kamara et al., 2020). Also noted by Sandi et al. (2020) is the migration of indigenous plants exacerbated by land use practices caused by changes in indigenous plant species.

4.7.3 Factors influencing changes in indigenous plant species diversity in Chegutu District

It is confirmed in this study that climate changes do not operate independently of other ecological aspects in influencing changes in indigenous plant species diversity. As a result, human disturbance regimes and other natural phenomena have also modified indigenous plant species diversity in Chegutu district. Changing climatic conditions in connection with human activities led to changes in biodiversity, as reported in the Islands of Ameland (Scholes, 2020, Afuye and Kalumba, 2021). Although many aspects operate in juxtaposition with climatic changes in the manipulation of indigenous plant species diversity, it must be stressed that sufficient substantiation confirming climate changes has either directly or indirectly conquered as the key influencing many environmental developments and changes in biodiversity.

It is further noted in this research that climatic changes indirectly influence indigenous plant species diversity. This results from the impacts of changes in land use practices driven by changing climatic conditions. For example, in Mhondoro, there is excessive and indiscriminate cutting of the Mopane tree for selling as it is insurance to deal with economic challenges caused

by changes in climate. Most households in Chegutu district rely on agriculture as their livelihood and depend on rain-fed agriculture. Severe and frequent droughts caused by the changing climate pushed communities to find alternative ways of irking a living hence, the sale of firewood resulted in discriminatory cutting down of indigenous plants, which led to alterations in indigenous plant species diversity. Boutaj et al. (2019) also made this observation and asserted that the knock-on impacts of climatic changes on vegetation are significant because of climate-induced alterations in land use. Pecl et al. (2017) submit that changes in climate result in modifications of several characteristics of ecosystems and disturbances like pests, veld fire and disease occurrence, which further drive changes in the ecosystem, including indigenous plant species diversity. Therefore, changing climatic conditions lead to alterations in indigenous plant species diversity. However, the changes might be harmful or helpful depending on existing ecological circumstances, such as edaphic and human influences.

4.7.4 Climate change and indigenous plant species diversity

This research sought to appreciate relationships among bioclimatic elements and the diversity of indigenous plant species. Study findings have shown that nearly all the climatic variables related to precipitation analysed mainly contribute to the condition of indigenous plant species diversity in Chegutu district. As a result, adjustments of the bioclimatic elements result in modifications of indigenous plant species diversity. Among the elements related to precipitation with the strongest influence on indigenous plant species diversity are the precipitation of the warmest quarter and mean monthly precipitation. Banze et al. (2018) and Malhi et al. (2020) made the same observation in their findings.

Moreover, the study indicated precipitation of the warmest quarter as above other elements related to precipitation in controlling indigenous plant species diversity. The decline in plant species diversity as temperatures rise entails that the tolerance of some indigenous plant species dwindles when the maximum temperatures of the warmest month increase. The findings are in agreement with the present observation of the influence of temperatures of the warmest month on plant species diversity (Gwitira et al., 2013), in which generally, a negative correlation between plant species diversity and hotness is likely to occur if the temperature surpasses 25°C (Gwitira et al., 2013). Byrne et al. (2019) also confirmed the same sentiments in a research that predicted a

decline in the diversity of plant species diversity when temperatures rise by 1.8°C. Therefore, it must be pointed out that studies have drawn attention to the fact that very hot environmental conditions result in a reduced tolerance of certain species, thus decreasing plant species diversity.

Results of this research also give credibility to a study in South Africa (Afuye & Kalumba, 2021), which concluded that temperatures play an essential part in plant species diversity alterations. Moncrieff et al. (2015; Wheatley (2018), and Sandi et al. (2020) made related claims echoing that climate changes exacerbate the instability of ecosystem balance as a result of movements and changes of viable relationships resulting from altered composition, richness and evenness of plant species. This research substantiates the views put forward by the metabolic assumption of ecology, which argues that an organism's metabolic processes are determined by the most observed patterns in the environment. Metabolic processes are affected by warming; hence, warming determines essential biological processes and biological diversity. As a result, rising temperatures severely affect the properties of food webs, with an additional impact on the population stability of indigenous plant species and ecosystem changes.

Climate change entails long-term changes in climate variables. Accordingly, the impact of bioclimatic variables on indigenous plant species diversity suggests that an adjustment in climatic conditions leads to changes in plant species diversity. Sandi et al. (2020) suggest that increases in temperature leads to changes in precipitation patterns that change the ecological surroundings where biomes get adjusted and are affected by new diseases and pests, leading to modifications of indigenous plant species diversity. Climatic changes in Chegutu district and the correlation between bioclimatic parameters and indigenous plant species diversity revealed in this research means that indigenous plants are changing their composition, phenology, physiology and distribution. Moncrieff et al. (2015) and Wheatley (2018) observed that changes in appropriate climatic surroundings for specific plant varieties result in alterations in the abundance and variety of indigenous plant species.

This research further notes that climatic changes indirectly influence indigenous plant species diversity. This results from the impacts of changes in land use practices driven by changing climatic conditions. For example, in Mhondoro, there is excessive and indiscriminate cutting down of the Mopane tree for selling as it is insurance to deal with economic challenges caused

by changes in climate. Most households in Chegutu district rely on agriculture as their livelihood and depend on rain-fed agriculture. Severe and frequent droughts caused by the changing climate will push communities to find alternative ways of living; hence, the sale of firewood results in discriminatory cutting down of indigenous plants, which leads to alterations in indigenous plant species diversity. Boutaj et al. (2019) also made this observation and asserted that the knock-on impacts of climatic changes on vegetation are significantly caused by climate-induced modifications in land uses. Pecl et al. (2017) submit that changes in climate result in modifications of several characteristics of ecosystems and disturbances like pests, veld fire and disease occurrence, which further drive changes in the ecosystem, including indigenous plant species diversity. Therefore, changing climatic conditions lead to alterations of indigenous plant species diversity. However, the changes might be harmful or helpful depending on existing ecological circumstances, such as edaphic and human influences.

4.7.5 Estimating the impact of climatic changes on indigenous plant species diversity in Chegutu district

Climatic changes remain the leading factor contributing to the decline in plant species diversity in Chegutu district, even though other factors like veld fires, edaphic factors as well as changes in land-use also influence the diversity of plant species in this ecosystem. Furthermore, it is established that the changing climate does not work in isolation from other ecological influences. Consequently, anthropogenic activities, edaphic factors, and physical phenomena contribute to the alterations of indigenous plant species diversity in Chegutu district. Although some aspects operate in combination with changing climatic conditions in inducing changes in plant species diversity, there is a need to highlight that adequate scientific facts indicate that climate change either directly or indirectly controls the environmental processes, including modifications in indigenous plant species diversity.

As revealed in this study, the decline in precipitation over the long term constitutes climatic change. Indigenous plants and most species require precipitation for growth and reproduction. The water scarcity due to the decline in rainfall total during the study period led to alterations of climatic envelopes of some species, and some have failed to reproduce. Water scarcity encourages changes in phenology, physiology, migration, loss of species and subsequently,

changes in indigenous plant species diversity. Eventually, it results in the reduction of indigenous plant species evenness and richness. Variations in tolerance levels of species to ecological modifications commonly determine changes in indigenous plant diversity. Additionally, modifications of ecological gradients lead to interaction changes between the species through invasions, attacks by pests and herbivory. Therefore, this research submits to the notion that a reduction in rainfall, either significant or not, is closely related to a reduction in indigenous plant species diversity in semi-arid environments.

This study has also exposed that the participants agree with empirical evidence obtained from field observations that the changing climatic conditions are undeniably causing changes in indigenous plant species diversity. In particular, participants' views have shown that indigenous plant species diversity in the district is shrinking due to distress related to the impact of climatic changes. Results of this research have also shown that declining precipitation, together with a surge in temperatures, is linked to the spread of persistent foreign species and the disappearance of certain indigenous plant species. Hence, the increasing temperatures tend to sustain the multiplication of persistent alien plants. The research witnessed the widespread increase of *Lantana Camara* species in Mhondoro and its isolated presence in the district. Some patchy incidences of *Cactus Rosea* and wild Oats have also been witnessed across the district.

Participants testified that invasive plants had become a nuisance since their numbers were tremendously increasing, causing indigenous plant species to become extinct. The venomous invasive species flourish owing to conducive climatic environments created by the changing climate. Some persistent foreign species tend to change the chemical conditions of the soil forming environments that are not favourable for growing some tree species. The resulting impact is a reduction of indigenous plant species diversity. The declining diversity of indigenous plant species has been widespread across the district where the *Lantana Camara* plants have occupied the largest part of the farming land. This has caused a decline in richness of herbaceous plants in the district, mostly in communal areas. The perceived reduction in the diversity of indigenous plant species in Chegutu district concurs with the findings found by Mudzengi et al. (2017) that the proliferation of persistent alien plants decreases plant species diversity, predominantly herbaceous plants. Matata et al. (2019) also noted a reduction in herbaceous

species diversity in ecosystems invaded by the *Lantana Camara*. Hence, changes in climate either directly or indirectly affect the diversity of indigenous plant species.

4.8 Summary

The chapter presented the findings and discussions of the evaluation of the sensitivity of indigenous plant species diversity to a changing climate in Chegutu district. Overall, findings of the study have confirmed that the changing climate mainly influences indigenous plant species diversity in the study area. Other factors like changes in land use and the proliferation of invasive plant species also influence plant species diversity. Decreasing rainfall and increasing temperature are significantly reducing plant species diversity. The study also found that NDVI is a useful proxy indicator of changes in indigenous plant species diversity.

CHAPTER V: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter looks at the study's conclusions and recommendations. The conclusions are presented in the order of specific objectives, starting with climate trends between 1984 and 2020, followed by indigenous plant species diversity trends, factors influencing changes in indigenous plant species diversity, the relationship between indigenous plant species diversity and climate, and lastly the impact of climatic changes on indigenous plant species diversity in Chegutu district between 1984 and 2020. Specific recommendations will be suggested for observations made from the study results.

5.2 Conclusions

5.2.1 Climate trends between 1984 and 2020

The initial objective of this research aimed at determining a considerable pattern in elements related to climate that could confirm a changing climate from 1984 to 2020 in the district. Quantitatively, it came out that parameters associated with temperature, such as monthly mean maximum temperatures, monthly mean temperatures, maximum temperatures of the warmest quarter, and minimum temperatures of the coldest month, changed considerably during the study period. A qualitative analysis of the study's findings confirmed that a more significant proportion of participants confirmed temperature increases during the study period. Generally, trends of climatic elements confirm a warming trend with a rise in all elements related to temperature except the minimum temperatures of the coldest month, which have fallen during the time under review but enabling a warm pattern.

In addition, results of the research concluded that there is a huge shift in variables linked to rainfall during the time under review. A significant decline in the total annual rainfall, monthly mean rainfall, and precipitation of the warmest month were evident. Results of interviews and questionnaire surveys confirm that phenomena related to climate change, such as heat waves, strong winds and droughts, increased their occurrence and severity during the study period. The conclusions of this study confirm the technical view that, generally, worldwide climatic change

is occurring, and the rate of change varies geographically. Study results confirmed that indigenous plant species are vulnerable to environmental changes, resulting in changes in their phenology to adapt or die. The changes lead to modifications in their composition.

The results of climatic data, interview responses and questionnaire survey results gathered from residents' familiarity and local understanding concluded that a significant climate change occurred during the study period. A clear climate trend was noticed in the study area through continuous warming of temperature, falling precipitation as well as rising occurrence and severity of phenomena related to climate change, such as droughts. Generally, a progressive aridness of the district was noted during the study time. Climate change occurred in Chegutu district during the period under study, and it could still be taking place due to the scientific evidence of changing bioclimatic elements. For that reason, there was need to examine the sensitivity of indigenous plant species diversity to a changing climate in the district so as to direct the crafting of laws and approaches that can deal with changing climate at the district stage and gain knowledge for the implementation of policies at provincial, national and regional scales respectively.

5.2.2 Indigenous plant species diversity trends from 1984 to 2020

The second objective of this research aimed to determine trends of indigenous plant species diversity in Chegutu district between 1984 and 2020. Results indicate a statistically significant drop of indigenous plant species diversity. The significant declining pattern indicates a reduction of indigenous plant species diversity as the atmosphere progressively warms. The study noted that the impact of climatic changes on indigenous plant species diversity is taking place through the complementary effects of a reduction in the availability of rainfall and warming temperatures. Consequently, the result is the modification of interactions among indigenous plant species.

5.2.3 Factors influencing changes in indigenous plant species diversity for the past 36 Years (1984-2020)

The third objective of this research aimed at examining the factors influencing changes in the diversity of indigenous plant species from 1984 to 2020. Results show that indigenous plant

species diversity is greatly influenced by elements related to both rainfall and temperature. As a result, climatic elements influence the diversity of indigenous plant species, either directly or indirectly, through the change of natural environmental conditions appropriate for the creation and well-being of certain plant varieties. Climatic changes resulted in indigenous plant species reactions, including range changes, the timing of life cycle events, and hence changes in diversity patterns. Also noted by the research are the direct and indirect effects of climatic changes emanating from other factors, including changes in land use and fire systems, among others. However, the research was quick to recognise that climatic changes lead to causal changes in all the modifications and, as a result, remain the prominent feature influencing the dwindling of indigenous plant species diversity in Chegutu district.

5.2.4 Relationship between the diversity of indigenous plant species and climate

The fourth objective of this research was aimed at assessing the correlation between the diversity of indigenous plant species and bioclimatic variables. This objective aided the appreciation of the effect of climatic changes on indigenous plant species diversity. The research employed a multi-method strategy to ascertain the cause-effect correlation among climate and indigenous plants because the relationship does not always mean causality. Hence, an assessment of indigenous plant species data, bioclimatic data, and interview and questionnaire survey views led to the conclusion that the diversity of indigenous plant species is correlated to bioclimatic parameters related to temperature and rainfall. Localised extinctions and invasions, among other effects, were caused by spatial and temporal changes in bioclimatic elements, with significant changes in indigenous plant species diversity.

Furthermore, the study submits that indigenous plant species diversity indicated by the SWI is controlled by bioclimatic parameters correlated to rainfall, including the mean monthly rainfall, precipitation of the warmest quarter and the total annual rainfall. As a result, the decline in these rainfall variables decreases the moisture available for some indigenous plant species sensitive to climate to thrive, leading to their drying up and disappearing.

In addition, the diversity of indigenous plant species is, to a great extent, correlated with temperature-related bioclimatic variables, including the maximum temperature of the warmest month, mean monthly maximum temperatures, mean monthly temperature and minimum

temperature of the coldest month. The study concludes that bioclimatic variables influence indigenous plant species diversity. Increasing temperatures lead to a reduction in indigenous plant species diversity. Conversely, for the minimum temperature of the coldest month, a temperature rise is correlated to a rise in the diversity of indigenous plant species. Results of the study pertaining to mean monthly temperatures confirm that when temperatures are less than 20°C, temperature increase is positively correlated to an increase in indigenous plant species diversity save for the continuous temperature increase which is related to a decrease in the diversity of indigenous plants. Therefore, the research concluded that indigenous plant species diversity is significantly affected by bioclimatic elements related to rainfall and temperature.

5.2.5 The impact of climatic changes on indigenous plant species in Chegutu district between 1984 and 2020

This study's fifth and last objective was to evaluate the climatic changes' impact on indigenous plant species diversity. The results of this study confirmed that the influence of a changing climate on indigenous plant species diversity is taking place through the subsequent effects of moisture reduction and warming temperatures. The resultant effect is the alteration of relations between a variety of plants through increased competition, herbivory, diseases and pests as well as attacks by invasive species. Therefore, this research concludes that a changing climate contributes in the decline of indigenous plant species diversity during the time under review, as confirmed by variations in NDVI. Essentially, the research established that climatic changes reduce the diversity of indigenous plant species in a semi-arid environment.

5.3 Recommendations

As revealed in this research, the sensitivity of indigenous plant species to climatic changes is confirmed by diversity changes during the study period. Changes in climate will further result in environmental alterations in an ecosystem owing to adjustments of patterns of interaction. The resultant effect is the loss of balance in the ecosystem, which will, either directly or indirectly, impinge on communities, given the reliance of people on ecosystem services. Recommendations guided by crucial study results may be considered by the Ministry of Environment, Climate Change, Tourism and International Trade, National Parks and Wildlife Authority, Environmental

Management Agency, Forestry Commission of Zimbabwe, Mupfure sub-Catchment Council, and Nongovernmental organisations operating in semi-arid places.

1. In view of the observation that a rise in variables related to temperature is correlated to the decrease in indigenous plant species diversity, it therefore calls for organisations in charge of the managing of ecosystems to be capacitated fully with skills to monitor climate change impacts on the diversity of indigenous plant species, given the importance of indigenous plants to people. Capacitating organisations responsible for managing ecosystems would go a long way in preventing the likely invasions, migrations, and extinctions of key indigenous plant varieties in local ecosystems. The capability to detect climatic changes effects on indigenous plant species diversity depends on well-resourced organisations with regards to skilled workers, remote sensing resources, and enough equipment to frequently gather field data for long-term examination of changes. For this reason, conducting fieldwork regularly is necessary since it is essential for the analysis as well as interpretation of remote sensing data. Fieldwork is indispensable in terms of authenticating remote sensing data and spotting the influence of climate change and how species adapt, particularly indigenous plant species.

2. The observation of the capability of remote sensing in the pursuit to appreciate the response of indigenous plant species to changing climate by means of Landsat imagery at local scale is a massive stride in an effort to come up with national and ultimately worldwide checking methods to observe the diversity of indigenous plant species. However, coarse-resolution imagery may reduce the accuracy of predicting the attributes of environmental variables. Whilst this study has used Landsat 7 Thematic Mapper imagery (for 1990 and 2000) and Landsat 8 Thematic Mapper imagery (for 2010 and 2020) with a spatial resolution of 30m and a spectral resolution of 15m, it is necessary to carry out a further inquiry into climatic changes impact on the diversity indigenous plant species making use of satellite imagery with a temporal, spatial, and higher spectral resolution, such as those from satellites equipped with spectral sensors, for more precise forecasts. Satellites with spectral sensors would be recommended since they assist in differentiating and recording indigenous plant varieties on the basis of their respective features.

3. Given the observation that climatic changes remain a major contributing factor towards changes in indigenous plant species diversity, there is a need to fully understand ecosystem

modifications influenced by the changing climate through regular documentation of the state of species diversity and the discovery of likely adaptation mechanisms for specific indigenous plant species. This ensures that the current diversity of indigenous plant species is preserved and enhanced. Since the current climate conditions may regulate climate change impacts on indigenous plant species diversity, this method should be used in various climatic areas.

4. Given the multifaceted nature of indigenous plant species diversity issues, there is a need for policymakers, environmentalists, biologists, geographers, and remote sensing specialists to work together. Globally, several methods are used to analyse ecosystems' biodiversity, which has resulted in a surge of diverging and overlapping conclusions. This discord calls for consistent methods of inquiry as well as ways of quantifying plant species. Teamwork between organisations is indispensable since a multidisciplinary strategy is needed to understand climatic changes and the resultant impacts on the diversity of indigenous plant species.

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Appendix I: Questionnaire Survey

Questionnaire Survey: Sensitivity of indigenous plant species diversity to climate change in a semi-arid area of Chegutu district in Zimbabwe

My name is Madzikatidze Wellington, an MPhil student at Great Zimbabwe University. I am carrying out a research which is part of requirements towards the fulfillment of my studies for MPhil in Geography and Environmental Science. The research is purely academic but it is truthfully anticipated that the research findings will help local, national and regional policy makers as a body of knowledge that will assist in decision making, planning and management of indigenous plant species diversity in the face of environmental modifications driven by climate change. The main objective of the study is to assess the sensitivity of indigenous plant species diversity to climate change in a semi- arid area of Chegutu district in Zimbabwe.

The success of this research depends on your contribution as the key source of data. I, therefore, kindly seek your support and cooperation through setting aside part of your valuable time to respond to this questionnaire document. Kindly note that throughout the whole process, the responses you give are purely for academic purposes and will be treated with highest confidentiality to protect your rights and privacy. You are advised not to write your name. You are requested to tick or briefly explain based on the question provided. You are also kindly requested to be as honest as possible in providing your responses.

SECTION A: BACKGROUND INFORMATION

| 1. Age in years | Tick below | 2. Gender | Tick below | 3. Level of education | Tick below |
|-----------------|------------|-----------|------------|-----------------------|------------|
| 20-34 | | Male | | Primary | |
| 35-44 | | Female | | Secondary | |
| 45-54 | | | | Tertiary | |
| 55 and above | | | | | |

4. For how long have you been residing in this village? (*Tick appropriate box*).

| | | |
|---|--------------------|--|
| 1 | 0-10 years | |
| 2 | 11-19 years | |
| 3 | 20 years and above | |

SECTION B: CLIMATE CHANGE EXPERIENCE

5. Is climate change a problem in your area?

YES NO

6. If your answer to 5 above is 'Yes', how much climatic changes have you experienced in your area in terms of:

a) Minimum temperature increase? None Little Much

b) Mean annual rainfall? None Little Much

c) Minimum seasonal temperatures? None Little Much

d) Maximum seasonal temperatures? None Little Much

e) Length of the growing season? None Little Much

Others: Specify.....

7. In terms of mean temperature, how do you describe the changes you experienced in the last 20 to 36 years in your area?

None Increase Decrease Not sure

8) In terms of mean rainfall, how do you describe the changes you experienced in the last 20 to 36 years in your area?

None Increase Decrease Not sure

9) How do you describe rainfall variability in your area between the years 1984 and 2020?

None Little High

10). How often do you experience drought conditions in your area?

Once in 10 years Twice in 10 years More than twice in 10 years
 Every year None

11). How do you describe the severity of the drought conditions in your area?

Not severe Moderately severe Highly severe

12) How often do you experience floods in your area?

Rare Often Very often

14). Overall, what is your experience with regards to climate change in your area?

.....

SECTION C: INDIGENOUS PLANT SPECIES DIVERSITY CHANGES OVER 20- 36 YEARS

15). Have you observed any changes in indigenous plants in your area over the past 36 years?

Yes No

16). If yes, what kind of changes do you observe? (*Tick all appropriate*)

| | |
|---|--------------------------|
| i) Increase in the number of indigenous plant species | <input type="checkbox"/> |
| ii) Decrease in the number of indigenous plant species | <input type="checkbox"/> |
| iii) Extinction of some indigenous plant species | <input type="checkbox"/> |
| iv) Other (Specify) | <input type="checkbox"/> |

17). Describe the changes in tree cover. (*Tick all applicable*).

Change in structure Change in composition Change in cover

Change in distribution

Others (Specify).....

18). What could be the factors influencing changes in indigenous vegetation in your area? **Tick all applicable.**

Changes in climatic patterns Human activities

Others (Specify).....

19). If you ticked human activities in 18 above, what could be the reason for human activities to drive natural vegetation changes? **Tick all applicable.**

| | |
|---|--|
| Agricultural activities | |
| Harvesting indigenous trees for selling | |
| Harvesting indigenous trees for domestic use | |
| Others (specify) | |

20).To what extend do you think climate change results in changes in the diversity of indigenous plant species?

None Little Moderate Great

21). Kindly list indigenous plant species that have decreased in number in your area over the past 20-36 years.

.....

22). Kindly list indigenous plant species that have increased in number in your area over the past 20-36 years.

.....

23).Overall, what is your comment about climate change and its impact on indigenous plant species diversity?

.....

Thank you so much for sharing your views in this important survey. Your contribution is greatly appreciated.

Appendix II: Interview Guide for Key Informants

Interview Guide for Key Informants: Sensitivity of indigenous plant species diversity to climate change in a semi-arid area of Chegutu district in Zimbabwe

Introduction

My name is Madzikatidze Wellington, an MPhil student at Great Zimbabwe University. I am carrying out a research which is part of requirements towards the fulfillment of my studies for MPhil in Geography and Environmental Science. The research is purely academic but it is truthfully anticipated that the research findings will help local, national and regional policy makers as a body of knowledge that will assist in decision making, planning and sustainable management of indigenous plant species diversity in the face of environmental modifications driven by climate change. The main objective of the study is to assess the sensitivity of indigenous plant species diversity to climate change in a semi- arid area of Chegutu district in Zimbabwe. The success of this study depends on your contribution as the main source of data. I, therefore, kindly seek your support and cooperation through setting aside part of your valuable time to respond to my questions. Kindly note that throughout the entire interview process, the responses you give are purely for academic purposes and will be treated with highest confidentiality to protect your rights and privacy.

GUIDING QUESTIONS

1. What are the factors influencing the changes in plant species diversity in your area?
2. Describe the climatic changes that you have observed in Chegutu district over the past 36 years. Specify patterns of climatic variables
 - a) Temperature
 - b) Rainfall
3. Describe the indigenous plant species found within your area.
4. Do you think climate change affects indigenous plant species diversity? If so, in what way?
 4. Are there any reports of indigenous plant species that have gone extinct over the past 36 years in Chegutu district?

5. What is the role of your organisation with regards to climate change and vegetation diversity issues?
6. What do you think is the significance of biodiversity data, specifically indigenous plant species diversity data, to national development and policy making?
7. What strategies are in place to reduce the impact of climate change on indigenous plant species diversity?
8. Does climate change influence the use of indigenous plant species by communities?

Thank you so much for your participation in this important interview.

Appendix III: Observation Guide

Observation Guide: Sensitivity of indigenous plant species diversity to climate change in a semi-arid area of Chegutu district in Zimbabwe

| | | | |
|-------------------------------------|------------------------|---------------------------|------------------------|
| 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 interference | None | low | medium | high | |
| 4. Main land cover class | Primarily vegetated area | Primarily non vegetated area | Cultivated/ managed | Artificial surfaces | Bare areas |

| | | | | |
|--|------------|----------------------|--------------------|-------|
| 5. Dominant vegetation type | Trees | shrubs | grass | other |
| 6. Wood leaf type | Broad leaf | Needle leaf | | |
| 7. Wood cover rating | Absent | <20% | 21-60% | >61% |
| 8. Wood cover spatial distribution | Continuous | Fragmented | | |
| 9. Woodland type | Natural | Plantation | Orchard | Other |
| 10. Vegetation description | | | | |
| 11. General vegetation distribution | Continuous | Scattered/ clustered | Scattered isolated | |

| 12. Site | Environmental aspect | Level of climate change impact | | | | | Remark |
|----------|----------------------------|--------------------------------|-------------------|--------------------|---------------|-----|--------|
| | | No impact | Negligible impact | Significant impact | Severe impact | N/A | |
| Forest | | | | | | | |
| | Indigenous trees diversity | | | | | | |
| | Herbaceous diversity | | | | | | |

Comments.....

| Name of indigenous plant species identified | Average height | Number | Average abundance ranging |
|---|----------------|--------|---------------------------|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| Total number of indigenous plant species | | | |

Appendix IV: Great Zimbabwe University Confirmation Letter



CHAIRMAN'S OFFICE
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GREAT ZIMBABWE UNIVERSITY

15 September, 2021

TO WHOM IT MAY CONCERN

RE: CONFIRMATION LETTER: MADZIKATIDZE WELLINGTON :M187764

This letter serves to confirm that **Madzikatidze Wellington: M187764** is a bonafide student in Master Of Philosophy [MPHIL] Geography And Environmental Science at Great Zimbabwe University in the Department of Physics, Geography and Environmental Science.

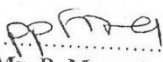
As part of the degree programme, he/she is carrying out a research project entitled,

Sensitivity of indigenous plant speceies diversity to climate change in a semi arid environment:

The case of Chegutu district, Mashonaland West, Zimbabwe

May you therefore, kindly assist him/her in any way possible.

Thank you


.....

Mr. B. Mapurisa

Chairperson – Department of Physics, Geography and Environmental Science.

GREAT ZIMBABWE UNIVERSITY
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Scanned with CamScanner

Appendix V: Authority to carry out research in Chegutu district

