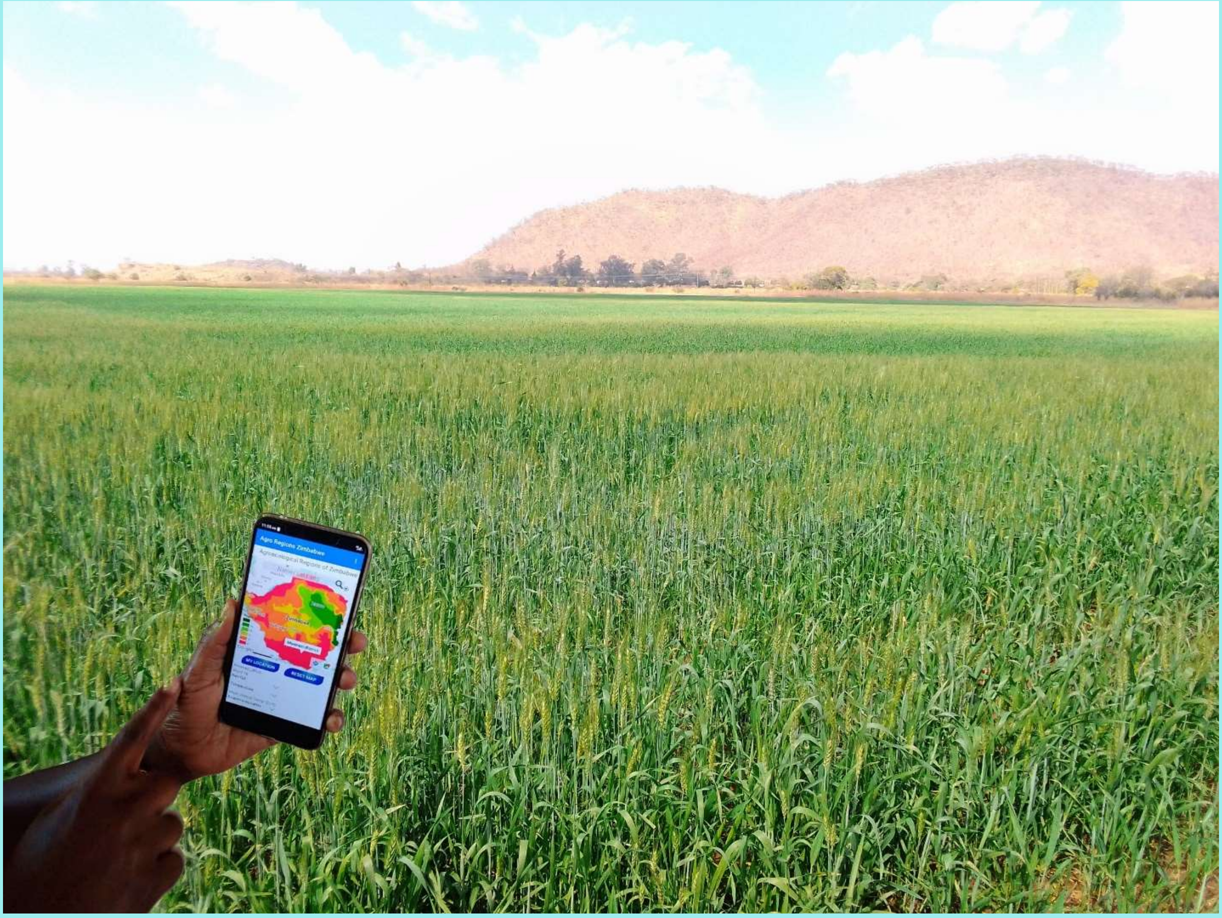
REVISION OF ZIMBABWE'S AGRO-ECOLOGICAL ZONES



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The 'Revision of Zimbabwe's Agro-Ecological Zones using Geospatial Capability' is part of seven Government of Zimbabwe national projects under the Zimbabwe National Geospatial Agency (ZINGSA) for the Ministry of Higher and Tertiary Education, Innovation, Science and Technology Development. The following are the leaders of the seven ZINGSA projects:

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EXECUTIVE SUMMARY

Agriculture remains a key sector to the economy of Zimbabwe providing livelihoods to more than 70% of the population and supplying raw materials for the predominantly agro-based economy. Land degradation, climate change, loss of biodiversity and ecosystem services pose significant challenges for the majority of the people who derive their livelihoods from agriculture. Moreover, the agricultural sector is key to employment creation, raising living standards, alleviating rural poverty and assuring food and nutritional security. In this way, increased agricultural productivity through sustainable management of land and water resources offers an important opportunity for the country to achieve Sustainable Development Goals (SDGs). However, much of the agricultural sector is predominantly rain-fed and therefore highly sensitive to climate variability and change. The country is characterized by diverse climatic patterns with the eastern highlands receiving more than 1500 mm of rainfall while the southern and western parts of the country are dry and characterized by erratic rainfall of less than 500 mm per year. On the other hand, mean annual temperature decreases from about 23°C in the low-lying areas in the south western parts of the country to about 18°C in the eastern highlands. The diverse climatic pattern is a key determinant of vegetation pattern and soil characteristics. Since climate is the main determinant of agricultural practice, it is important to delineate geographical regions into homogenous zones where variations in climate determine the agricultural activities practised in these areas.

To date, agricultural practice in Zimbabwe has been based on Agro-ecological Zones/Natural Regions, hereafter referred interchangeably as AEZs or simply Natural Regions (NRs), which were developed by Vincent and Thomas in the 1960s (Vincent and Thomas, 1960). These AEZs were later modified by the AGRITEX Department in 1984 and the revised map is hereafter referred to as AGRITEX (1984). Although the AEZs developed in the 1960s provided an adequate basis on which agricultural practice in the country was based, the changes induced by climate change has made the applicability of these zones difficult. Climate change has altered temperature and rainfall regimes thereby affecting patterns of agricultural practice relevant for different regions in the country. Current observations indicate that climate change has disrupted the normal climatic patterns in such a way that the traditionally recognized AEZs are no longer in tandem with the expected agricultural productivity, hence reduced agricultural yields. Despite the observed changes in the climatic pattern which directly affects crop and livestock production, agricultural practice in the country is still being planned based on the traditional AEZs developed in the 1960s with some slight modifications in 1984. This threatens the sustainability of the agricultural sector due to deployment of unsustainable agricultural practices which are incongruent with prevailing climatic conditions. This mismatch between land capability and agricultural practice leads to a number of undesirable outcomes such as land degradation, loss of biodiversity and ecosystem services and consequently results in poor performance of the sector, which is key to the economy of Zimbabwe. Poor agricultural yields reduce economic growth particularly for agro-based economies hence the need to restructure the agricultural sector to reflect current trends in climate.

In response to the urgent need of aligning agricultural practice with the changing climatic patterns, the Government of Zimbabwe through the Ministry of Higher and Tertiary Education, Innovation, Science and Technology Development initiated a revision of the country's agro-ecological zones. Based on the observed pattern of rainfall and temperature and their influence on agricultural practice, the revision of the AEZ had two main objectives: 1) to redefine the AEZs based on the current climate trend and recommend land-use practices for each zone, and 2) to develop an interactive software (Agro Zim mobile application) that would assist users of the updated AEZ to get important spatially explicit information required to guide agricultural practice in Zimbabwe. In this regard, geospatial technologies combined with rigorous statistical analysis of climatic data, field validation and stakeholder consultations were applied to redefine the AEZs of Zimbabwe. All geospatial layers important in determining agricultural practice together with rainfall and temperature were overlaid in a GIS environment in order to define homogeneous zones where different land-use practices were recommended. The main advantage of the current AEZ definition is that it goes beyond the conventional approach and includes an interactive Android based software that is not only user friendly but freely available. The Agro Zim App allows stakeholders to obtain information on the different farming activities in each AEZ. This application was developed after the realization that access to climate information and advisory services is key in enhancing agricultural productivity. The ease of information accessibility ensures that the marginalized and vulnerable small-scale farmers make more informed and timely decisions at the click of a button on their mobile phones. The redefined zones were validated through stakeholder consultation in all the provinces of Zimbabwe where user needs for the mobile application were also collected.

The main finding of this study is that there are significant spatial shifts in AEZ between the original zones developed by Vincent and Thomas in 1960 and newly delineated zones. Specifically, a smaller proportion of the country are experiencing better climatic patterns than previously observed and were thus assigned to AEZ that are more productive than in the original classification. However, a larger proportion of the AEZ shifted towards drier and less productive categories. There was a general agreement based on climate data and stakeholder consultations that the region previously classified as NR V be split into NR Va and NR Vb to reflect the distinct climatic patterns that are now being experienced in this region. NR Vb was regarded as not suitable for sustaining any form of rain-fed agriculture, even the growing of drought tolerant crops. The results of this study underscore the importance of geospatial capabilities and Information Technology in optimising resource use in the agricultural sector. Most importantly, this report can serve as a valuable reference guide for policy makers, development practitioners, funding institutions, extension agents, farmers, researchers and other stakeholders who have interest in agriculture. Thus, the revised AEZ together with the mobile application present a new milestone for reviving the agricultural sector and restoring the country to its former bread basket status under a changing climate.

TABLE OF CONTENTS

EXECUTIVE SUMMARY vi
TABLE OF CONTENTS ix
LIST OF FIGURES xii
LIST OF TABLES xvi
LIST OF ACRONYMNS xvii
DEFINITION OF TERMS xviii
CHAPTER 1 : GENERAL INTRODUCTION 1
- 1.1 Background 1
- 1.2 Potential use of revised AEZ Map 4
- 1.3 Summary 5

CHAPTER 2 : BASIS OF AGRO-ECOLOGICAL REVISION IN ZIMBABWE 6
- 2.1 Introduction 6
- 2.2 Shifts in rainfall and temperature regimes 6
- 2.3 Changing seasonal characteristics of rainfall 10
- 2.4 Trends in monthly rainfall patterns 13
- 2.6 Spatial Temperature trends 17
- 2.7 Shifts in Potential Evapotranspiration 21
- 2.8 Vegetation productivity trends 23
- 2.9 Soils of Zimbabwe 28
- 2.10 Summary 32

CHAPTER 3 : MATERIALS AND METHODS 33
- 3.1 Data Sources 33
- 3.2 Comparison of satellite derived elevation and climate data with field measurements 33
- 3.3 Data analysis 37
- 3.4 Field Visits and Stakeholder Participation 38
- 3.6 Field visits and stakeholder consultations on zone boundaries 41
  - 3.6.1 Manicaland Province fieldwork 44
  - 3.6.2 Midlands Province fieldwork 45
  - 3.6.3 Masvingo Province fieldwork 46
  - 3.6.4 Mashonaland West Province fieldwork 47

3.6.4 Mashonaland Central Province fieldwork ... 49
3.6.5 Mashonaland East Province fieldwork ... 50
3.6.6 Matabeleland North Province fieldwork ... 51
3.6.7 Matabeleland South Province fieldwork ... 53
3.8 Incorporation of field survey findings to the development of AEZ map ... 54
3.9 Accuracy assessment of AEZ ... 55
3.10 Change detection in the spatial structure of AEZ from 1960 to 2018 ... 56
3.11 Summary ... 56
CHAPTER 4 : REVISED AGRO-ECOLOGICAL ZONES OF ZIMBABWE ... 57
4.1 Automatic generated AEZ map ... 57
4.2 Evaluation of the new AEZ (ZINGSA AEZ, 2020) ... 58
4.3 ZINGSA AEZ (2020) ... 58
4.4 Changes in the spatial distribution and extent of agro-ecological zones ... 59
4.5 Characteristics of each Zone and recommended land use ... 62
4.6 Summary ... 67
CHAPTER 5 : AGRO ZIM MOBILE APPLICATION ... 68
5.1 Introduction ... 68
5.2 Objectives ... 68
5.3 Expected Outcomes of the Agro Zim Mobile Application ... 68
5.4 Methodology and Design ... 69
5.4.1 Development Method ... 70
5.4.2 System Architecture Components ... 70
5.4.3 Database ... 70
5.4.4 Web Services ... 71
5.4.5 Mobile Application ... 71
5.4.6 Interoperability Layer ... 71
5.4.7 Mobile Application Architecture ... 71
5.5 System Requirements ... 71
5.5.1 Functional Requirements of the Agro Zim App ... 71
5.5.2 Non-Functional Requirements of the Agro Zim App ... 72
5.6 System Menu ... 72

5.6.1 System Configuration 72
5.6.2 Data Flow 72
5.7 Summary 73
CHAPTER 6: RECOMMENDATIONS 74
REFERENCES 75
LIST OF ANNEXES 77
Annex I: Agro Zim Mobile Application User Manual 77
Annex II: Provincial maps of the Revised Agroecological Zones 85
Annex III: List of Stakeholders Consulted in the Provinces 90
Annex IV: Location, elevation and Station Code of Weather Stations where data used in this Project were obtained 94

LIST OF FIGURES

Figure 1.1: Agro-ecological zones produced by a) Vincent and Thomas (1960) and (b) 1984 AGRITEX modified agro-ecological zones/natural regions of Zimbabwe 3
Figure 2.1: Regime shift analysis of maximum temperature using (a) CUSUM technique ansd (b) Regime Shift Detector from 1951-2017 for the rainfall season ONDJFM.................................. 8
Figure 2.2: Temporal pattern of (a) total rainfall total and (b) CUSUM values for Zimbabwe from 1950 to 2017 based on the ONDJFM season 9
Figure 2.3: Changes in the start of the rainfall (mm) season between the period 1951 to 1981 and from 1982 to 2016 for (a) Zimbabwe and (b) selected towns. (*The rainy season is in Julien days*) 10
Figure 2.4: Spatial variation in the termination of the rainfall season between 1951 and 1981 and 1982 and 2016 for (a) Zimbabwe and (b) selected towns. *(Negative values indicate early termination while positive values imply late termination of the rainfall season. The days of the season are in Julian days)*... 11
Figure 2.5: Spatial variation in the changes in the length of the rainfall season between the period 1951 to 1981 and from 1982 to 2016 for (a) Zimbabwe and (b) selected towns. *(Negative values indicate contracting whilst positive values imply expansion of the rainfall season)*................... 11
Figure 2.6: Spatial variation in the changes in the number of rain days between the period 1951 to 1981 and from 1982 to 2016 (a) Zimbabwe and (b) selected towns. (*Negative and positive values indicate the number of rain days below and above the average respectively)* 12
Figure 2.7: Spatial variations in changes in the length of longest dry spells between the period 1951 to 1981 and from 1982 to 2016 for (a) Zimbabwe and (b) selected towns. *(Negative and positive values indicate the length of dry spell days below and above the average length respectively)* 12
Figure 2.8: Spatial trends in monthly rainfall in January (a), February (b), March (c), April (2d), May (e) and June (f).. 13
Figure 2.9: Spatial trends in monthly rainfall July (a), August (b), September (c), October (d), November (e) and December (f) 14
Figure 2.10: Spatial trends in annual (a), seasonal (b) first half season (c) and second half season (d) rainfall 15
Figure 2.11: Mean differences in the maximum temperature between the pre-shift period (1951-1965 and 1966-1981) and the post-shift period (1982 to 2001). (*P-values are for the differences between the two means using a 2-tailed t-test)* 16
Figure 2.12: Mean differences in the minimum temperature between the pre-shift period (1951-1965 and 1966-1981) and the post-shift period (1982 to 2001). (*P-values are for the differences between the means using a 2-tailed T-test*).. 17
Figure 2.13: Spatial trends in monthly maximum temperature January (a), February (b), March (c), April (d), May (e) and June (f)... 18
Figure 2.14: Spatial trends in monthly maximum temperature July (a), August (b), September (c), October (d), November (e) and December (f) 18

Figure 2.15: Spatial trends in monthly minimum temperature January (a), February (b), March (c), April (d), May (e) and June (f) 19
Figure 2.16: Spatial trends in monthly minimum temperature July (a), August (b), September (c), October (d), November (e) and December (f) 20
Figure 2.17: Spatial trends in annual maximum temperature (a), maximum winter season temperature (b) annual minimum temperature (c) and minimum winter season temperature (d) 21
Figure 2.18: Temporal manifestation of the PET for the rainfall season (ONDJFM), winter season (AMJJAS) and the annual period for Zimbabwe from 1901 to 2017 22
Figure 2.19: Spatial trends in NDVI in the months of January (a) , February (b) , March (c), and April (d) 24
Figure 2.20: Spatial trends in NDVI in the months of (a) May), (b) June , (c) July and (d) August 25
Figure 2.21: Spatial trends in NDVI for the months of a) September , b) October , c) November and d) December 26
Figure 2.22: Spatial trends in annual NDVI. (Hatches show areas with significant NDVI trends) 27
Figure 2.23: Spatial distribution of Soils in Zimbabwe 28
Figure 3.1: Correlation of ASTER derived elevation and in-situ elevation measurements in Zimbabwe 34
Figure 3.2: Comparison of in-situ and Satellite derived temperature from WFDEI 35
Figure 3.3: Mean annual rainfall from CHIRPS data versus in-situ observations in Zimbabwe . 36
Figure 3.4: GIS layers used to redefine Agro-Ecological Zones of Zimbabwe 37
Figure 3.5: Framework Flow Chart for redefining Agro-Ecological Zones of Zimbabwe 38
Figure 3.6: Map showing routes and GPS points taken in (a) Manicaland, (b) Midlands, (c) Masvingo, (d) Mashonaland West, (e) Matabeleland South Province (f) Mashonaland Central, (g) Mashonaland East, and (h) Matabeleland North Provinces. 43
Figure 3.7: Typical forestplantation in Natural Region I. The photo shows direction to Mutarazi Falls in Nyanga (5/5/2019) (left panel). Team taking coordinates of the edge of the dense evergreen forest of Natural Region I near Mutare (right panel) 44
Figure 3.8: Stakeholder consultation in Mutare District AGRITEX Offices (left panel). Stakeholder input for Makoni District (right panel) 44
Figure 3.9: Agro-ecological Zones validation meeting with stakeholders (top panel) and field observation in Midlands Province 45
Figure 3.10: AGRITEX officers discussing the changed Kwekwe District Natural Regions boundaries (left panel). The crops and land use options currently recommended by AGRITEX extension officers for Midlands Province (left panel) 46
Figure 3.11: Bush trees interspaced with grass for grazing in cattle ranching Farm near Masvingo (left panel). Typical Natural Region IV vegetation in Gutu South (right panel) 46

Figure 3.12: AGRITEX Extension Officers displaying their inputs to their districts' Natural Regions in Masvingo Province (left panel). Meeting with stakeholders to confirm the new Natural Regions' district boundaries in Masvingo (right panel) 47
Figure 3.13: Images from the Mashonaland West Province vegetation typical of RN III (left panel) and farms which have been turned into wildlife conservancies (right panel)............................. 48
Figure 3.14: AGRITEX officer checking on the concurrence of the boundaries from the automated map with what is observed on the ground (left panel). Hurunge District map indicating a very high rate of concurrence with what was observed in the ground (right panel).................................... 48
Figure 3.15: Images from the Mashonaland Central field trip.. 49
Figure 3.16: Images from the Mashonaland Central field trip.. 50
Figure 3.17: Natural region boundary demarcation during the field work (left panel). Typical area where the underlying soil significantly changed the natural vegetation within a region near Wedza. 51
Figure 3.18: A stakeholder from AGRITEX concurs with the district NR map presented (left panel) and was indicated satisfaction by putting OK on the district map (right panel).......................... 51
Figure 3.19: Different types of vegetation in region Va near Victoria Falls (left panel) and Tsholotsho (right panel)... 52
Figure 3.20: Discussion of Matabeleland district NR boundaries at the AGRITEX provincial Offices in Bulawayo (left panel) and the new recommended land use per natural region (right panel)... 52
Figure 3.21: Thorny bushes on bare ground in Natural Region Vb in Beitbridge District (left panel) and plants adapted to low rainfall in Matebeleland South Province (right panel)....................... 53
Figure 3.22: AGRITEX extension officers discussing the new NR boundaries (left panel) and recommending new crop varieties so suit the new drier and warmer climate of their districts (right panel)... 54
Figure 3.23: The distribution of ground control points used for accuracy assessment and iterative improvement of agro-ecological zones map 55
Figure 4.1: Automatically generated first draft of agro-ecological zones map of Zimbabwe...... 57
Figure 4.2: Revised Agro-Ecological Zones of Zimbabwe (*ZINGSA AEZ, 2020*)...................... 58
Figure 4.3: A comparison of (a) Agro-Ecological Zone maps by Vincent and Thomas (1960) and (b) AGRITEX (1984) with (c) ZINGSA AEZ (2020) 60
Figure 4.4: Transition matrix between ZINGSA AEZ (2020) and AEZ delineated by Vincent and Thomas (1960) and Ministry of Agriculture (1984)... 61
Figure 4.5: Locations with stable and transformed Agro-Ecological Zones between 1960 and 2020 62
Figure 4.6: Variation in mean annual rainfall and probability of exceeding 500 mm annually in different Agro-Ecological Zones of Zimbabwe.. 63
Figure 4.7: Probability of receiving annual rainfall exceeding 300mm (left) and 1000mm (right) 63
Figure 4.8: Variations in the quality of rainfall season in Agro-Ecological Zones 64

Figure 4.9: Variation of elevation and temperature in Agro-Ecological Zones of Zimbabwe 65
Figure 5.1: Basic System Architecture 69
Figure 5.2: Basic Mobile Application Architecture 70
Figure 5.3: Model View Controller architecture 71
Figure 5.4: Data Flow Diagram for AEZ Map attributes 73

LIST OF TABLES

Table 2.1: Major characteristics of the soil groups of Zimbabwe 29
Table 3.1: Accuracy assessment of ASTER DEM data in Zimbabwe 34
Table 3.2: Accuracy of WFDEI temperature retrievals before and after bias correction 35
Table 3.3: Effect of bias correction on accuracy of rainfall retrievals from CHIRPS data 36
Table 3.4: Fieldwork dates and the total number of recorded GPS points within the province. .. 42
Table 4.1: Area occupied by each of the revised Agro-Ecological Zones/Natural Regions 59
Table 4.2: Recommended land use [land management practices] in Agro-Ecological Zones of Zimbabwe 65

LIST OF ACRONYMNS

AEZ	Agro-Ecological Zones
AGRITEX	Agricultural Extension
API	Application Programming Interface
ASTER	Advanced Space-borne Thermal Emission and Reflection Radiometer
CHIRPS	Climate Hazards Group Infrared Precipitation with Station
CRU	Climate Research Unit
CUSUM	Cumulative Sum technique
DBMS	Database Management System
DEM	Digital Elevation Model
GIS	Geographical Information Systems
GPS	Global Positioning System
GUI	Graphic User Interface
HTML	Hypertext Markup Language
ICT	Information and Communication Technology
IPCC	Intergovernmental Panel on Climate Change.
JFM	January to March
MSD	Meteorological Services Department of Zimbabwe
MVC	Model View Controller
NDVI	Normalized Difference Vegetation Index
NR	Natural Region
OND	October to December
ONDJFM	October to March
PET	Potential Evapotranspiration
PHP	Hypertext Preprocessor
RSD	Regime Shift Detector
SDK	Software Development
SDK	Software Development Kit
SQL	Structured Query Language
TS	Time Series
URL	Uniform Resource Locator
WFDEI	WATCH-Forcing-Data-ERA-Interim
XML	Extensible Markup Language
ZINGSA	Zimbabwe National Geospatial and Space Agency

DEFINITION OF TERMS

Rain day: when a place receives at least 0.85mm (measurable and able to be converted to inches) over a 24-hour period.

Dry day: when place receives precipitation amounts less than the amount required for it to be classified as a rainy day.

Start of rainfall season: when a station receives 20mm in 1 or 2 days and there is no dry spell of more than 10 days in the next 20 days.

End of rainfall season: a day before the 30th of April that a place receives at least 15mm of rainfall.

Length of season: The difference between the end of rainfall season date and the start of the rainfall season date.

Dry spell: number of consecutive dry days within the length of the season.

Wet spell: number of consecutive rain days within the length of the season.

Rainfall: all forms of precipitation including (drizzle, showers, hail, etc.).

PET: Potential Evapo-Transpiration is the potential evaporation from soils plus transpiration by plants and only occurs at the potential rate when the water available for this process is non-limiting.

AEZ: An Agro-Ecological Zone is an area of land which has similar characteristics related to land suitability, potential production and environmental impact.

CHAPTER 1 : GENERAL INTRODUCTION

1.1 Background

Land and water resources management are important in the achievement of sustainable food security in most developing countries with agro-based economies. Proper management of water and land resources play a crtical role in reducing land degradation and water loss thereby maintaining high biodiversity and enhance the quality of the environment. Zimbabwe has not been spared from the negative effects of climate change and climate variability, hence an urgent call for national capacities to develop a more integrated approach to the management of natural resources which appear to be rapidly reducing ecosystem service provision. As such, an integrated approach is required to appraise and improve the ability of the country to plan and monitor the use and management of land resources to increase national agricultural productivity while maintaining land and environmental quality. Revisiting the seemingly outdated agro-ecological zones (AEZ) developed by Vimcent and Thomas in 1960 with the aim to redefine them so as to avail updated information to farmers, planners and policy makers should play a critical role in this regard.

Zimbabwe is predominantly semi-arid and is characterised by relatively high agro-ecological diversity with different agricultural systems. The high agro-ecological diversity requires science-based agricultural land use planning and environmental management so as to maintain healthy ecosystems. The main determinants of the high diversity are climate, landscapes and soils in combination with human activities. To capture the current climate change impacts on the high agro-ecological diversity in the country, there is need to adopt a reclassification scheme that accurately classifies this diversity into homogeneous regions where the resulting updated different landuses can be applied. In this regard, the the previously delineated agro-ecological regions were revisited in order to incorporate changes in climate and thus provide updated zones capable of providing a current integrated framework for country-level agricultural planning. Agricultural development planning and sustainable use of natural resources rely predominantly on accurate classification of regions into different AEZs. Once AEZs have been delineated, they work as a vehicle that not only propel but guide agricultural practice in the country through enabling successful application of farming systems in defined locations. Appropriate policy intervention then provides potential for agricultural research and planning that promotes diverse farming and production systems, each fitting well into a particular reclassified zone. In this regard, revisiting the AEZs becomes a critical vehicle with potential to meaningfully catapult the agro-based economy of Zimbabwe to higher productivity levels.

In recent, years, observations indicate that the changing climate has the potential to disrupt the the traditionally recognized natural systems. In fact, according to the IPCC, there has been a general global warming trend of 0.13°C/decade from 1956–2005 (IPCC, 2007) which was updated to 0.12°C/decade for the period 1951–2012 (IPCC, 2013) in the Assessment Report 5. Global warming and associated climate change has long-term consequences for many socio-economic sectors particularly agriculture , food security and ecosystems. Climate change is one of the factors contributing to low agricultural yield particularly in rainfed systems such as in Zimbabwe as there has been a general shift in the suitability of crops that can be grown in different regions. For instance, as a result of climate induced changes, some regions have become unsuitable for the growth of the main food crops including maize (*Zea mays*), wheat (*Triticum aestivum*), Irish potato

(*Solanum tuberosum*), groundnuts (*Arachis hypogaea*), finger millet (*Eleucine corocana*), pearl millet (*Pennisetum glaucum*), sorghum (*Sorghum bicolor*) and some cash crops such as apples (*Malus domestica*), banana (*Musa acuminata Colla*), coffee (*Cofea arabica*) and sugar-cane (*Saccharum officinarum*) which they used to adequately sustain. Despite the shift in suitability induced by climate change, farmers have continued to follow the traditional way of practising agriculture as there has been no revision in the pattern of agricultural practice.

Despite the lack of understanding of these climate change instigated variations and major alterations in the agricultural and socio-economic development as well as natural resource base, Zimbabwe currently uses AEZ (or Natural Regions) map initially developed in 1960 by Vincent and Thomas, during the then Rhodesia. This work produced a map that divided Zimbabwe into five AEZs, with best agricultural suitability being allocated to Natural Region (NR) I and the least to Natural Region (NR) V (Figure 1.1a). Although this map appears to have withstood the test of time (despite being modified by AGRITEX in 1984 - Figure 1.1b), there is a growing consensus among researchers, farmers and development practitioners that it has outlived its usefulness. Such calls have become increasingly relevant due to increased crop failure emanating from changes in rainfall patterns and recurrent droughts thereby affecting agricultural production systems: the backbone of the country's development. As such, the continued utilization of this seemingly outdated map to inform agro-economic national planning is severely affecting its full revenue generation potential.

Advances in technology in areas such as Geotechnologies i.e., Geographical Information Systems (GIS) and Remote Sensing have provided unlimited opportunities to integrate various spatial datasets that are important in the delineation of homogeneous regions that constitute agroecological zones. Geotechnologies have now (and will continue to) revolutionize the way data is collected, analysed and archived. Thus relative to the 1960's, these research techniques have become not only more efficient and accurate, but also cost effective. They have also drastically reduced data processing time. Hence, when employed in the context of agro-ecological zoning, they can rapidly provide novel approaches to effectively monitor and manage land resources in an integrated manner. As such, the ability of the GIS platform to handle multiple datasets (e.g. land use, elevation structures, soil types, and climate and land inventory datasets, etc) and aggregate them into a single map, provides an opportunity for AEZ delimitation with additional zone characterizations. At the same time, satellite remote sensing can avail digital databases of information on natural resources and, parameters of vegetation indices, surface temperature, evapotranspiration, and crop water requirements. The provision of these datasets by modern technology therefore becomes a key motivating factor for this work. Most importantly, local experts and farmers, who have observed and "peer reviewed" these environmental parameters and their interactions with ecosystems over a long period could be handy in augmenting these technologies.

Though the climate change instigated shift in natural regions was not the motivating factor decades back, revisiting the existing agro-ecological boundaries is not new to Zimbabwe. For example, AGRITEX made initial attempts to revise the AEZs in 1984, but did not improve much as there was a lot of over generalization such as grouping together regions with different physiography, temperature and soils. As a result, regions IIIa and IIIb, for example, were completely lost in the updated version (Figures 1.1a and Figure 1.1b). Recent attempts by Chikodzi et al., 2013 and

Mugandani et al., 2012 to redefine the AEZs pointed towards the failure of the existing AEZs to provide objective basis for agricultural planning in the country.

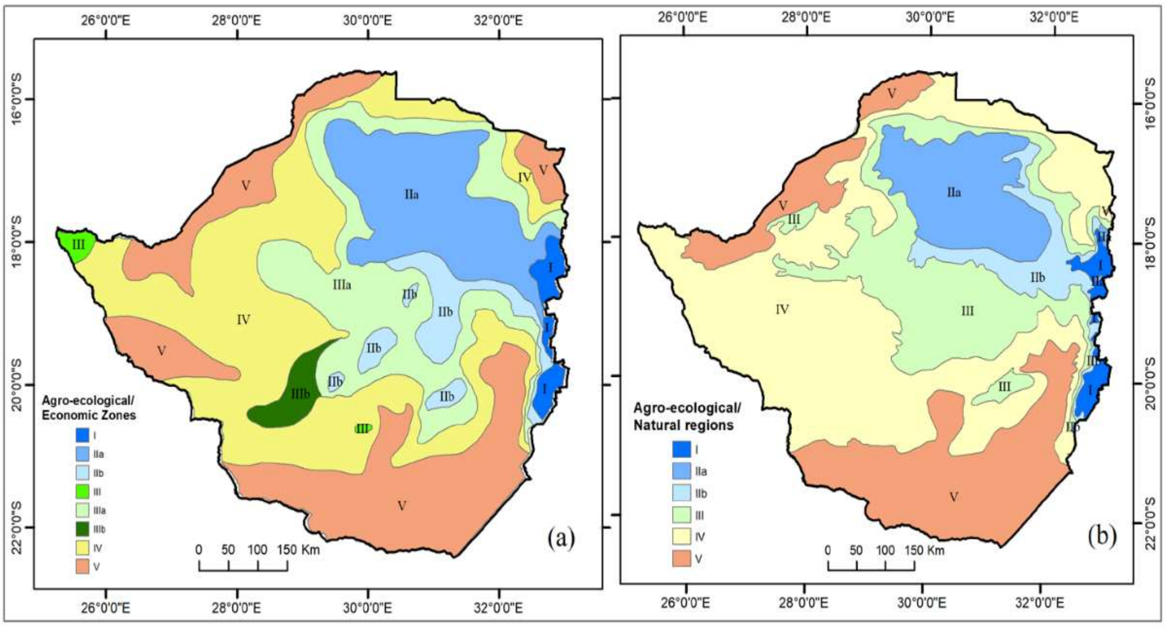

Figure 1.1: Agro-ecological zones produced by a) Vincent and Thomas (1960) and (b) 1984 AGRITEX modified agro-ecological zones/natural regions of Zimbabwe

The current revision of the AEZ map acknowledges that, while the overall pattern of AEZs in Zimbabwe is stable, primarily due to the static nature of most of the variables used to determine the boundaries like soils and elevation, climate change has led to significant shifts in agricultural practice within the AEZ. In this context, the current work provides climate change impacts on agro-ecological suitability and productivity since the development of the previous AEZ map in 1960. It also takes advantageof the combination of remotely sensed data such as satellite based precipitation and normalized difference vegetation index (NDVI) that are more spatially coherent to complement observed climate data from national meteorological stations. In addition, to delineation of AEZ, the current work also adds an interactive map with advisory services. This application intends to provide location-specific information on fertilizer use, rainfall and temperature characteristics etc., on an android based platform. The application is not limited for use at macro level, but also enables local and micro level planning so that it becomes more effective in optimizing sustainable agricultural development planning. There are plans to make the application provide an interactive platform with the capability of self-adjusting the boundaries as directed by the input of the latest climate data from the continually changing climate. However, the application will, in no way, substitute advisory services offered by extension officers.

1.2 Potential use of revised AEZ Map

For agro-based economies such as Zimbabwe, it is more beneficial that investment in agricultural production be increasingly directed at AEZs (and in some cases at farm level) where output benefits are expected to be greatest. However, limits to the productive capacity of land resources are set by climate, soil and landform conditions as modified by the use and management of the land. In this regard, climate change in addition to such factors as competition with industrial and urban demands, degradation and pollution are causing a decline in both quantity and quality of essential natural resources, such as land and water. The resulting problem is one of mounting pressure on the existing natural resources. Thus the initial step requires that the zones themselves be accurately defined and climate change updated as the defining input parameters change.

It is envisaged that once the AEZ map and accompanying mobile application provide accurate, relevant and easily available information about the target environments, they become standard tools to be reliably employed as enablers for agricultural research and investment. Since agricultural determinants such as rainfall, temperature, cropping patterns and agriculture management are highly dynamic, the pattern of AEZs may change significantly under the background of global climate changes. As such, an assessment of shifting patterns of AEZs in Zimbabwe is pivotal in guiding the nation's current and future agricultural development that guarantees national sustainable food and nutritional security through meaningful investment in agriculture. The revised AEZ map therefore provides scientific recognition of land resources and possible land exploitations, as well as interactions between specific land units with a specific use, thus paving the way for sustainable development.

The revised AEZ map has the following application areas:

a) In land use planning and policy the AEZ map:
   - makes it possible to use land according to its biophysical potential and limitations, in order to protect soil resources from degradation and at the same time to meet farmers' demands for optimal crop production; and
   - provides the basis for policy formulation and land-use planning through revealing answers to the following questions:
     How is land with different potentials and constraints distributed within the country and in component provinces or districts?
     What uses can be recommended on different types of land in different locations?
     How do potential yields vary among locations, years and seasons?
     What is the balance between population density, land availability and food production in specified areas?, and
     What is the impact of improvements in inputs or management?

b) In Agriculture the AEZ map can:
   - be used to predict potential productivity for a specific crop in a particular location;
   - be used in determining crop water requirements
   - be used as the main analysis units of agricultural production;
   - be used for expanded crop coverage and dryland management techniques;
   - provide information on location specific optimum seed variety use;

- provide location based fertilizer recommendations depending on soil type; and
- provide policy guidance for agricultural research and climate proofing the agricultural sector.

c) In Disaster Risk Reduction the AEZ map can:
   - be used in land-use planning to identify suitable agricultural, flood-prone and drought-susceptible and ecologically sensitive areas that may be prone to degradation;
   - be employed in the designing of appropriate agricultural adaptations for reducing vulnerability and ;
   - complement the development of long-term drought mitigation measures like irrigation potential.

1.3 Summary

The observed changes in climate inevitably make it imperative that the country revises its AEZs to reflect potential shifts in suitability of agricultural activities since the first attempt by Vincent and Thomas in 1960. The old AEZ do not capture changes in climate parameters that have taken place since the 1960s and may therefore not provide current information for guiding national government and stakeholders in planning for sustainable agriculture in the country. The revised AEZ map will support the development of enabling agricultural strategies including land-use policies through:
easily accessible essential farming information for an individual farmer at any point in the country;

- the provision of appropriate, area-specific, agricultural information;
- the provision of national agricultural inputs, and/or of relief programmes;
- the setting of agricultural research priorities, and the establishment of networks for agro-technology transfer;
- the formulation of legislation or guidelines to regulate and minimize environmental damage, and the establishment of environmental monitoring;
- the identification of appropriate development programmes or projects per province; and
- avail region specific information for complimenting NGO relief and development efforts.

CHAPTER 2 : BASIS OF AGRO-ECOLOGICAL REVISION IN ZIMBABWE

2.1 Introduction

Climate, mainly rainfall and temperature, is the key determinant of agricultural crop production. Human activities have resulted in anincrease in greenhouse gases (GHGs) emissions into the atmosphere. The GHGs affect the climate system through increasing temperature and shifting moisture regimes. A long term analysis of climate data indicate that global temperatures have increased by an average rate of 0.74°C from 1906 to 2005 (IPCC, 2019). Similarly, rainfall has changed by different magnitudes in different regions. The change in rainfall and temperature has influenced agricultural practice through shifting crop suitability in different regions. Previous studies have shown that the geographical suitability of crops is modified by changes in climate variables (Lane & Jarvis, 2007; Fischer et al., 2005; Matarira et al., 2004). Agricultural practice in Zimbabwe is guided by AEZs developed by Vincent and Thomas in 1960. Since the delineation of the current AEZs by Vincent and Thomas in 1960, a number of climatic changes have occcurred. These changes have greatly influenced the socio-economic system since the climatic conditions are now different from the initial conditions when the first AEZs were developed. Thus, the changes that have occurred over the past 60 years have had profound effect on both crop and livestock suitability across the country. This section provides an overview of the key trends observed within the biophysical environment which provide a basis for agro-ecological rezoning. Specifically, the chapter focuses on providing evidence of changes in the frequency and intensity of dry spells, precipitation and temperature including their implications to Zimbabwe's agricultural sector. Such parameters as seasonal rainfall characteristics (i.e. total rainfall, dry spells, and rainfall season's length including onset and cessation dates), temperature regimes, and evapotranspiration are important in determining the quality of the growing period at specific locations, as they may influence crop growth.

2.2 Shifts in rainfall and temperature regimes

Shifts in rainfall and temperature were detected using the cumulative sum technique-(CUSUM) - (Ibanez et al., 1993) and the Regime Shift Detector (RSD) by Rodionov (2004). The former represents the running total of observation deviations from the mean based on the same interval which are then plotted over time (years) to locate the point indicating an abrupt change (Figura et al., 2011; Dionne et al., 2009; Overland et al., 2008; Breaker, 2007; Overland et al., 2006). The latter method uses the Student's t-test and F-test to determine the probability level for the identified year of regime shift in the mean and/or variance. This technique involves sequential data processing. The current work uses a cut–off length of 20 years and a probability level of 0.01 to confirm statistical significance.

The preliminary detection of the shift was performed on Tmax data from 1951 to 2017 using the CUSUM method for the whole rainfall season (ONDJFM). Tmax was selected ahead of Tmin since the former parameter is more influential in reducing soil available moisture than the latter. This method detected 1982 as the shift year (Figure 2.1a) and the result was further corroborated by the RSD technique which identified significant changes in temperature around the year 1982 (Figure 2.1b). This shift was significant at 99.5% confidence level. Consequently, the post 1982 period was considered the new regime for the climate of Zimbabwe. As a result the redefined AEZs were determined using climate data from the years 1982 to 2017.

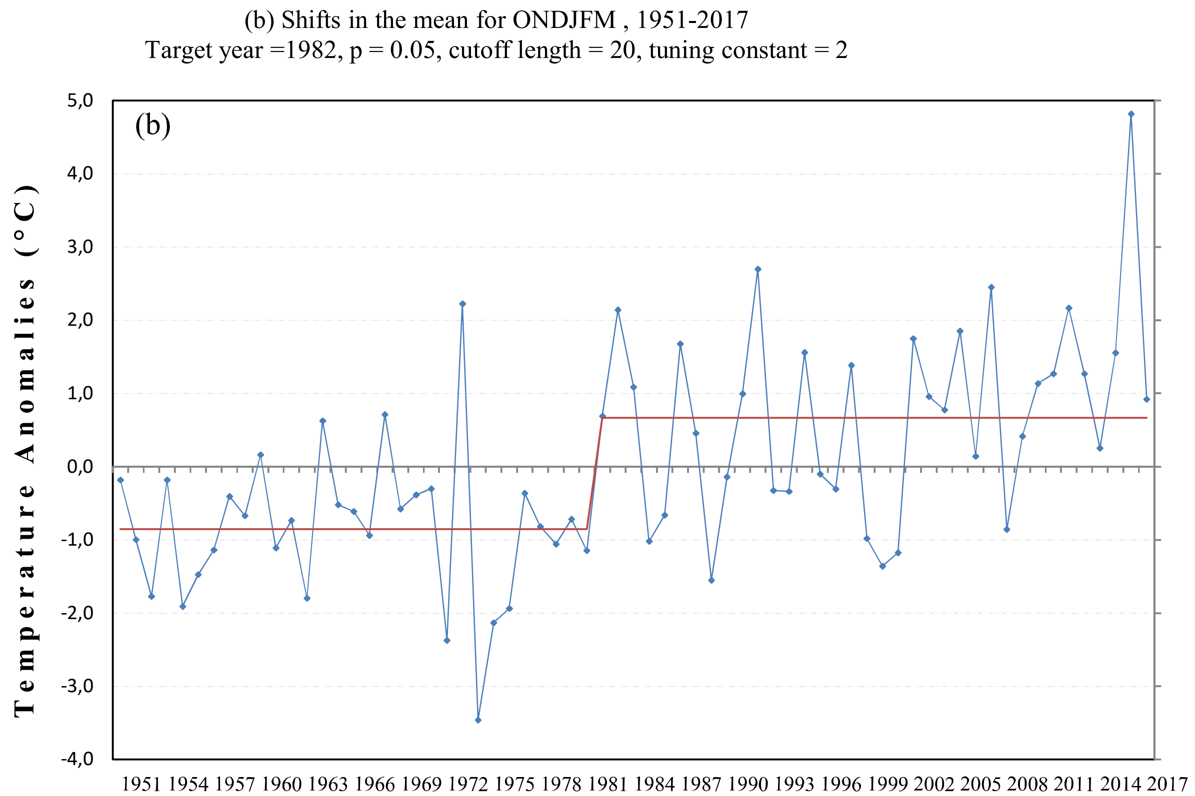

Figure 2.1: Regime shift analysis of maximum temperature using (a) CUSUM technique ansd (b) Regime Shift Detector from 1951-2017 for the rainfall season ONDJFM

Results based on the shift detected in 1982, show notable but insignificant difference (p=0.19) between the resulting adjacent means in rainfall. Although this difference is not statistically significant, the drying out of the country after 1982 is quite evident (Figure 2.2a). The CUSUM technique which was employed on the rainfall time series indicate decreasing values from 1982 (Figure 2.2b) which then turned to negative in 1990 and remained in this phase for the rest of the period. The coinciding changes of rainfall and temperature in 1982 suggest a climate shift during this period. This suggests that 1982 can be reasonably taken as the climate shift year for Zimbabwe in which rainfall and temperature shifted to a new regime. Therefore the epoch before 1982 is herein referred to as the pre-shift period whilst the era after 1982 is considered the post-shift period.

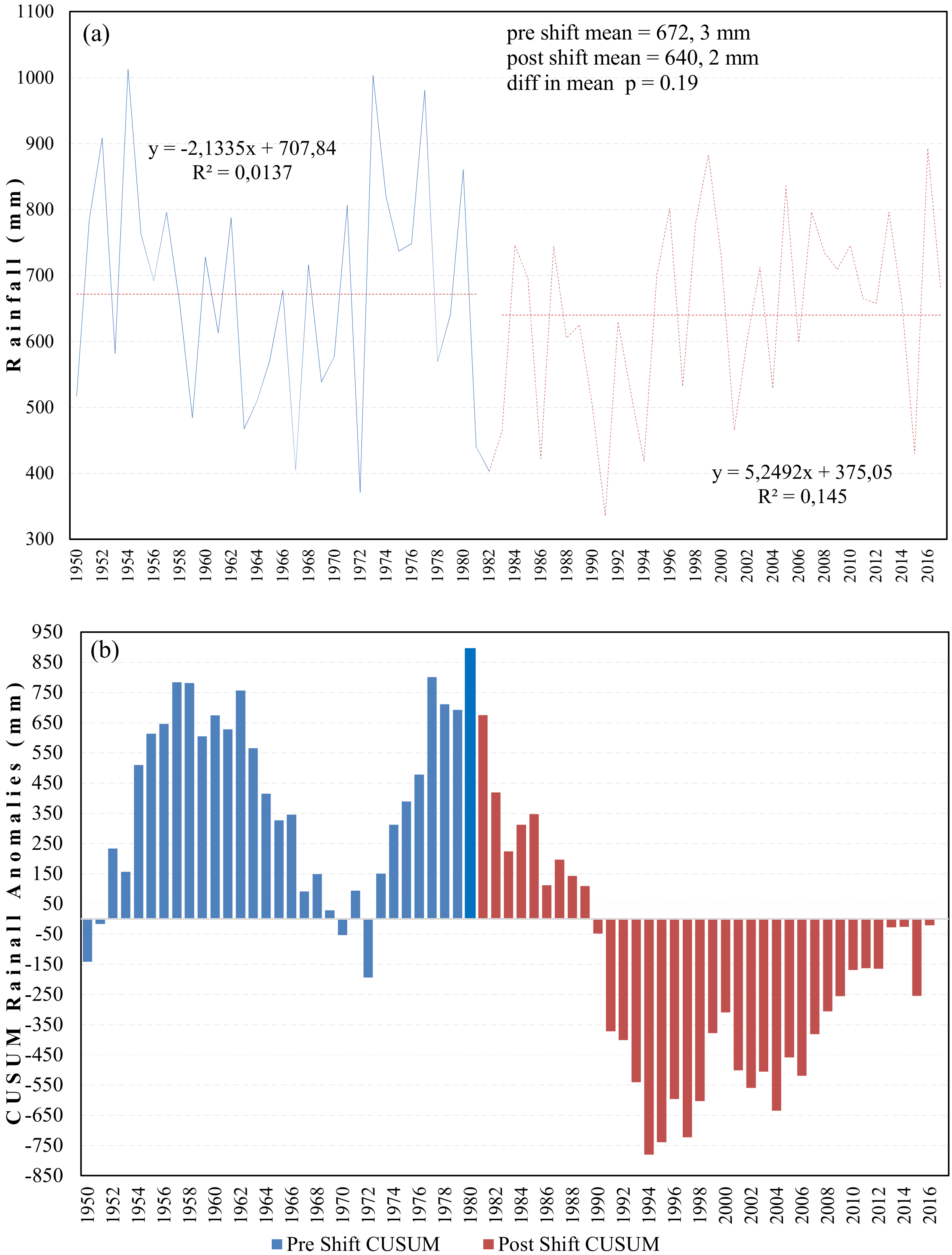

Figure 2.2: Temporal pattern of (a) total rainfall total and (b) CUSUM values for Zimbabwe from 1950 to 2017 based on the ONDJFM season

2.3 Changing seasonal characteristics of rainfall

WMO climatic periods of 1951 to 1981 and 1982 to 2010 which is extended to 2016 were used to determine the changes in intra-seasonal rainfall characteristics. The spatial variations in the change in start of rainfall season (SOS) are illustrated in Figure 2.3. It can be observed that the whole country has experienced a change in the start of the season. In fact, the greater part of the country now experience a late start to the season by as much as 18 days while some regions experience an early start to the season. Typical areas that have experienced late start to the rainfall season include Mashonaland Central, Mashonaland East, Mashonaland West, Matabeleland North, northern parts of Midlands and the greater part of Manicaland. In contrast, Matabeleland South, Masvingo and southern parts of Matabeleland North have now shifted towards an early start to the rainfall season.

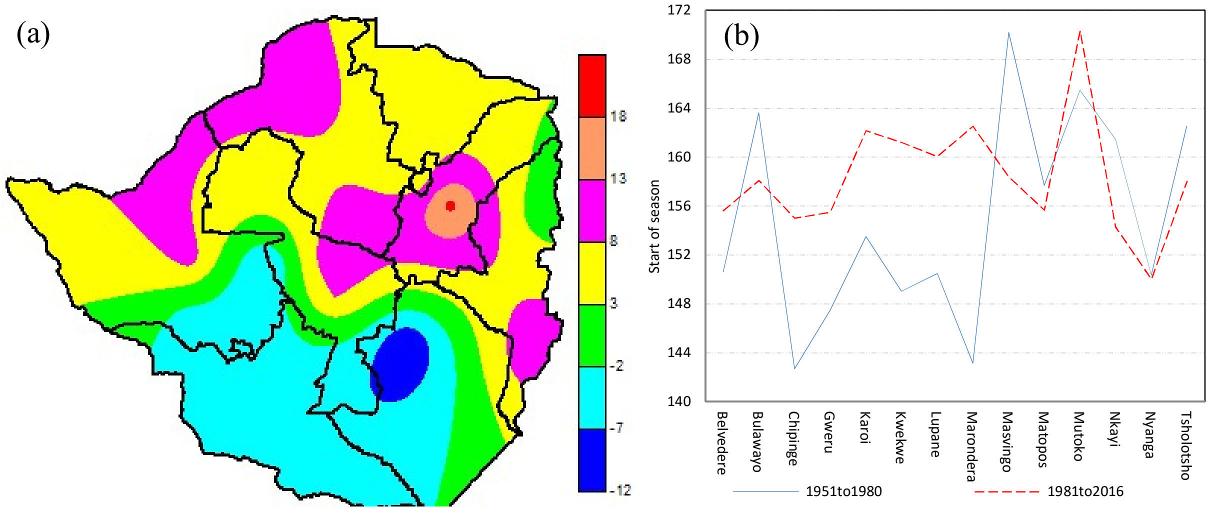

Figure 2.3: Changes in the start of the rainfall (mm) season between the period 1951 to 1981 and from 1982 to 2016 for (a) Zimbabwe and (b) selected towns. (*The rainy season is in Julien days*)

While the rainfall is starting late, the termination of the season is occurring early resulting in the contraction of the season (Figure 2.4) thereby affecting the types of crops and livestock that thrive in the respective areas.

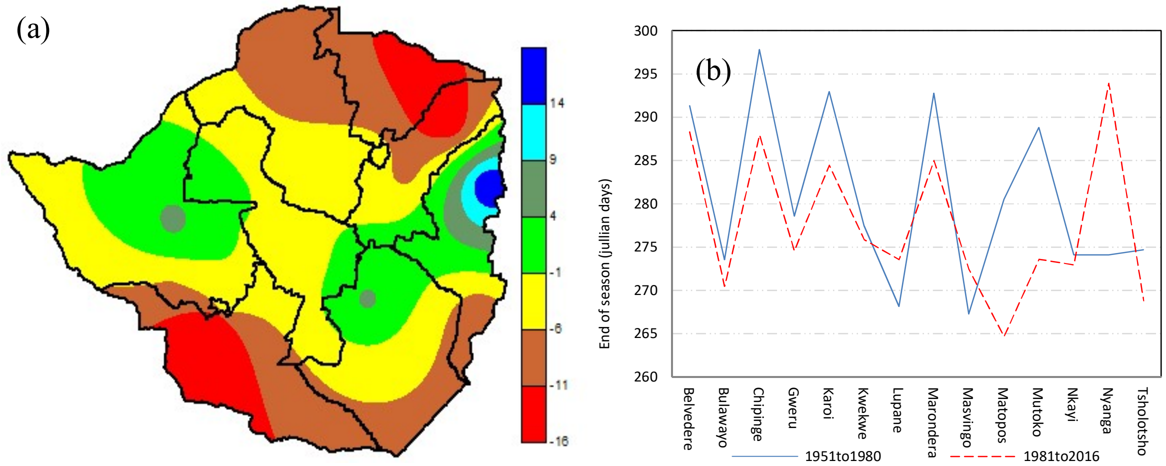

Figure 2.4: Spatial variation in the termination of the rainfall season between 1951 and 1981 and 1982 and 2016 for (a) Zimbabwe and (b) selected towns. *(Negative values indicate early termination while positive values imply late termination of the rainfall season. The days of the season are in Julian days)*

Figure 2.5 demonstrates that the greater part of the country has experienced a reduction in the length of the rainfall season of up to 30 days. An exception is the eastern highlands (around Nyanga) where the length of the season has increased by up to 15 days.

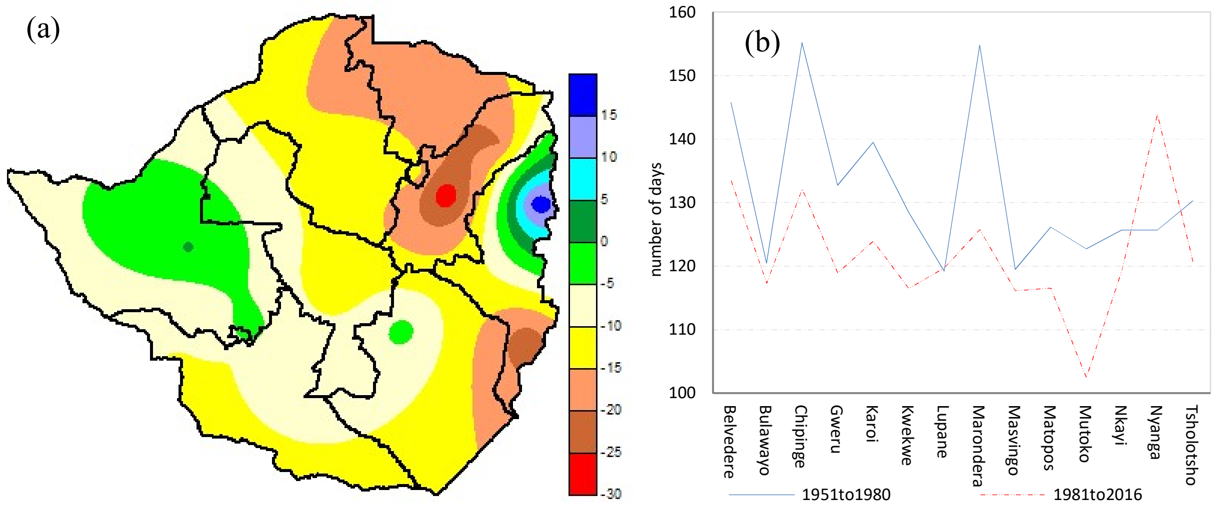

Figure 2.5: Spatial variation in the changes in the length of the rainfall season between the period 1951 to 1981 and from 1982 to 2016 for (a) Zimbabwe and (b) selected towns. *(Negative values indicate contracting whilst positive values imply expansion of the rainfall season)*

The season has also experienced a decrease in the number of rainy days thereby further affecting water availability during the growing season (Figure 2.6). In contrast, areas in the eastern highlands have actually experienced an increase in the number of rainy days of between 1 to 14 days.

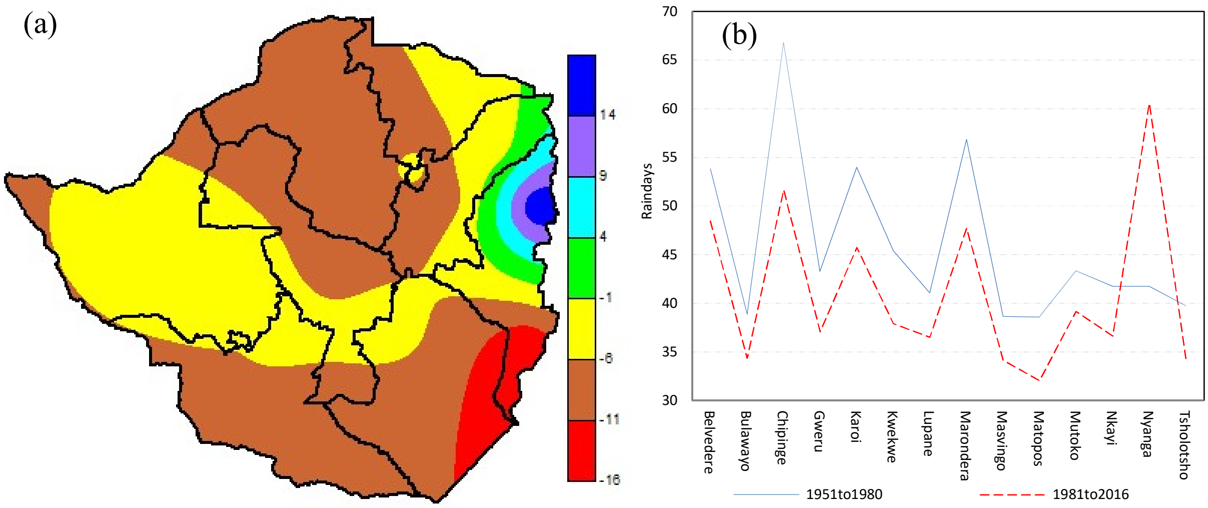

Figure 2.6: Spatial variation in the changes in the number of rain days between the period 1951 to 1981 and from 1982 to 2016 (a) Zimbabwe and (b) selected towns. (*Negative and positive values indicate the number of rain days below and above the average respectively)*

Apart from a reduction in the number of rainy days, every part of the country has experienced an increase in the length of dry spells except in the northern parts. Results of the analysis indicate that the country is now experiencing an increase in the number of dry spells during the rainfall season of up to 20 days (Figure 2.7).

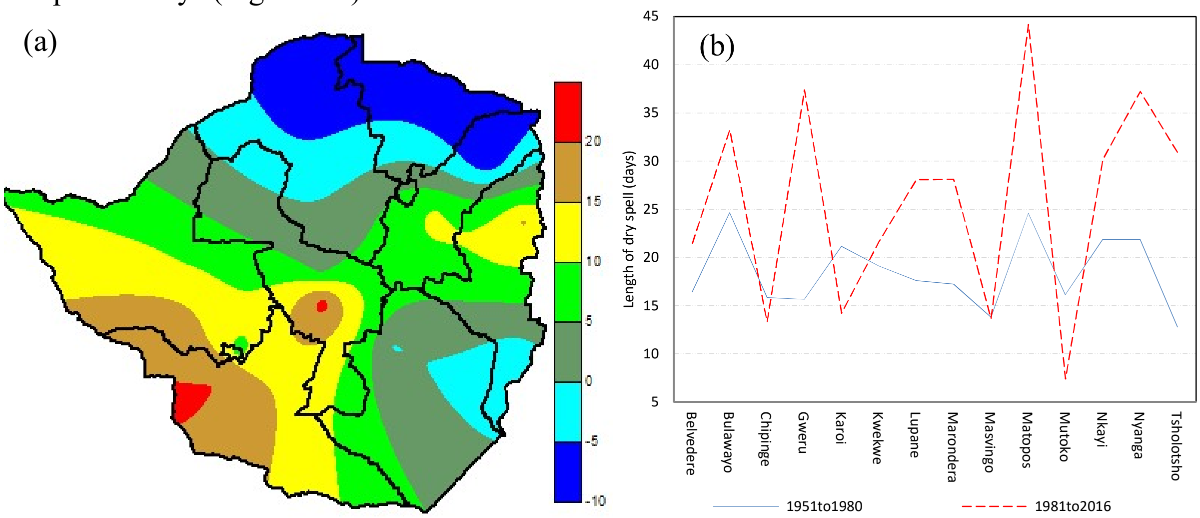

Figure 2.7: Spatial variations in changes in the length of longest dry spells between the period 1951 to 1981 and from 1982 to 2016 for (a) Zimbabwe and (b) selected towns. *(Negative and positive values indicate the length of dry spell days below and above the average length respectively)*

2.4 Trends in monthly rainfall patterns

Spatio-temporal analysis at the annual scale based on rainfall data from 1982 to 2018 show no significant trends in the months of January (Figure 2.8a), February (Figure 2.8b) and March (Figure 2.8c). In contrast, rainfall in the months of April (2.8d), May (2.8e) and June (2.8f), July (Figure 2.9a), August (Figure 2.9b) and September (Figure 2.9c) show a general significant decrease in rainfall. For instance, significant negative trends were detected in the central, western and northern parts of the country during the dry season i.e., April to September. Since Zimbabwe receives most of its rainfall during summer, these trends in the dry season do not significantly affect rain-fed agriculture.

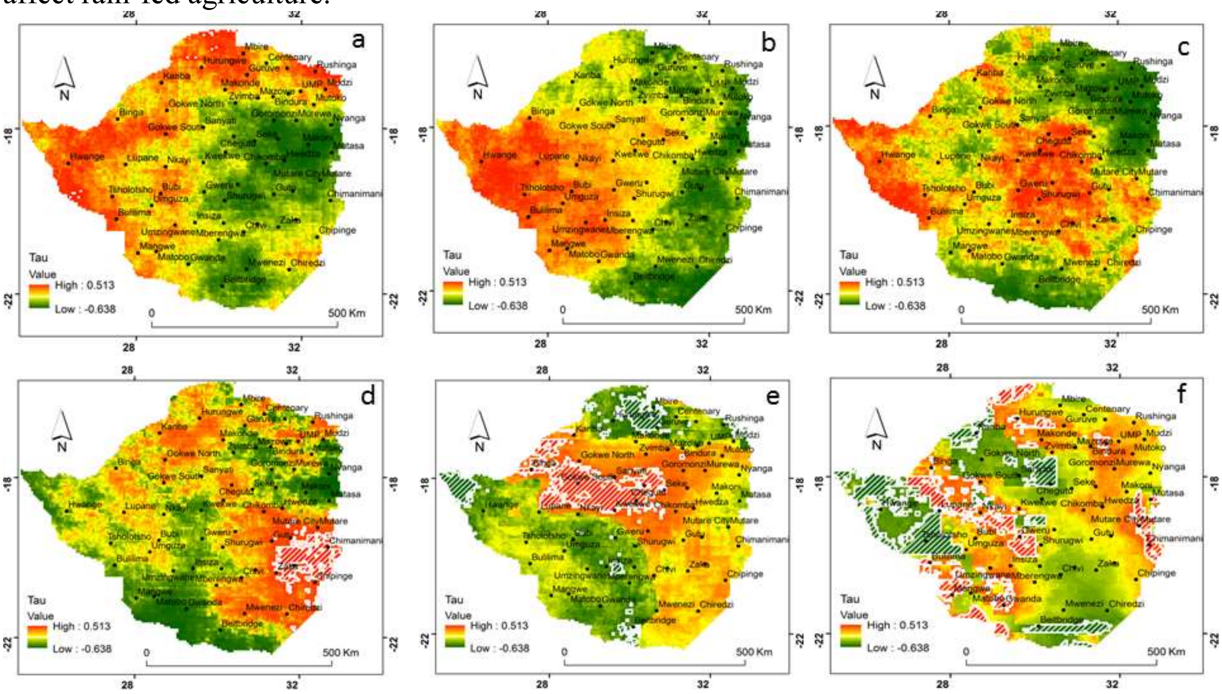

Figure 2.8: Spatial trends in monthly rainfall in January (a), February (b), March (c), April (2d), May (e) and June (f)

Significant positive trends in rainfall were observed in November and December but these were confined to central and western parts of the country (Figure 2.9).

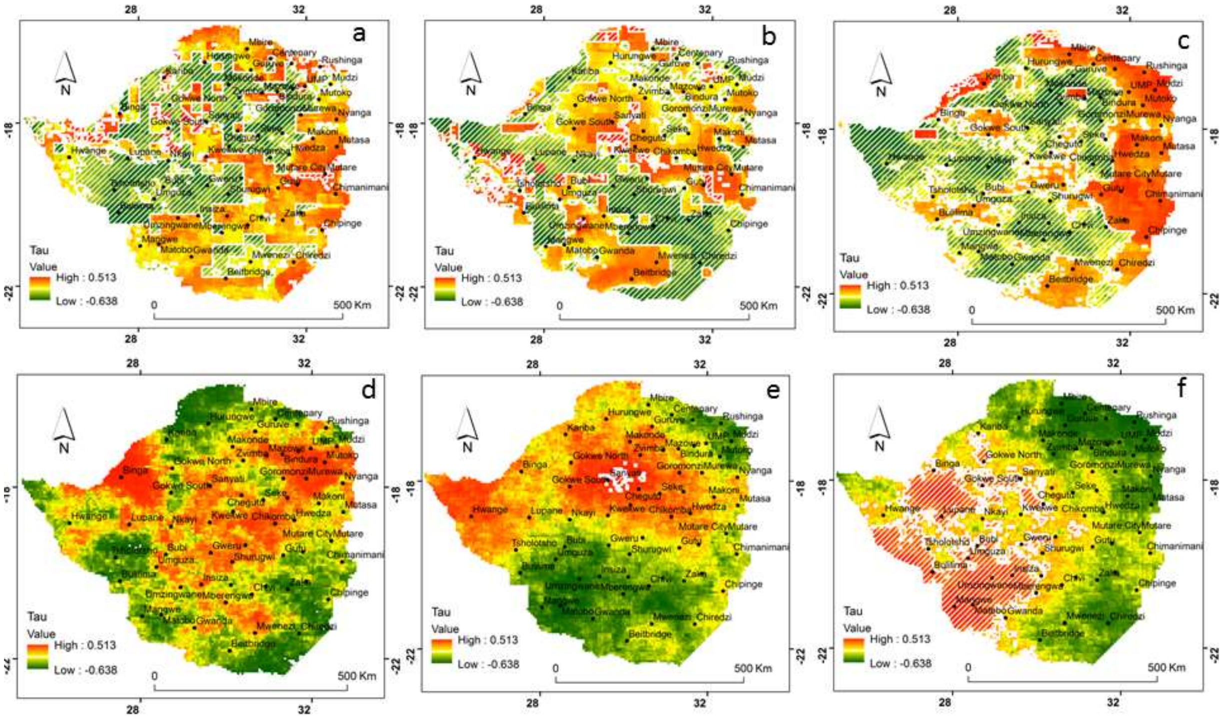

Figure 2.9: Spatial trends in monthly rainfall July (a), August (b), September (c), October (d), November (e) and December (f)

When rainfall is analyzed across the rainfall season (October to March), first half of the season (October to December), second half of the season (January to March) and at the annual scale, significant positive trends are detected in the central and western parts of the country (Figure 2.10). Although negative trends in rainfall were detected in the north, eastern and southern parts of the country, the decreases were not statistically significant. Central to western parts of the country experienced a significant increase in annual and seasonal rainfall.

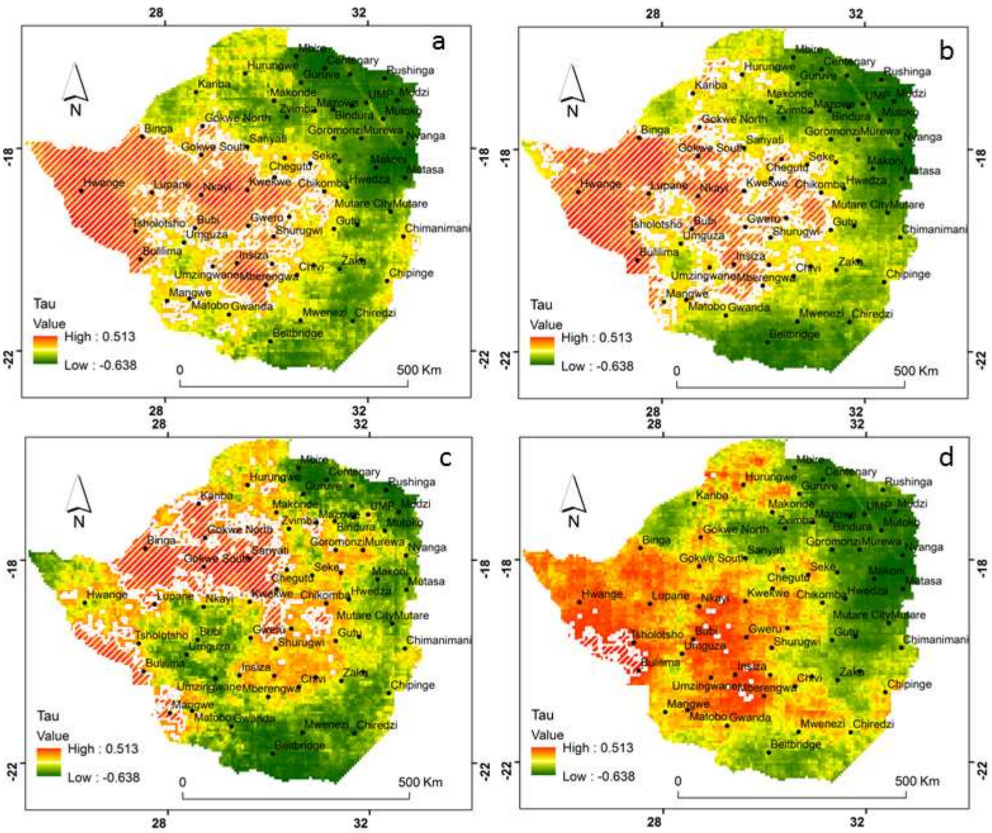

Figure 2.10: Spatial trends in annual (a), seasonal (b) first half season (c) and second half season (d) rainfall

2.5 Regime Shift in temperature

To test whether there are any significant changes in temperature since the delineation of agriculture zones by Vincent and Thomas (1960), the pre-shift period was divided into two epochs of 15 years, i.e., 1951 to 1965 (the period largely coinciding with initial AEZs) and the period 1966 to 1981 (the period immediately after initial AEZs but before the shift). The post-shift period covers 1982 to 2001. Results of the Student-t test analysis indicate that there are no significant differences ($p>0.05$) in the pre-shift epochs in terms of minimum and maximum temperatures (Figures 2.11 and 2.12) thereby suggesting similarities in temperature regimes during this period. However, a comparison of both minimum and maximum temperatures between pre- and post-shift periods show significant differences ($p<0.05$) in these two variables across the two periods except for Hwange, Kadoma and Henderson stations. Thus, these results suggest significant warming in maximum temperature (Tmax) across the country with magnitudes of increase in Tmax averaging 1° C.

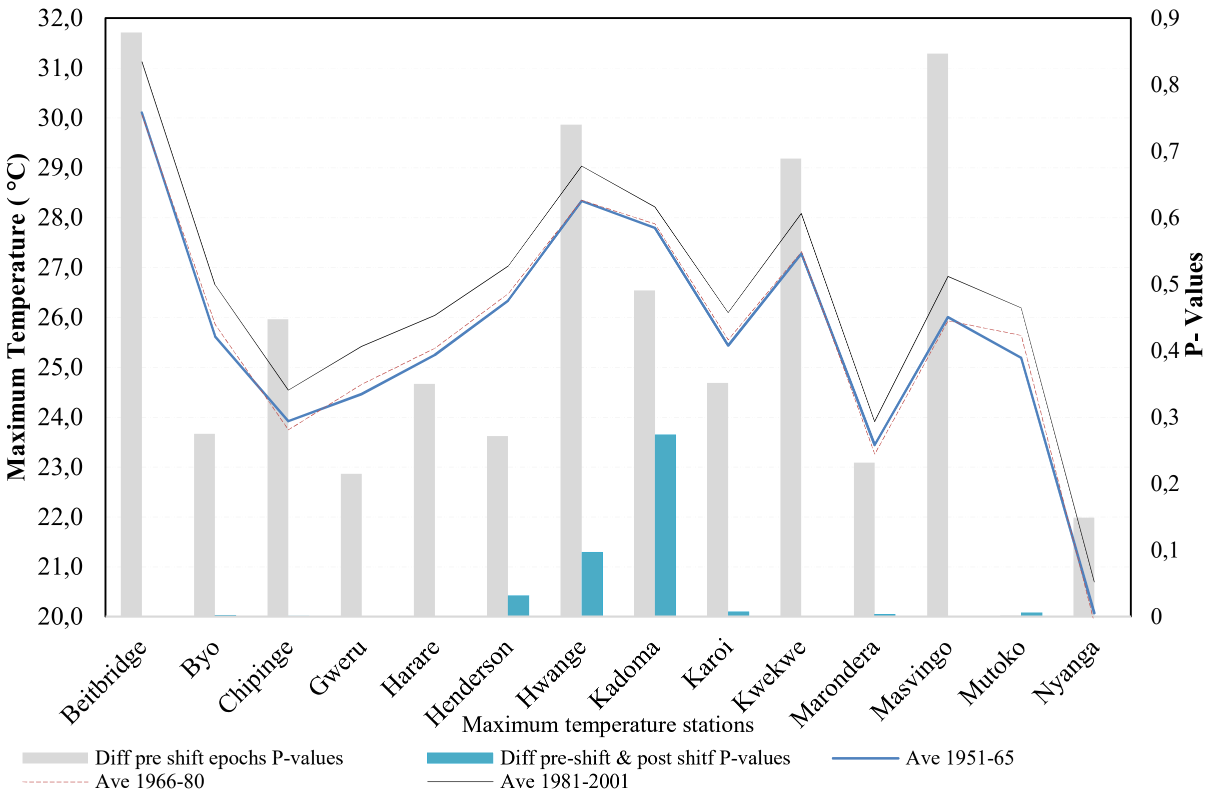

Figure 2.11: Mean differences in the maximum temperature between the pre-shift period (1951-1965 and 1966-1981) and the post-shift period (1982 to 2001). (*P-values are for the differences between the two means using a 2-tailed t-test)*

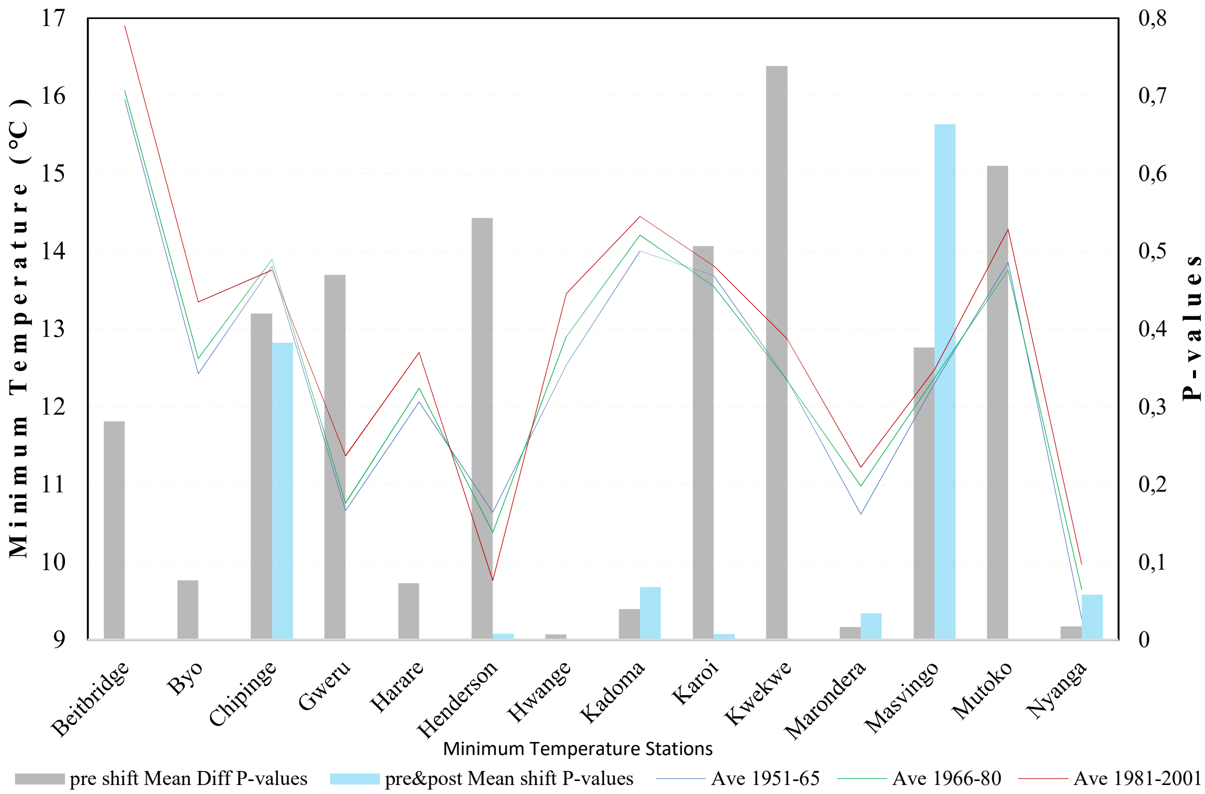

Figure 2.12: Mean differences in the minimum temperature between the pre-shift period (1951-1965 and 1966-1981) and the post-shift period (1982 to 2001). (*P-values are for the differences between the means using a 2-tailed T-test*)

2.6 Spatial Temperature trends

Mann-Kendall trend analysis indicates that monthly maximum temperature has generally increased but with significant positive trends in February, May and June in the central, eastern and southern parts of the country (Figure 2.13).

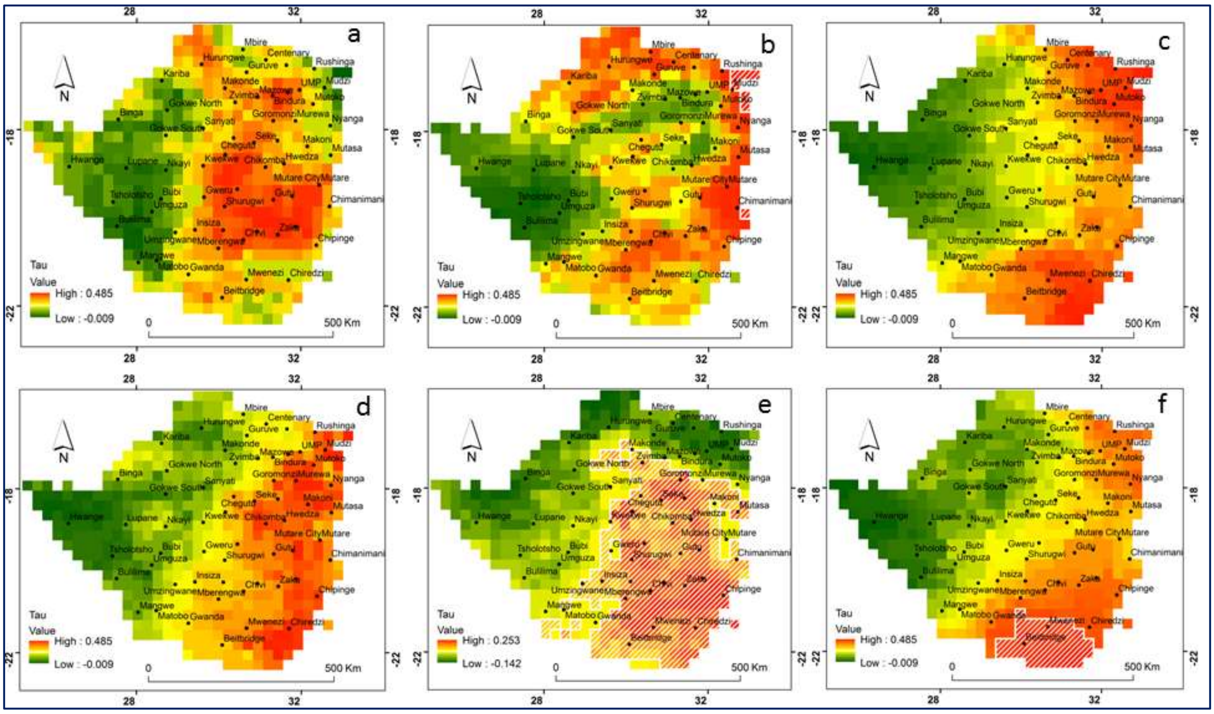

Figure 2.13: Spatial trends in monthly maximum temperature January (a), February (b), March (c), April (d), May (e) and June (f)

On the other hand, significant negative trends were detected in the month of August in the southern parts of the country around Beitbridge (Figure 2.14).

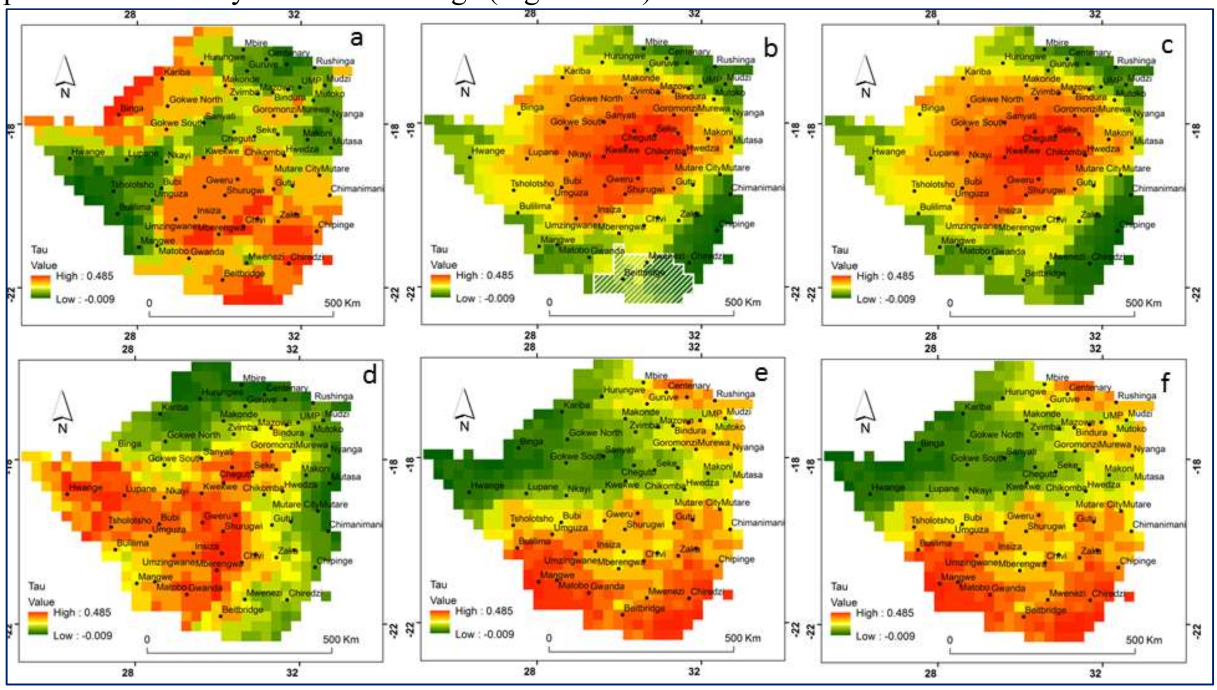

Figure 2.14: Spatial trends in monthly maximum temperature July (a), August (b), September (c), October (d), November (e) and December (f)

The results of monthly minimum temperature for the period of 1989 to 2012 are shown in Figures 2.15 and 2.16. Significant negative trends in temperature were observed in the winter months (May, June and July) suggesting that winter months are getting colder. Areas in which negative trends in minimum temperature were detected include Hurungwe, Guruve, Lupane and Mbire.

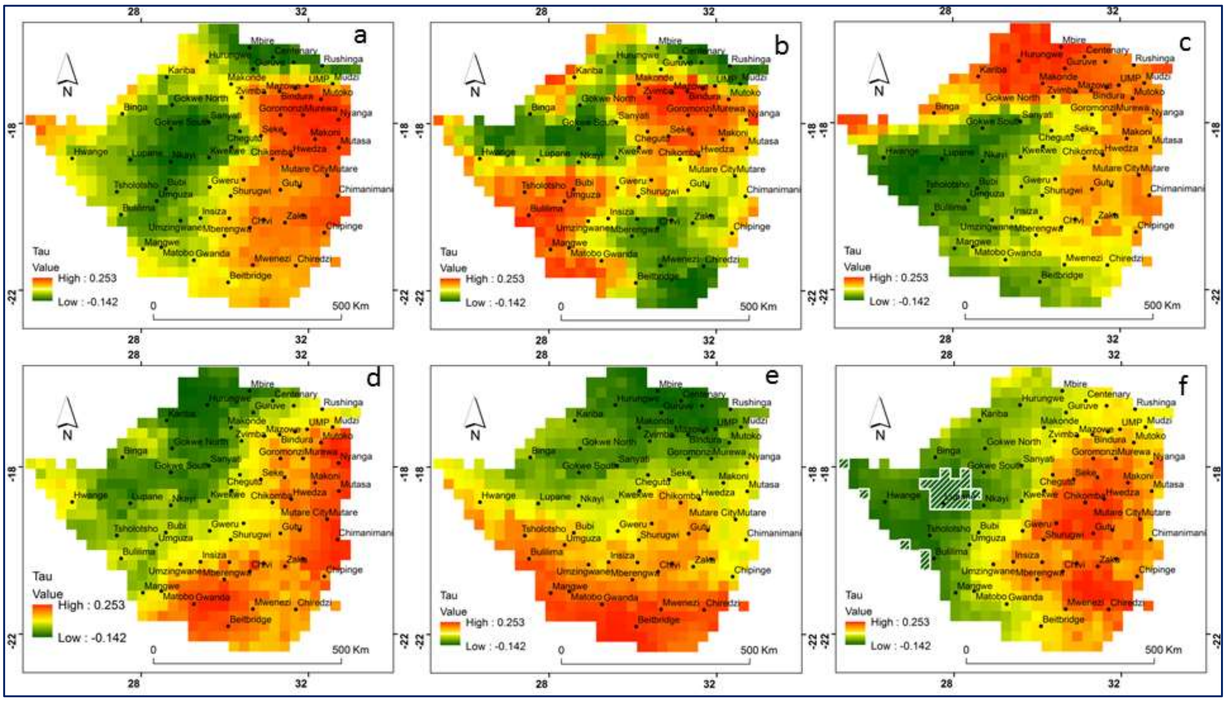

Figure 2.15: Spatial trends in monthly minimum temperature January (a), February (b), March (c), April (d), May (e) and June (f)

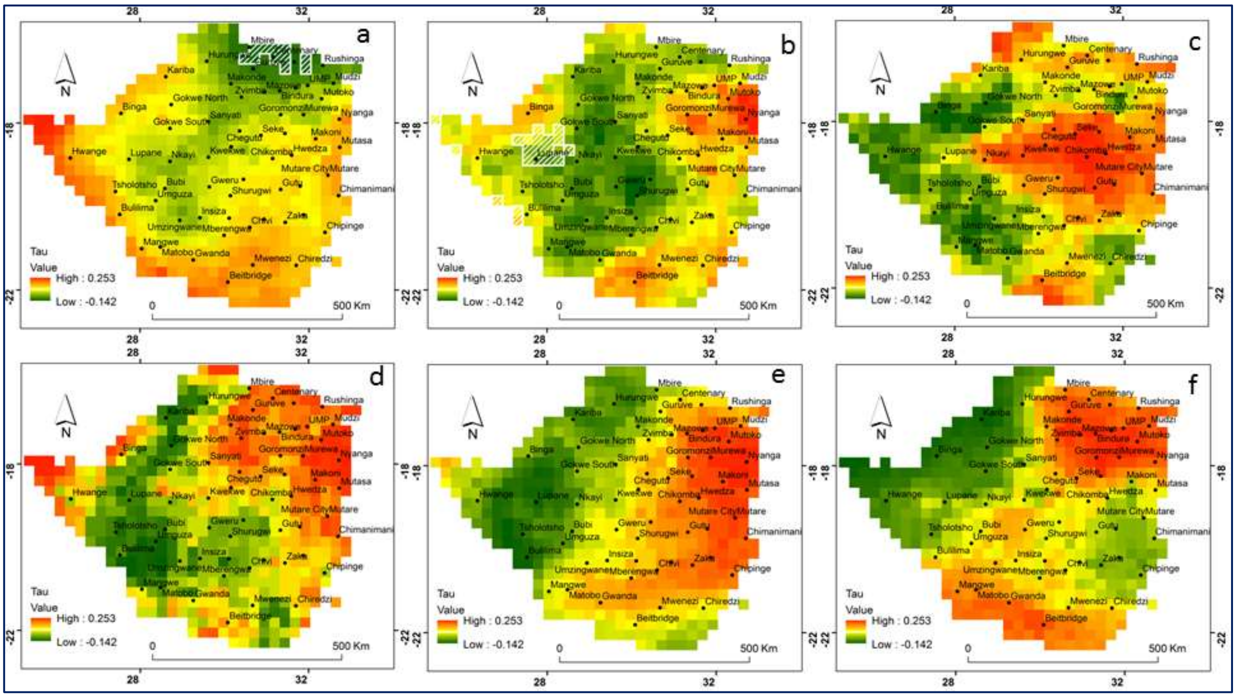

Figure 2.16: Spatial trends in monthly minimum temperature July (a), August (b), September (c), October (d), November (e) and December (f)

On an annual and seasonal scale only areas around Lupane, Hwange and Tsholotsho showed a significant decreasing trend in annual minimum temperature (Figure 2.17c). All other areas did not exhibit any significant change in both annual and winter season minimum and maximum temperatures.

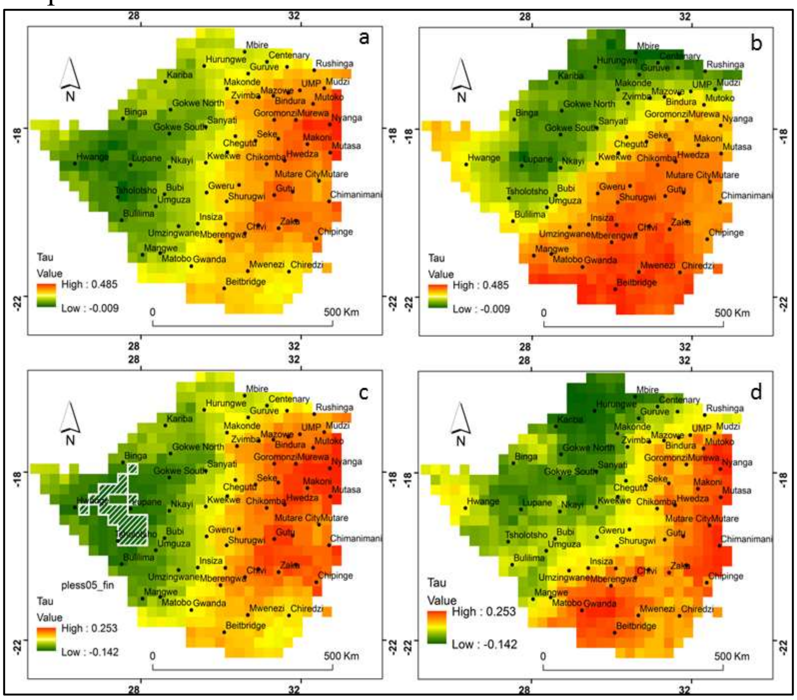

Figure 2.17: Spatial trends in annual maximum temperature (a), maximum winter season temperature (b) annual minimum temperature (c) and minimum winter season temperature (d)

2.7 Shifts in Potential Evapotranspiration

The Climatic Research Unit (CRU) Time-series (TS) dataset of potential evapotranspiration (PET) downloaded from the CRU website *https://crudata.uea.ac.uk/cru/data/* was used as a proxy to examine if there was a shift in evapotranspiration. The specific PET dataset used in trend analysis was the CRU CY data version 4.04 which consists of monthly average PET for the period 1901 to 2019 (Harris et al., 2020; Lu et al., 2011). However, for Zimbabwe data were available for the 1901 to 2017 period. The area-weighted means are used to calculate the monthly spatial averages. The other advantage of using this data is that it provides an independent data source to confirm the existence of the shift in the early 1980s. Figure 2.18 shows that PET is greater during the rainfall season than during the relatively dry winter period. When analyzed according to epochs, it is realized that the means of the pre 1942 epoch and that for 1943 to 1981 were not significantly different for all three timeframes considered. However, a significant shift in the mean is visible around 1981 for the 1942 to 1981 and post 1981 epochs. This demonstrates that throughout the 20^{th} century, a significant shift was only found around 1982. This is quite interesting as the shift also coincides with that in temperature and rainfall. This observation increases the confidence in selecting the post 1981 period for determining climate change induced shifts in the country's AEZs developed by Vincent and Thomas in 1960. It is also noted that all the epochs did not have any significant trends implying that the climate was changing in regimes rather than gradually. A shift to higher PET values indicate more water that is lost to the atmosphere instead of being available for plants and animals.

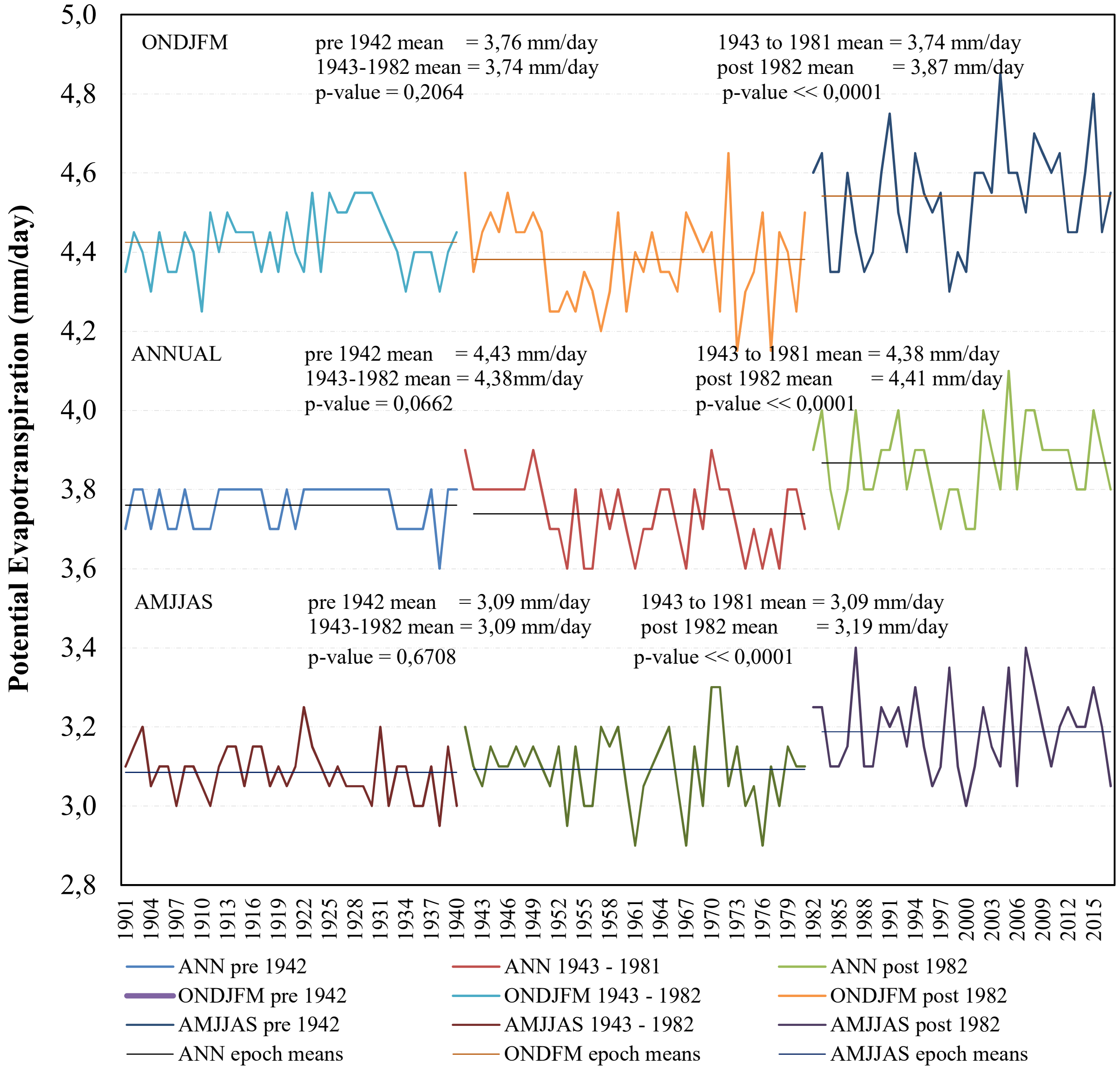

Figure 2.18: Temporal manifestation of the PET for the rainfall season (ONDJFM), winter season (AMJJAS) and the annual period for Zimbabwe from 1901 to 2017

The analysis is done for pre 1942, 1943 to 1982 and the post 1982 epochs with the epoch means shown as straight lines. P-values for the differences between the means are shown in the insert.

The increase in PET during the ONDJFM coupled with a decrease in precipitation points towards increasing aridity and less moisture availability for crops across the country. Our results have important implications to cropping and rangeland systems in water limited regions like Zimbabwe, where evapotranspiration can account for as much as >95% of annual precipitation (Huxman et al., 2005). This is critical as evapotranspiration significantly influences productivity in mostly rain-fed agricultural systems that are characteristic of semi-arid regions. The progressively high PET values, coupled with a decline in rainfall result in moisture deficit at critical plant phenological stages leading to poor crop yields, particularly for the long season varieties (Lu et al., 2011). Moreover, rainfall events are confined to few and sporadic large storms during the rainfall season implying soil water storage is therefore an important resource during non-rainy periods. Unsustainable agricultural practices have resulted in soil degradation, particularly loss of organic matter, compaction, salinization and accelerated soil erosion, which further reduce water storage capacity of the soil. In particular, loss of soil depth due to soil erosion reduces water available for plant growth via a reduction rooting depth. For instance, given an optimal rooting depth a crop can survive through a dry spell and this reduces as soil depth decreases. On the other hand, increasing the amount of soil cover is essential to reduce loss of water through evaporation while carbon sequestration increases the soil's water holding capacity.

Therefore, the deployment of management practices that seek to reduce soil erosion, sequester or stabilize soil organic matter, reduce soil sealing and compaction are important to manage water storage in the semi-arid areas of Zimbabwe. Conservation Agriculture (CA) is considered as one of the viable options for addressing the challenges related to soil water storage capacity and improving climate resilience in general. However, despite receiving significant attention from policy makers, the adoption of CA is low and fragmented. Therefore, policies that create an enabling environment for the adoption of these sustainable land management practices are now critical than ever in light of the climate change instigated increase in PET.

2.8 Vegetation productivity trends

Climate, especially rainfall and temperature, has significant influence on vegetation through its effect on plant biochemical processes, growth rates, carbon allocation patterns, nutrient cycling among other key processes (Grime et al., 2008). Thus, changes in climate influence vegetation structure and productivity in a given geographic area. Given the strong relationship between vegetation and climate, it is expected that vegetation structure and productivity reflect changes in climate. In this study, trend analysis was performed on Advanced Very High Resolution Radiometer (AVHRR) derived NDVI, an indicator of plant productivity, to determine changes in plant productivity that can be attributed to climate change. To understand these changes, specific focus for determining trends was placed on areas with limited human impacts such as forest reserves, national parks and other protected areas based on their distribution in the AGRITEX (1984) AEZs. The focal areas for identifying trends were therefore Chirinda, Tarka and Stapleford forests, and Nyanga National Park (NR I), Doma (NR II), Umfurudzi and Hartley nature reserves (NR III), Gwai/Mbembesi, Ngamo, Dewure and Chirisa/Chizarira (NR IV) and Gonarezhou, Hwange and Mana Pools/Hurungwe (NR V).

Trends of NDVI at the monthly scale from January to April are shown in Figures 2.19. There are no consistent trends over the four months as the trends vary by place and by month at national level. The month of March is expected to have the most vegetation productivity as it is the peak of the growing season. Trends for this month show decreasing trends in vegetation vigour in all the areas of focus except for Chirisa/Chizarira and Gonarezhou which have parts showing a positive trends (Figure 2.19). This indicates that natural vegetation productivity peaks are decreasing in many natural areas across the country, which can be explained by climatic factors.

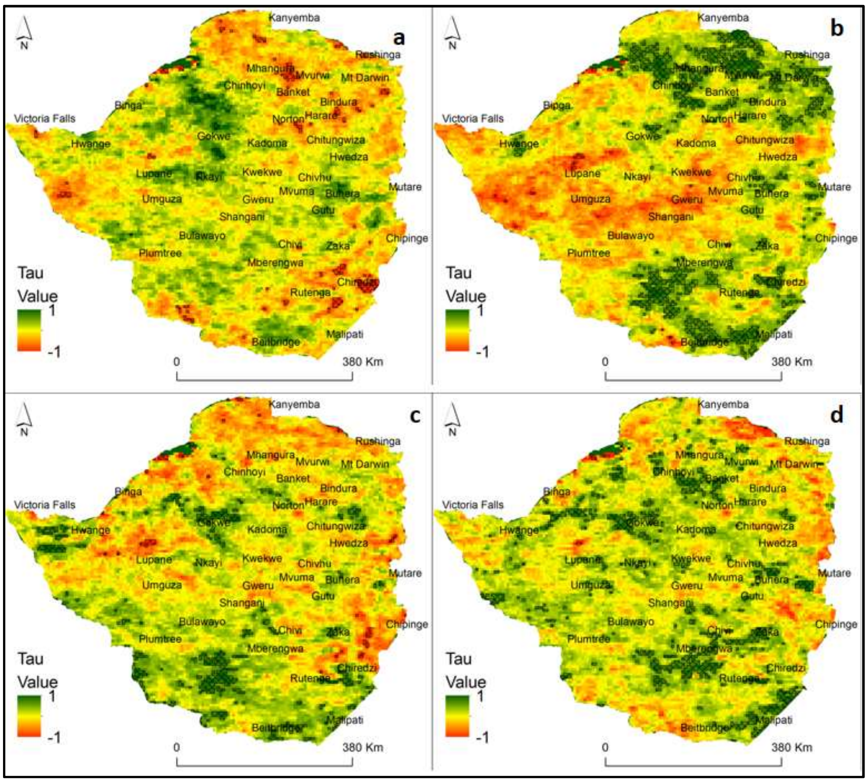

Figure 2.19: Spatial trends in NDVI in the months of January (a) , February (b) , March (c), and April (d)

The dry season in Zimbabwe traditionally starts in May to September and is expected to correspond to low vegetation vigour including in natural areas due to reduced influence of annual grasses and the deciduousness of the dominant trees. Assessment of vegetation trends in the early dry season show positive trends for most of the country for May but negative trends in June. The negative trends for June indicate that compared to previous years the levels of vegetation productivity in the country were getting lower than before. Although still negative, the trends are not as severe in the focus protected areas and national parks, which are indicative of climate-mediated changes compared to other land use types (Figure 2.20b). Except for Mana Pools/Hurungwe and Chirisa/Chizarira areas, the vegetation trends for July and August are positive, notably in Gonarezhou and Hwange.

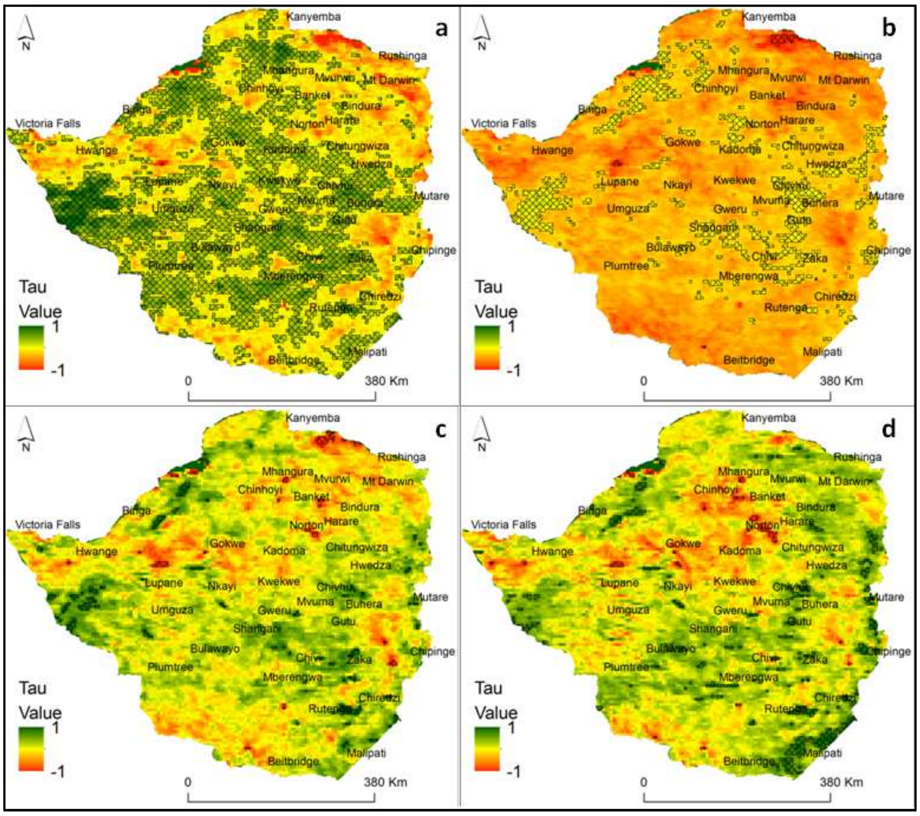

Figure 2.20: Spatial trends in NDVI in the months of (a) May), (b) June , (c) July and (d) August

The critical period for vegetation stress is the period between September and December which normally coincide with first rains that spur natural vegetation and crop productivity. Results for this period show that there are significant positive trends in vegetation in August coinciding with the flush shooting of deciduous species in miombo systems except for the central areas, which are however dominated by farmlands. Negative trends are observed for the months of October and December in most areas especially in all of the selected protected areas except Nyanga National Park (Figure 2.21b-d).

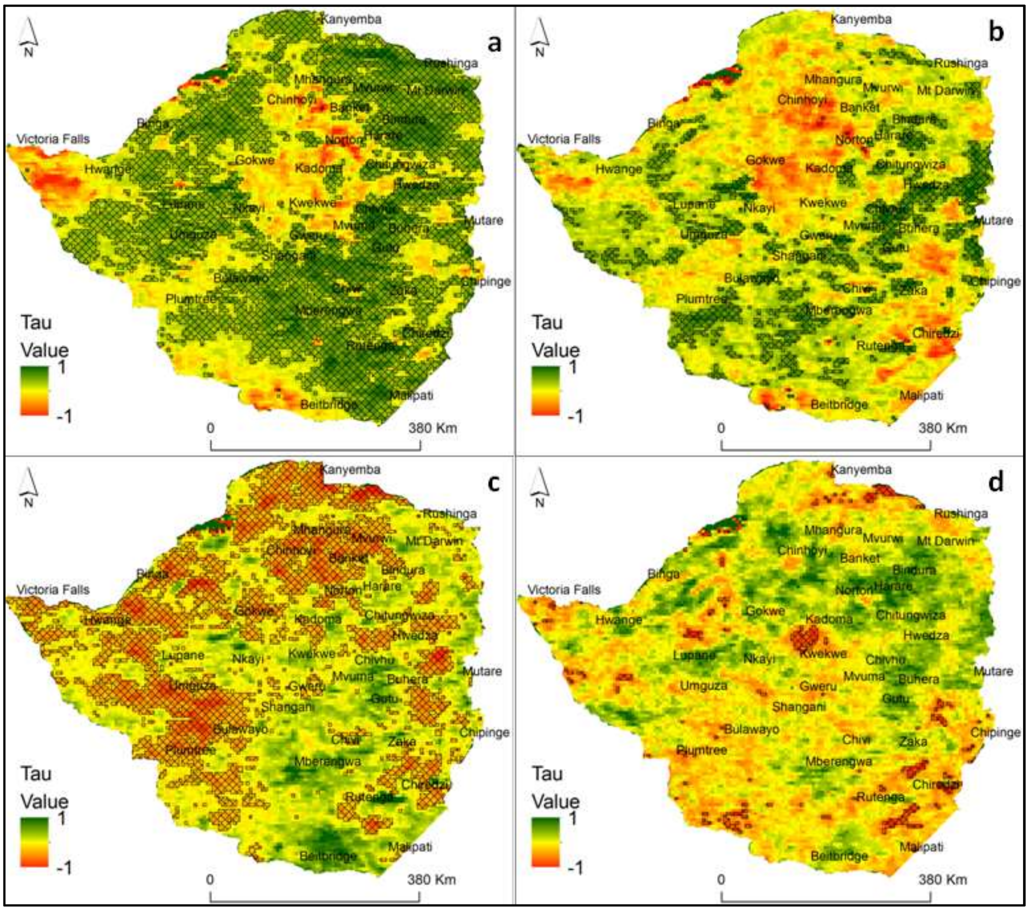

Figure 2.21: Spatial trends in NDVI for the months of a) September , b) October , c) November and d) December

The trends in annual NDVI are shown in Figure 2.22. These results show that the greater part of the country has experienced significant negative trends in vegetation. Most importantly, all focus sites across the regions are showing negative trends, with many of them being significant. These negative trends in annual NDVI trends are buoyed by the severe negative trends in the dry season (June and July) and the lean season (August to December).

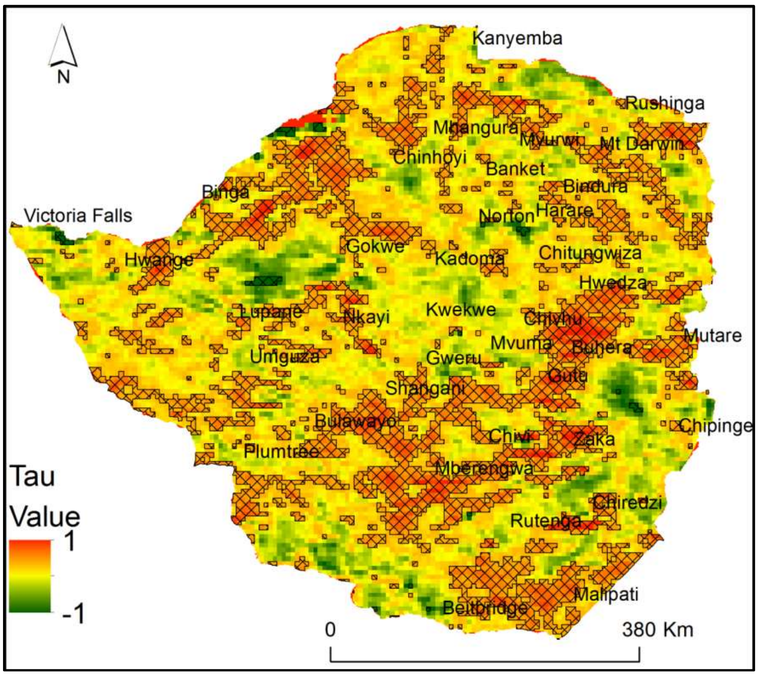

Figure 2.22: Spatial trends in annual NDVI. (Hatches show areas with significant NDVI trends)

The NDVI trend analysis show that the long term vegetation density and/or productivity is deteriorating in the country, and by only considering that this is happening in protected areas, it can be explained by changes in climatic characteristics. Important observations are that the dry season vegetation decreases are becoming more severe (June/July trends) while the recovery from the dry period both is now poor compared to before (September/October/November trends). These shifts in the vegetation regimes have serious implications in terms of ecosystems processes and other primary-production based systems. Overall, we conclude that the observed changes in the vegetation regimes especially in focus areas indicate that the natural ability of the biophysical environment to support and sustain vegetation is decreasing in most areas and shifting in a few other areas. It is known that climate (temperature and rainfall) are the dominant factors in the biophysical environment, this corroborates the results in Section 2.2.2 about changes in these parameters. These observed changes in vegetation in regions that are considered to have been generally undisturbed by human influence becomes an important indicator of the changes in natural regions of Zimbabwe as vegetation is an important variable for condition/state of the environment.

2.9 Soils of Zimbabwe

The distribution of soils of Zimbabwe (Figure 2.23) are strongly influenced by geology or parent materials and amount of rainfall received in a particular area. The type and amount of clay which determine the soil's chemical and physical characteristics are largely determined by the nature of parent materials and the degree of physical and chemical weathering the soils have undergone. Degree of weathering and leaching depends on the amount of rainfall received in an area. Thus, the less (highly) weathered soils are restricted to AEZs receiving low rainfall amounts. As such the strong relationship between climate and the soils has resulted in the significant similarities between the soil type spatial patterns and the AEZs of the country as depicted in Figure 2.23 and 1.1 respectivley. The soild of Zimbabwe are divided into four orders according to the Zimbabwe Soil Classification System, which are Amorphic, Calcimorphic, Kaolinitic and Natric. The amorphic order has two soil groups, lithosol and regosol; calcimorphic two groups, vertisol and siallitic; kaolinitic three groups, fersiallitic, paraferrallitic and orthoferrallitic and lastly the natric order has one soil group, sodic. Soils groups in the Amorphic, Calcimorphic and Natric orders are relatively less weathered and leached and generally but not exclusively are found in areas of low rainfall. Soil groups in the Kaolinitic order are relatively more weathered and leached. Fersiallitic soils are moderately weathered and leached and paraferrallitic soils intermediately weathered and leached whilst orthoferrallitic soils are highly weathered and leached occurring in AEZs of high rainfall. Fersiallitic soils are found in areas with mean total annual rainfall around 850 mm and orthoferrallitic soils occur in areas receiving greater than 1000 mm per annum and paraferrallitic soils occur in areas receiving rainfall intermediate of the two.

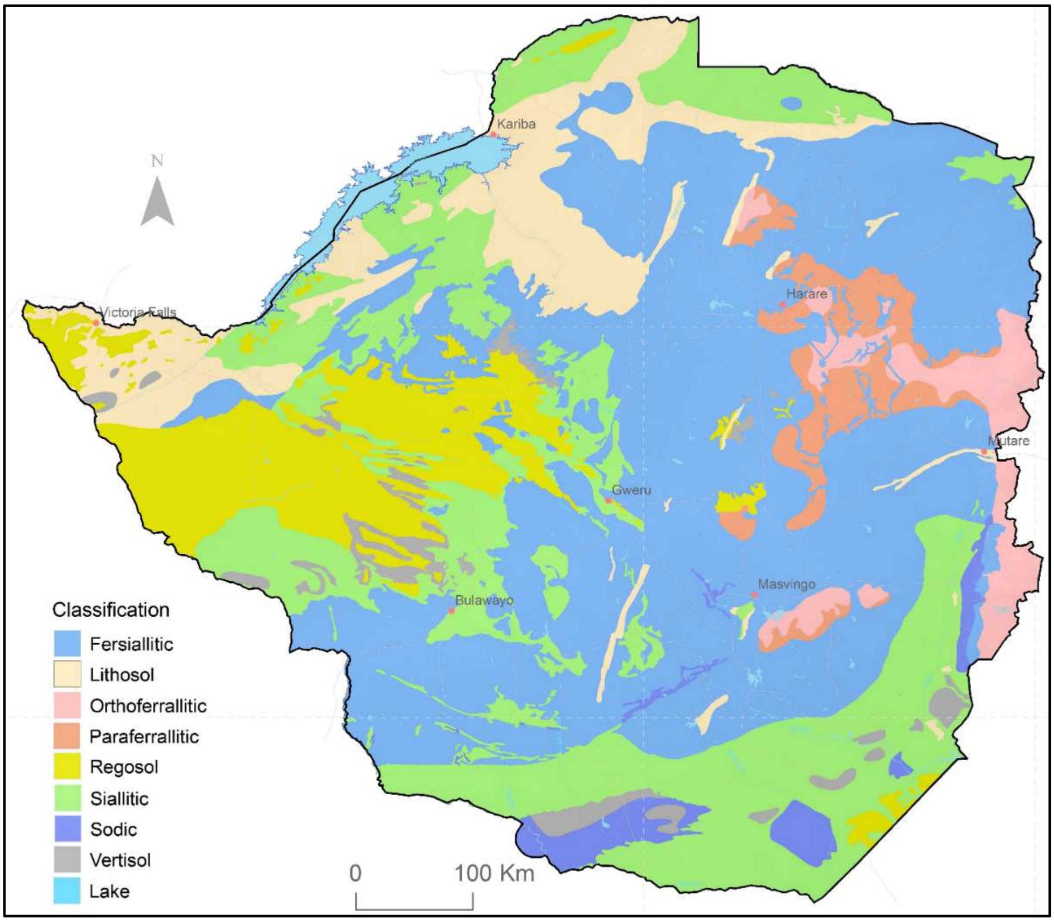

Figure 2.23: Spatial distribution of Soils in Zimbabwe

It is however important to note that studies have shown that some soils in Zimbabwe, have undergone significant degradation due to loss of significant quantities of organic matter (Mtambanengwe & Mapfumo, 2005), and soil erosion (Soropa et al., 2019). Water that is available for plant growth is strongly affected by rooting depth, which is a function of soil depth: Plant available water (PAW) = (field capacity-wilting point) × effective rooting depth. In this regard, although the soil resource can be considered static for the purpose of the current work, some significant changes have occurred since the development of the AEZs in the 1960s, which tend to have a bearing on available water capacity of the soils. The water holding capacity of a soil is strongly affected by soil texture (clay content), structural effects (organic matter content, soil depth and compaction, crusting and sealing) and the salinity level. While, the clay content could be relatively static, soil degradation, particularly loss of organic matter (Mtambanengwe & Mapfumo, 2005), compaction, salinization and accelerated soil erosion, are threatening the soil resource's water holding capacity. Soil organic matter plays a key role in improving the soil water holding capacity. A reduction in soil organic matter content therefore decreases soil available water capacity. On the other hand, a compacted soil will have low porosity and low water holding capacity. Meanwhile, soil salinity reduces plant available water since salts have strong attraction for water molecules. Soil erosion reduces rooting depth and hence plant available water. This means that taking two soils A and B that have the same texture but having differences in either organic matter content, level of compaction, salinity and soil depth would have different water holding capacities (available water capacity), leading to differences in soil moisture availability periods even if the two soils receive the same rainfall regimes. Table 2.1 shows the characteristics of the soil groups, their land use and limitations while Figure 2.22 shows their distribution.

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Table 2.1: Major characteristics of the soil groups of Zimbabwe

Soil Group	**Genesis**	**Occurrence and distribution**	**Land-use and limitations**
Lithosol	Have not had adequate time to develop beyond their present depth either because of climatic conditions or other environmental factors.	May occur extensively on flat areas especially in areas underlain by rock which is relatively resistant to weathering such as southern part of Zimbabwe. In higher rainfall areas, lithosols are associated with broken or hilly terrain where the relatively high rate of erosion is partly responsible for the shallowness.	Because of shallowness, the soils are not arable. Most common use is as game reserves and national parks.
Regosol	Mostly developed from Kalahari sands. Soils are poor in nutrients and nutrients are supplied by extensive groundwater below the sands. Vegetation consists of fairly closed woodland in some areas whereas in others, it is thick thorny bush.	Extensive in the western part of the country from around Nyamandlovu just north of Bulawayo to Victoria Falls including parts of Hwange, Lupane, Nkai and some parts of Gokwe and the belt extends into Botswana.	Major limitations are their low nutrient reserves and high permeability associated with low water holding capacity. Traditional and hardy crops such as sorghum, finger millet, pearl millet, and maize varieties requiring less than 120 days to maturity can thrive in these areas. Other uses include indigenous forests, game

Soil Group	Genesis	Occurrence and distribution	Land-use and limitations
			reserves and national parks.
Vertisol	Major occurrences developed from jurrassic basalt. Major occurrences in low rainfall areas. Relative aridity of the areas result in limited weathering and leaching of weathering products. Also found in the higher rainfall areas as part of soil catenas where soils developed from mafic parent materials. Soils occupy lowerslope positions where there is accumulation of leached weathering products.	Major areas of vertisols are associated with basalt and mudstone formations. Chisumbanje has the most extensive area of vertisols with an area of about 40,000 ha which extends into Mozambique. Other areas include parts of Gokwe and the Zambezi valley.	Forms the best irrigable land in the semi-arid parts of the country where they are extensive. Main crops are winter wheat, cotton and sugar cane. Soils are inherently fertile, rich in bases, although they require moderate applications of nitrogen and phosphorus fertilizer to ensure economic yields. Main management challenges stem from the high amounts of expansive 2:1 clay minerals that make the soils very sticky when wet and very hard when dry.
Siallitic	Main features determining their occurrence are climate and topography. Predominant in low rainfall areas hence are relatively unleached with high base status. Like vertisols in high rainfall areas, they are also found as part of soil catenas where soils are developed from mafic parent materials. Soils occupy lower to mid-slope positions where there is accumulation of leached weathering products.	Predominant in the Save-Limpopo and south and south-east low veldt, semi-arid south and south west and in the Zambezi Valley. Also common along river valleys, where they are irrigated.	Siallitic soils in Zimbabwe have very high agricultural potential especially where water is available for irrigation. Ranching of cattle and wildlife is an important activity in areas where water is not readily available.
Fersiallitic	Consists of moderately leached soils with kaolinite the dominant mineral and some 2:1 lattice clays and appreciable amounts of free sesquioxides. Some reserve of weatherable minerals is present in most fersiallitic soils. In low rainfall areas fersiallitics are generally limited to siliceous parent material and become confined to mafic parent materials as rainfall increases.	These are the most extensive soil group in Zimbabwe. Agriculturally they are the most important in the country because of the widespread occurrence and diverse uses to which they are put.	Their large areal extent, wide range of properties and moderate fertility coupled with the fact that they occur in moderate to high rainfall areas makes them the most important soil group in terms of crop production. Zimbabwe's maize belt is covered by these soils and soils from siliceous parent

Soil Group	Genesis	Occurrence and distribution	Land-use and limitations
			materials are important for tobacco production.
Paraferrallitic	Derived in situ from relatively highly leached granite parent material. Clay mineralogy is dominated by mostly kandites and substantial amounts of sesquioxides. In the previous classification, this soil order generally occurred in areas with rainfall ranging from 900 mm to 1,250 mm per annum.	Found in association with granite rock. Occurred on upland positions on the catena on the central plateau at relatively high altitudes. Most extensive belt occurs just outside Harare, eastward through Epworth, Marondera, Headlands into Rusape with long wide belt extending south-west through Hwedza to the Range (Chivhu) eastward again to Buhera.	The group is characterised by low fertility. They form some of the best tobacco soils in high rainfall areas. Also ideal for maize and groundnuts production. In all cases application of fertilizers especially nitrogen and phosphate is recommended.
Orthoferrallitic	Very deep, freely draining soils resulting from deep weathering of underlying rock, followed by intense leaching of bases, accelerated by high rainfall in the areas where they occur. Represents soils that have undergone different degrees of weathering by different pathways and variations appear to be a function of annual rainfall and parent material. Soils generally have relatively high clay content which is inert because of high amounts of kandites and sesquioxides.	Occurs in areas with annual rainfall greater than 1,000 mm per annum. Major areas are the Eastern Highlands, Bikita-Ndanga Highlands in the south-east of the country and isolated highland areas with locally high rainfall such as around Mvurwi, Marondera and Headlands.	Because of their relatively poor nutrient status, they are not used for normal cropping and are largely taken up by forests and growing tree crops especially tea and coffee. Dairying, based on both natural veldt and sown pasture, is another important activity.
Sodic	The soil group includes weakly and strongly sodic soils as well as saline-sodic soils with a lower exchangeable sodium percentage limit of 9. The main factor responsible for formation of this group is parent materials relatively rich in sodium-releasing weatherable minerals, the most important being sandstones, mudstones, grits and conglomerates of Karoo age and younger gneisses and granites of the basement complex.	Extensive areas coincided with areas of lowest rainfall in the Zambezi and Limpopo-Save Valleys. Also occurred in scattered localized small patches where mean annual rainfall was below 800 mm. Distribution is affected by parent material rich in sodium-releasing feldspars.	Not favoured for agriculture or engineering because of their undesirable chemical and physical properties. Largely impenetrable to roots and impermeable to water.

Source: (Nyamapfene, 1991; Thompson & Purves, 1978)

2.10 Summary

Strong association exist between soil and rainfall, rainfall and vegetation, and, soil and vegetation in Zimbabwe to such an extent that these agro-climatic relationships were largely the basis for the division of the country into five Natural Regions by Vincent and Thomas (1960). As such the objective of this chapter was to determine whether and to what extent climate parameters i.e., rainfall and temperature as well as vegetation productivity are changing as a first step towards revising the existing AEZs that were derived nearly 60 years ago. The influence of the underlying soils was inferred from the discussion on the characteristics and distribution of the soil resources of Zimbabwe. Results of this study indicate that there are significant trends in the climate variables assessed in the study. First, long term temperature and rainfall data indicate that there was a significant shift in the two climate parameters that was detected around 1981. Although there were variations in the direction of change in rainfall distribution across space and over time, the following general observations were made:

- late onset, early cessation and contraction of the rainfall season
- an increase in the number and length of dry spells, and,
- a decrease rainy days

Moreover, results of trend analysis based on temperature indicate a general increase in both maximum and minimum temperatures across the country for most months. Spatial analysis of rainfall time series indicated an eastward drying pattern while a significant seasonal and annual wetting trends was recorded from the central to the western parts of the country. Overall, results of climate analysis points towards climate change and the need to adjust farming systems in light of these changes. Time series analysis of NDVI showed that vegetation productivity in protected areas and generally across the country has decreased. The soils can be considered to be static for the purpose of AEZ, and they are divided into eight (8) soil groups distributed based on parent material and amount of rainfall received. As crop and livestock production are likely to be differentially affected by these changes, there is need to consider a suite of crops and livestock that thrive under the changed climate.

CHAPTER 3 : MATERIALS AND METHODS

3.1 Data Sources

Remotely sensed and in-situ observations were selected based on previous studies and expert knowledge of how they influence agricultural productivity. The variables considered in this exercise are rainfall quantity and quality attributes (seasonal rainfall amounts, start of season, length of dry spells, and maximum, mean and minimum temperature) soil parameters (including soil types and chemistry) and elevation data. *In-situ* meteorological data were obtained from the Meteorological Services Department (MSD) of Zimbabwe at daily, monthly and annual scales. The span period of the periods varied depending on the year the station was established and data availability. Although *in-situ* data is regarded as more accurate, it lacks adequate spatial coverage due to limited number of weather stations which also have variable length of historical archival data. As a result of the limitations of in-situ measurements, remote sensing derived data was used to compliment in-situ data. Remotely sensed data particularly from space-borne platforms offers wide spatial coverage and has acceptable temporal resolution. To improve the application of data derived from remote sensing, it was compared with observed measurements from ground stations. In this exercise, remotely sensed temperature data from the WATCH-Forcing-Data-ERA-Interim (WFDEI were downloaded freely from *https://rda.ucar.edu/*). The daily precipitation data from 1982 to 2018 were obtained from Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) at *https://www.chc.ucsb.edu/data/chirps*). The spatial resolution of the data is 50km (0.00227 degrees). Correlation analysis and bias correction were applied to compare the rainfall estimates from CHIRPS to in-situ observations. In addition to rainfall and temperature, elevation data were also used in this study. The elevation data were derived from the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) at a resolution of 30 m and freely downloaded from the United States National Aeronautics and Space Administration (NASA) website at *https://asterweb.jpl.nasa.gov/gdem.asp*. The elevation data were compared to field elevation data from meteorological stations as well as GPS measurements taken during fieldwork. The soil data were downloaded from the FAO website. All *in-situ* point measurements were converted to GIS format before continuous surfaces were created through kriging technique.

3.2 Comparison of satellite derived elevation and climate data with field measurements

The results of comparison between elevation derived from ASTER and field measurements are illustrated in Figure 3.1. The results indicate that there is strong positive correlation between satellite derived and in-situ elevation measurements in Zimbabwe. While there was generally strong agreement between elevation derived from ASTER and field measurements, for some areas there were gross disagreement between the two datasets (outliers). The strong agreement between ASTER derived DEM and observed elevation could be explained by the high precision of the ASTER data which about 30 m.

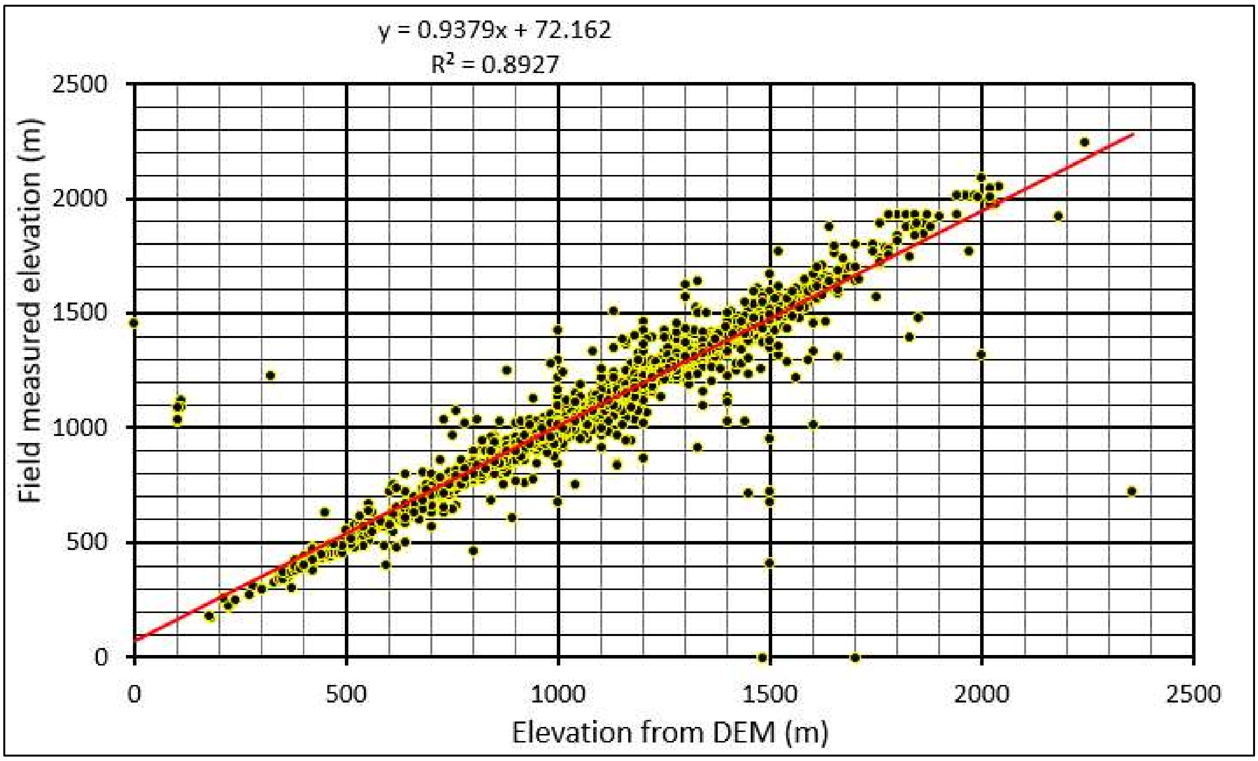

Figure 3.1: Correlation of ASTER derived elevation and in-situ elevation measurements in Zimbabwe

The application of bias correction to ASTER derived elevation which was expected to improve the accuracy did not yield any significant change in the difference between the two data sets (Table 3.1). Hence, it was deemed best to use DEM data without bias correction as the data correlated positively with field observations.

Table 3.1: Accuracy assessment of ASTER DEM data in Zimbabwe

	Raw satellite retrieval	Bias corrected
Bias (m)	105	-154
Mean Absolute Error (m)	21	124
Mean Percentage Error (%)	2	12
Root Mean Square Error (m)	38.8	124

Using selected measurement stations in Zimbabwe, the satellite-based temperature data from WFDEI was compared to in-situ measurements. The results are illustrated in Figure 3.2. The results show that to a large extent the satellite derived temperature closely mimicked in-situ measurements although, there were instances in which the two datasets exhibited marked differences. For example, for Nyanga satellite derived temperature over-estimated temperature by about to 3°C. For all locations, satellite derived temperature had mean values which overestimated observed measurements.

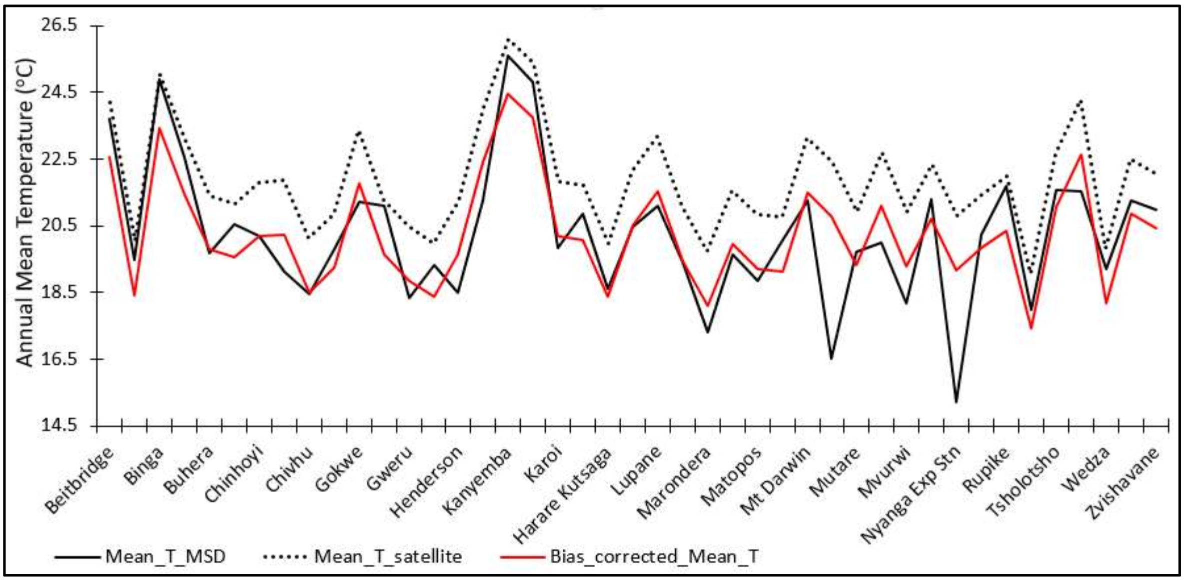

Figure 3.2: Comparison of in-situ and Satellite derived temperature from WFDEI

Bias correction was applied on the satellite derived temperature in an attempt to improve its accuracy. The bias from satellite derived temperature arises from the fact that surface temperature (from satellite data) will be compared to air temperature measured at 2 m above the ground (at weather stations) The results indicate that the application of bias correction reduced the percentage error from 8.53% to 4.49% (Table 3.2).

Table 3.2: Accuracy of WFDEI temperature retrievals before and after bias correction

	Raw satellite retrieval	Bias corrected
Bias (°C)	1.63	-0.7
Mean Absolute Error (°C)	1.62	0.87
Mean Percentage Error (%)	8.53	4.49
Root Mean Square Error (°C)	2.02	1.20

With the exception of a few locations such as Kezi, rainfall retrievals from CHIRPS satellite data over-estimated in situ measurement before and after bias correction (Figure 3.3). The extent of disparity varied with location with larger disparity observed in Chinhoyi, Mt Darwin and Nyanga than in other areas. Although the quantities differed, spatial patterns of rainfall were sufficiently detected by satellite measurements. Bias correction reduced the disparity between in-situ observations and satellite retrievals of rainfall.

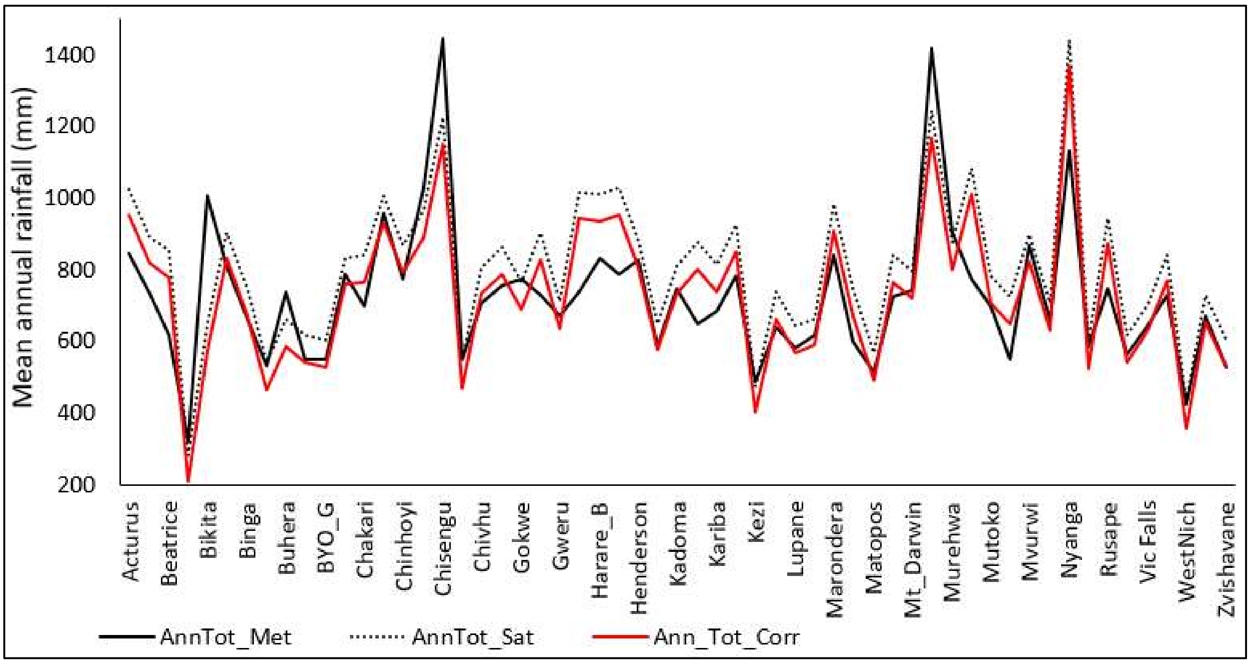

Figure 3.3: Mean annual rainfall from CHIRPS data versus in-situ observations in Zimbabwe

Rainfall data from CHIRPS improved in accuracy after bias correction (Table 3.3). The correction effort reduced Mean Absolute Error by close to 30mm from 109.3 mm to 81 mm. The same effort improved Mean Percentage error from 14.6% to 10.7%. The bias was because of indirectness of remotely sensed rainfall retrievals which use reflectance and emission of Visible and Infrared radiation by clouds (including cloud top temperatures) to estimate rainfall amount. Overestimation mainly occurs because not all cold or highly reflective clouds result in precipitation. Furthermore, high level crystalline cirrus clouds have very cold tops while they do not yield any precipitation since they are very thin. The use of satellite rainfall estimates from CHIRPS was thus best done after bias correction.

Table 3.3: Effect of bias correction on accuracy of rainfall retrievals from CHIRPS data

	Raw satellite retrieval	Bias corrected
Bias (mm)	74.5	0
Mean Absolute Error (mm)	109.3	81.0
Mean Percentage Error (%)	14.6	10.7
Root Mean Square Error (mm)	137.7	115.8

Geographical information systems and spatial analysis were applied to delineate the ZINGSA AEZ (2020) of Zimbabwe based on a number of layers. Figure 3.4 summarizes the data layers used in this study. The original AEZ map by Vincent and Thomas (1960) was based the strong linkages that exist between soil and rainfall, rainfall and vegetation, and, soil and vegetation in Zimbabwe. These close associations between soil, rainfall and vegetation were the basis for the division of the country into five NR which are largely agro-climatic but also take into account other relationships and physical factors that may affect agriculture.

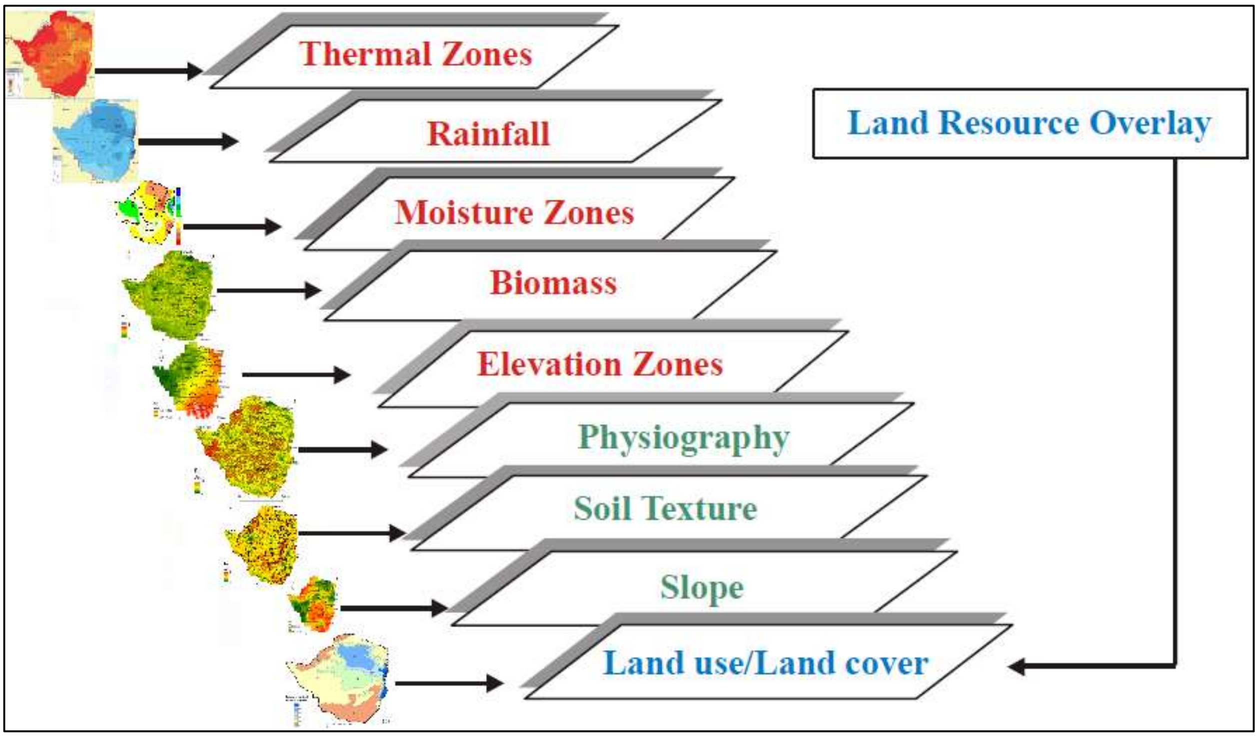

Figure 3.4: GIS layers used to redefine Agro-Ecological Zones of Zimbabwe

3.3 Data analysis

Agriculture is strongly dependent on climate in Zimbabwe hence agricultural practice was delineated based on productivity potential and constraints. In addition to climate factors, soil also influences agricultural activities. As a result the viability of crop and livestock production at any given point is determined by proportional contribution of the different factors. In this regard, all factors considered important in determining agricultural practice need to be considered when mapping AEZs. To incorporate the various factors, multivariate overlay analysis was applied in the mapping of AEZs of Zimbabwe. To accurately delineate the new AEZs of Zimbabwe, different the appropriateness of different approaches were tested.

In this exercise, conditional statements were applied in a GIS to delineate AEZ using in-situ measurements and remotely sensed data. The approach was similar to the one followed by Vincent and Thomas to allow for comparison in the regions delineated under different climatic regimes. Different ranges of values of precipitation attributes (i.e. dry spells, length of season, probability of annual rainfall exceeding 500 mm and total annual precipitation), temperature and elevation were considered to separate the country into different regions. Since temperature limits crop production in low rainfall areas to the north and south of Zimbabwe, the temperature variation was incorporated by splitting the country into two along the central watershed. As a result, places in the north assigned to NR III and NR IV based on other conditions but with mean summer temperature above 25 ^{o}C were assigned to NR IV and NR V, respectively. On the other hand places in the south assigned to NR III and NR IV based on other conditions but with mean seasonal temperature above 24 ^{o}C were allocated to NR IV and NR V, respectively. The justification is that when temperature is high, evapotranspiration increases resulting in plant moisture stress. The procedure was repeated until all mapping criteria were exhausted resulting in a first draft map of AEZs which was then used during field validation. Using field observations, available data and guidance by experts in different provinces of the country, the procedures were refined until a final AEZs map of Zimbabwe was obtained. Figure 3.5 is a flowchart explaining the sequence of procedures leading to the final AEZ map.

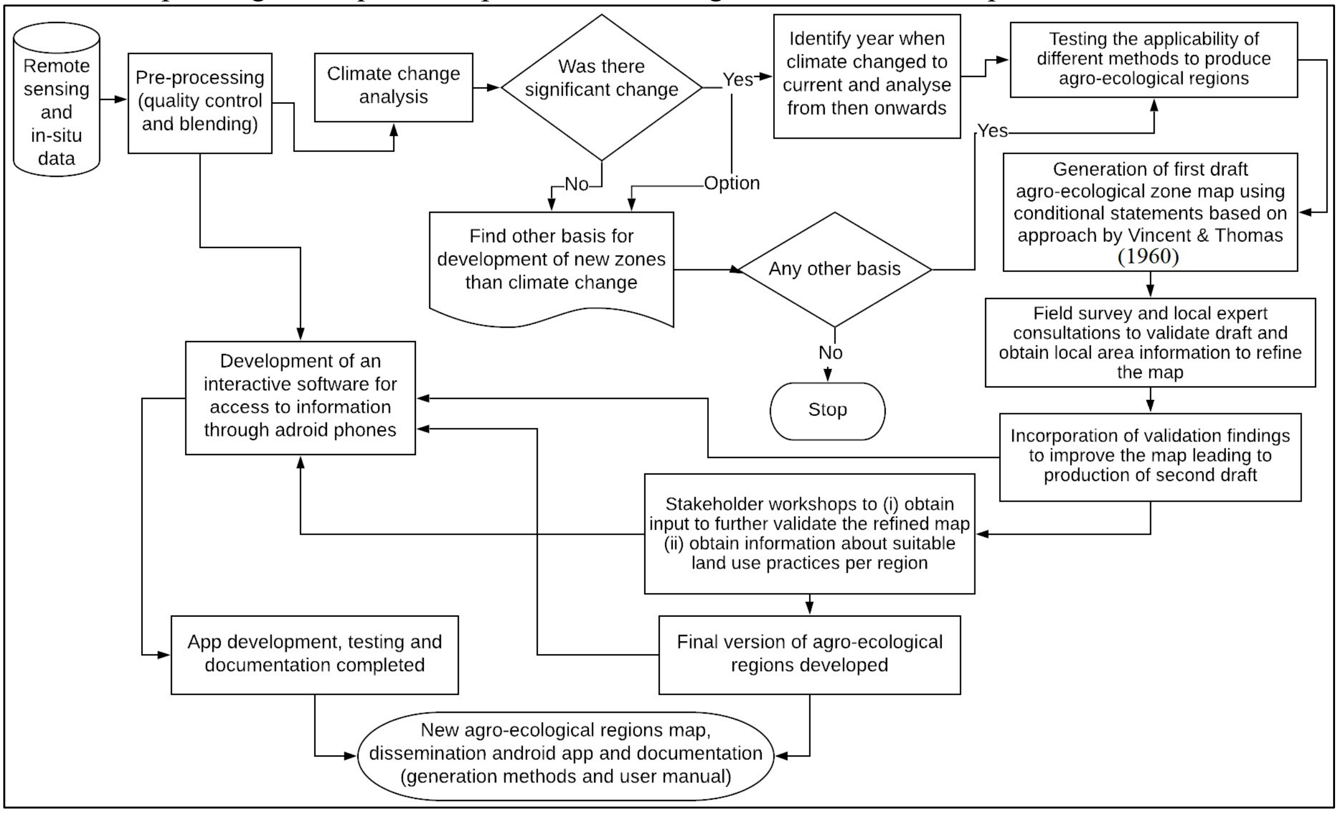

Figure 3.5: Framework Flow Chart for redefining Agro-Ecological Zones of Zimbabwe

3.4 Field Visits and Stakeholder Participation

The ZINGSA AEZs team embarked on a data verification exercise through field trips to the ten provinces of the country, including Harare and Bulawayo even though they are predominantly urban. The purpose of this exercise was to determine the extent to which the new zones tallied with what was being experienced on the ground. District and provincial AGRITEX officers and other stakeholders with knowledge of each area were consulted on whether the agricultural productivity and/or climatic experiences were the same as the ones shown by the maps generated. Members of the communities were also consulted on the changes observed in their localities for input to improve the draft maps. The team also made observations along routes not only in order to identify the dominant vegetation and land-use but to identify the potential boundary of the agricultural zone as well as to capture the coordinates of the locations using GPS. This is because effective rainfall, that is, a measure of moisture which enters the soil and becomes available for plant uptake, is the most critical climatic factor which creates stress conditions on plants and hence influences their distribution. Therefore vegetation type and distribution due to its higher spatial resolution served as the main proxy to demarcate the extent of boundaries to the AEZs. The GPS data and associated vegetation type were mostly taken through transect walks. This data was thenused to make changes of boundaries and the regions on the pre-generated maps. Where there seemed to be disagreements between the generated data and the information from the AGRITEX officers, the team resolved the issue by traveling to that specific area to make ground observations.

3.5 Vegetation Observations per Natural Region

Vegetation species identification was carried out in the field. Where it was difficult to identify the vegetation, local people were consulted to get the vernacular name. The vernacular name was then used to identify the botanical name using the botanical dictionary by Wild et al., (1972). Where it was difficult for local people to identify vegetation, samples and photographs were collected and taken to the National Herbarium in Harare for identification.

Generally, high population density and redistribution of land during the land reform program has resulted in disturbance and clearing of vegetation for cultivation and as a source of household energy and for curing tobacco by rural communities. In the areas with A2 farms, there are still some large areas with near climax vegetation. In smallholder farming areas, however, large areas have been cleared for cultivation and hence vegetation identification depended on relict vegetation communities limited to non-arable areas and edges of fields.

3.5.1 Natural Region I

The vegetation characteristics for NR I are unique to the country due to being molded through the distinct nature of the Eastern Highlands that are close to the border with Mozambique. These mountains' windward slopes benefit immensely from the watering through the persistent moist south-easterly winds originating from the Mozambique Channel. Forests typically occur on steep windward slopes and in sheltered valley sites. Here the high humidity beneath the tree canopies fed from transpiration nourishes the growth of many epiphytic ferns, fungi, lichens, and mosses resulting in a mosaic of grasslands and forest communities. The montane grasslands are dominated by *Loudetia simp*lex (russet grass) and *Themeda triandra* (red grass). However, vegetation in many places was cleared and replaced by tree plantations of *Pinus* and *Eucalyptus* species. In the high rainfall areas, open submontane *Themeda-Loudetia* grassland occurs, which gives way to bracken scrub with scattered trees such as *Faurea saligna*, *Harungana madascariensis*, *Pterocarpus rotundifolius*, *Catha edulis* and some *Protea* species (Bromely et al., 1968). In moist valleys and slopes evergreen subtropical montane forest and at lower elevations tropical evergreen forests occur and are often characterized with distinct *Albizia gummifera* and *A. adianthifolia*. In lower rainfall areas, miombo woodlands dominate *Brachystegia spiciformis (musasa [S]*and *B. utilis* and with further lowering of rainfall, species such as *Uapaka kirkiana* (*muzhanje/mushuku [S]*, *Parinari curatellifolia* (*muhacha [S]*, *Julbernadia globiflora (munhondo [S]* and *Brachystegia boehmii* (*mupfuti [S]*locally dominates (Anderson et al. 1993).

3.5.2 Natural Region II

Vegetation in the region comprises miombo woodland which is dominated by *B spiciformis; igonde [N])* and *J. globiflora; umshonkwe [N]).* Other tree species found in association with these two species include *Monotes glaber* (*mushava/munete [S]; inyunya [N]*); *U. kirkiana; umhobohobo [N]*); *Diplorhynchus condylocarpon* (*mutowa/musikanyimo [S]; inkamamasane [N]*); *Pseudolachnostylis maprouneifolia* (*mutsonzowa [S]; umqhobammpunzi [N]*) and *Lonchocarpus capassa* (*mupandapanda/munyamharadzi [S]; ichithamuzi/dungamuzi [N]*). On sandy soils *Combretum molle* (*mugodo [S]; umbondo [N]*), *Strychnos spinosa* (*mutamba/mun'ono [S]; umtamba/umhlali [N]*); *Terminalia sericea* (*mususu/mutabvu [S]; umangwe [N]*) and *P. curatellifolia; umkhuna [N]*) are most common and normally miombo woodlands is replaced by *P. curatellifolia* on edges/fringes of wetlands or areas with poor drainage which in turn gives way to scattered waterberry species such as *Syzsygium guineense* (*mukute [S]*) and *S. huillense (mukute-pasi [S])*. On some soils including heavier soils some common associates include *Piliostigma thonningii* (*musekesa/mutukutu [S]; ihabahaba [N]*); *Peltophorum africanum* (*muzeze [S]; usehla [N]*); and some *Acacia* and *Combretum* species. Where soils are shallow and gravelly *Brachystegia boehmii; itshabela [N]*) dominates and in some cases occurs as pure stands. On hilly terrain with rock outcrops, generally Brachystegia glaucescens dominates.

3.5.3 Natural Region III

Like NR II, dominant vegetation is miombo woodlands, but with more constituents species suited to drier conditions. As such, in the lower rainfall regions, the woodlands degrade into tree and shrub savanna, that is woody communities of lower stature 2 to 6 m and more open canopy. These include *Combretum apiculatum* (*mudziyaishe/mugodo [S]; umbondo [N]*); *Ormocarpum trichocarpum* and *O. kirkii* (*kapurupuru/mupotanzou [S]*); *Dalbergia melanoxylon* (*murwiti [S]; umbambangwe [N]*); *Kirkia acuminata* (*mubvumira [S]; umvumila [N]*); *Lannea discolor* (*mugan'acha/mumbumbu [S]; isigangatsha [N]*), *Afzelia quanzensis* (*mukamba/mungongoma [S]; umkamba [N]*). In some places the major miombo woodland species are *J. globiflora* and *B. boehmii* and some areas with clay soils have *Acacia-Combretum* woodlands where the notable feature is absence of *Brachystegia* and *Julbernadia* species. The Acacia species that dominate in *Acacia-Combretum* woodlands include *A. nilotica* (*mubayambondoro/muunga [S]; isanqawe [N]*), *A. rehmanniana* (*mubayambondoro/muunga [S]; iphucula [N]*), *A. nigrescens* (*chinanga [S]; umkhaya-omhlope [N]*) with *C. apiculatum* being co-dominant.

3.5.4 Natural Region IV

Vegetation in NR IV depicts a drier climate than in III and the species dominating depends on the location and soils. In the north-western areas, miombo woodlands dominated by *J. Globiflora* ang *B*. boehmii are found dominating in varying degrees. More xerophytic tree species are common. The associates may include *Schlerocarya birrea/caffra* (*mupfura/mutsomo [S], umganu [N]*), *K. acuminata*, *A. quanzensis*, *Colophospermum mopane* (*|mupani/musaru [S], iphane [N]*), *Crossopteryx febrifuga* (*muteyo/mubakatirwa [S], umphokophokwana [N]*) , Commiphora spp, *A. nigrescens*, *Cordyla africana* (*mutondo [S], ntondo [N]*), *Pterocarpcarpus angolensis* (*mubvamaropa [S], umvagazi [N]*), *P. antunesii* (*mukonazhou [S]*), *Xeroderris stuhlmannii* (*murumanyama [S], umthundulu [N]*), *Diospyros mespiliformis* (*mushuma [S], umdlawuzo [N]*), *Adansonia digitata* (*muwuyu [S], umkhomo[N]*) and *C. apiculatum*. In the west on Kalahari Sands, vegetation is dominated by *Baikiaea plurijuga* (*mukusi/gusi [S], umkusu [N]*). This occurs in association with *P. angolensis*, *Guibourtia coleosperma* (*muchibi [S], umtshibi [N]*), *A. quanzensis*, *T. sericia*, *B. spiciformis*, *Ricinodendron rautenenii* (*umgoma/umgongo [N]*) and *Commiphora mollis* (*muchamwa/mugumbati [S], iminyela [N]*).

In the south, vegetation on sandy soils is dominated a Terminalia-Burkea woodland with the main species being *T. sericea* and *Burkea Africana* (*mukarati [S], umnondo* [N]). The main associates include *S. birrea/caffra, umganu [N]*), *P. africanum*, *K. acuminata*, *Commiphora* spp, *Acacia* spp. C. apiculatum and *C. mopane, iphane [N]*). *C. mopane* is dominant in places. On loam and clay soils vegetation is mixed with *A. nigrescens* and *C. apiculatum* being co-dominant in places with some of the following species also occurring, *P. africanum*, *K. acuminata*, *Commiphora* spp, *C. apiculatum*, *C.imberb*e (*mutsviri/muchenarota [S]*) and *S. birrea/caffra. C. mopani and A. digitata* are usually scattered in the woodlands.

3.5.5 Natural Region V

This region has very dry climate and is characterized by near absence of miombo woodland species. Species such as *Colophospermum mopane*, *Adansonia digitata*, *Berchemia discolor*, *Acacia* and Combretum species increase in prominence than in region 4. *Lonchocarpus bussei*, *S birrea*, *Sterculia africana*, *K. acuminata*, *Cordyla Africana, Terminalia sericea* and *Commiphora* species may also occur in places.

In the northern part of the country, in the Zambezi valley, vegetation is a mixed thicket of *Commiphora*, *Combretum* and *Dichrostachys* species with *A. digitata*, *S. caffra*, *D. mespilliformis* and *C. mopane* occasionally standing out. In the west on Kalahari sand and surrounding areas, tall *C. mopane* trees replace the *B. plurijuga* found in NR IV. In the southern part of the country, on paragneiss parent material, C. mopane woodland occurs with A. nigrescens, C. apiculatum and C. imberbe. Scattered in the woodland include *Adansonia digitate, Schlerocarya birrea, K. acuminate,* and *Commiphora* spp. trees. Also found in the southern part are Acacia woodlands and in places Acacia bushlands depending on the nature of soils in the area.

3.6 Field visits and stakeholder consultations on zone boundaries

A total of 411 GPS data points was collected in the whole country during the field visits conducted as shown in table 3.4 (below). The aim was to observe the dominant local vegetation and assign the corresponding AEZ. Data points in Harare and Bulawayo provinces were included although they are predominantly urban regions. The routes taken during the fieldwork for all the provinces and GPS points are given in Fig. 3.6. The list of stakeholders that were consulted in the respective provinces is contained in the appendix section. The following subsections present fieldwork results of each province as well as the conclusions made after consultations with the local stakeholders (Table 3.4).

Table 3.4: Fieldwork dates and the total number of recorded GPS points within the province.

Province	**Fieldwork dates (dd/mm/year)**	**No of GPS points**
Manicaland	28/04/2019 – 04/05/2019 31/10/2019 – 06/11/2019 09/02/2020 – 12/02/2020 03/06/2020 – 04/06/2020	72
Midlands	30/03/2019 – 02/04/2019 19/09/2019 – 23/09/2019 08/02/2020 – 12/02/2020 18/03/2020 – 19/03/2020	52
Masvingo	16/09/2019 – 23/09/2019 11/03/2020 – 16/03/2020	29
Mashonaland West	31/07/2019 – 03/08/2019 16/06/2020 – 16/06/2020	60
Mashonaland Central	17/07/2019 – 27/07/2019 18/06/2020 – 19/06/2020	22
Mashonaland East	02/05/2019 – 06/05/2019 26/09/2019 – 30/09/2019 04/06/2020 – 05/06/2020	54
Matabeleland North	16/06/2019 – 20/06/2019 26/10/2019 – 30/10/2019 18/03/2020 – 18/03/2020	35
Matabeleland South	01/04/2019 – 06/04/2019 16/06/2019 – 20/06/2019 18/03/2020 – 18/03/2020	46
Harare	23/05/2020 – 24/05/2020	25
Bulawayo	14/06/2020 - 18/06/2020	16

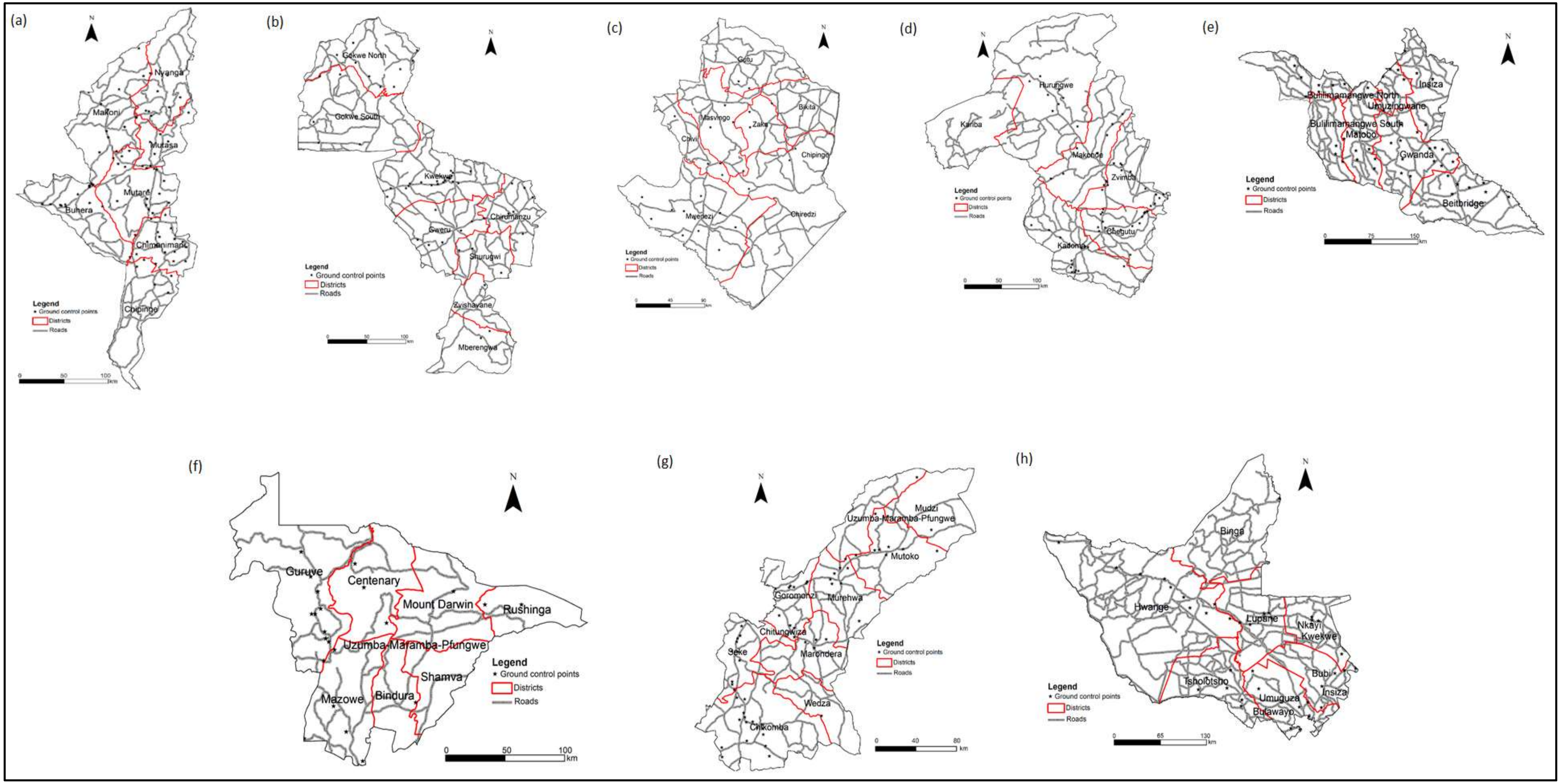

Figure 3.6: Map showing routes and GPS points taken in (a) Manicaland, (b) Midlands, (c) Masvingo, (d) Mashonaland West, (e) Matabeleland South Province (f) Mashonaland Central, (g) Mashonaland East, and (h) Matabeleland North Provinces.

3.6.1 Manicaland Province fieldwork

The Eastern Highlands dominate the **p**rovince which is characterized by dense evergreen vegetation, low temperatures with timber plantations dominating the high altitudes and steep slopes (Figure 3.7). It was evident the country's timber production is located in this region as indicated by high prevalence of sawmills. Diversified agriculture and livestock production, mainly dairy farming in combination with crops such as coffee (*Cofea Arabica)* and tea (Camellia sin*ensis), decidu*ous fruits, such as bananas (*Musa acuminata Colla*), and apples (*Malus domestica), and* horticultural *crops, such as* Irish potatoes (*Solanum tuberosum)*, field peas (*Pisum sativum) and oth*er vegetables *including flo*wers and grapes were observed in the area. However, temperature began to increase drastically and the vegetation carrying capacity rapidly deteriorated with movement towards the rain shadow regions in the south west and south. It became increasingly hot and visibly dry as the team headed towards NR V. This region has the steepest AEZ gradient in the country, moving from NR I to NR V in a distance of less than 10 km from Chipinge town towards the Save Valley.

Figure 3.7: Typical forestplantation in Natural Region I. The photo shows direction to Mutarazi Falls in Nyanga (5/5/2019) (left panel). Team taking coordinates of the edge of the dense evergreen forest of Natural Region I near Mutare (right panel)

It was noted and discussed with the stakeholders that the climate in the province had changed as evidenced by the shrinking of the rainfall season accompanied by increased frequency and intensity of dry spells.

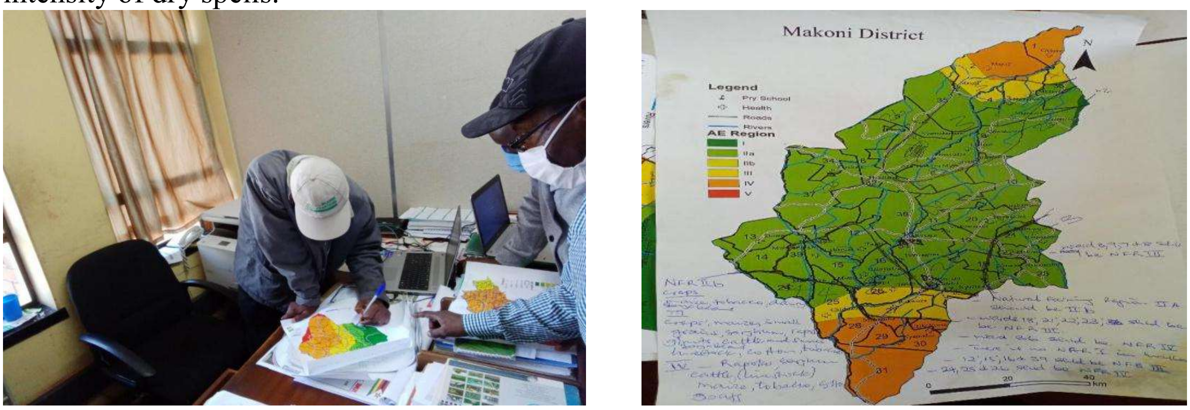

Figure 3.8: Stakeholder consultation in Mutare District AGRITEX Offices (left panel). Stakeholder input for Makoni District (right panel)

These rainfall characteristics have resulted in the changes of the all NRs (Figure 3.8, left panel). Of note was the observation that NR IIb was almost disappearing with NR III dominating the area. Consequently the local AGRITEX Extension officers were already recommending increasing the portion earmarked for growing drought tolerant crops within the fields of communal farmers.

3.6.2 Midlands Province fieldwork

It was observed that the agricultural production systems are based on drought-tolerant crops and semi-intensive livestock farming based on fodder crops. This was more prominent in Zvishavane and Mberengwa. Although the main crop grown was maize, it was visibly mostly of poor quality, testifying to the large intolerance of the region to high yielding maize production. Information from the Provincial Meteorological Officer indicated that this state was due to frequent mid-season dry spells and high temperatures. A significant portion of the province appeared to be used for extensive beef ranching and there was evidence of overgrazing especially in communal areas of Nhema in Shurugwi. Cotton appeared to do well in most areas and is grown as the major cash crop.

Figure 3.9: Agro-ecological Zones validation meeting with stakeholders (top panel) and field observation in Midlands Province

It was noted that the climate in the province had deteriorated through the shrinking of the rainfall season accompanied by increased frequency and intensity of dry spells. This resulted in the degradation of the all NRs (Figure 3.10, left panel). Of note was the observation that NR IIb was almost disappearing at the expense of expanding NR III. Consequently, the local AGRITEX Extension officer has already started recommending increasing the portion earmarked for growing drought-tolerant crops within the fields of communal farmers. The current recommended crops are shown in figure 3.10 (right panel).

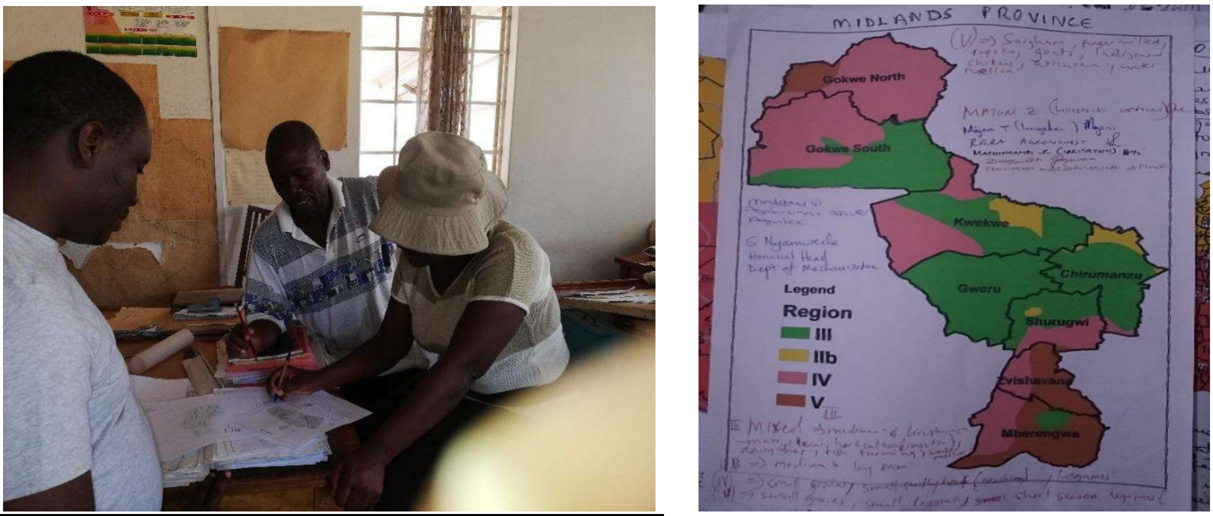

Figure 3.10: AGRITEX officers discussing the changed Kwekwe District Natural Regions boundaries (left panel). The crops and land use options currently recommended by AGRITEX extension officers for Midlands Province (left panel)

3.6.3 Masvingo Province fieldwork

The two field visits to Masvingo Province had routes which can be derived from the GPS data points taken as depicted in the Figure 3.6 (c). It was observed that the region is dominated by bush encroachment, especially by aggressive Acacia shrubs, formed impenetrable thickets in overgrazed rangelands (Figure 3.11, right panel). Open stands of trees of varying height from 6 to 10m depending on soil depth and drainage interspaced with grass were evident (Figure 3.11, left panel), especially to the northern regions of the Province.

Figure 3.11: Bush trees interspaced with grass for grazing in cattle ranching Farm near Masvingo (left panel). Typical Natural Region IV vegetation in Gutu South (right panel)

Cattle ranching, goat rearing and wildlife conservation are the dominant agro-based activities carried out in the region. Most arid regions of the province were located towards the Limpopo and Sabi valley, which is also dominated by thorny bushes and baobabs. In this south-eastern region of the province the intolerance to dryland cropping was evident hence very few crop fields could be seen. In fact, the region bordering South Africa and Mozambique is home to Great Limpopo Transfrontier Park. The province also has some of the most successful Communal Areas Management Programme for Indigenous Resources (CAMPFIRE) community-based natural resource management programs in the country. CAMPFIRE is one of the first programs to consider wildlife as renewable natural resources, while addressing the allocation of its ownership to indigenous peoples in and around conservation protected areas.

Though the stakeholders in Masvingo (Figure 3.12, left panel) confirmed that the climate had essentially degraded the farming activities in the province, they concurred that the area south of Chiredzi in the Save and Limpopo valleys had changed to such an extent that rain fed agriculture was increasingly becoming impossible. Hence the stakeholders concurred that the region is now quite different and no longer fit the description of NR V (Figure 3.14, right panel). Since this suggestion resonated well to what had been proposed by stakeholders in Matabeleland South, it was later suggested to split NR V into two distinct regions of NR Va and NR Vb.

Figure 3.12: AGRITEX Extension Officers displaying their inputs to their districts' Natural Regions in Masvingo Province (left panel). Meeting with stakeholders to confirm the new Natural Regions' district boundaries in Masvingo (right panel)

3.6.4 Mashonaland West Province fieldwork

Two visits were carried out in this region with the routes taken indicated by the GPS points shown earlier in Fig. 3.6c. It was observed that the region is dominated by commercial farms where maize (*Zea mays*) is predominantly grown as evidenced by massive grain silos in Banket and Kadoma. Cattle ranching farms (Figure 3.13, left panel) and wildlife conservancies near Chegutu (Figure 3.13, right panel). Tobacco commercial farming was also noted as evidenced by the prevalence of flue curing barns. Of note was Zvimba communal area where rampant tree felling had been done for tobacco curing. There was evidence that the province's communal areas had been overgrazed leading to massive land degradation. Isolated tree stands could be seen in the midst of thatching grass. It was noted that most of the province has had a severe impact of the changing climate with crop yield being significantly reduced.

Figure 3.13: Images from the Mashonaland West Province vegetation typical of RN III (left panel) and farms which have been turned into wildlife conservancies (right panel)

Discussions with the stakeholders noted that there was not much difference between what the automatic NR map had produced and what was on the ground in most districts. It can be noted that stakeholders who analyzed the district boundaries from the automated map (Figure 3.14, left panel) concurred with their expert knowledge as highlighted by the stakeholder comments shown in Figure 3.14, right panel for Hurungwe map.

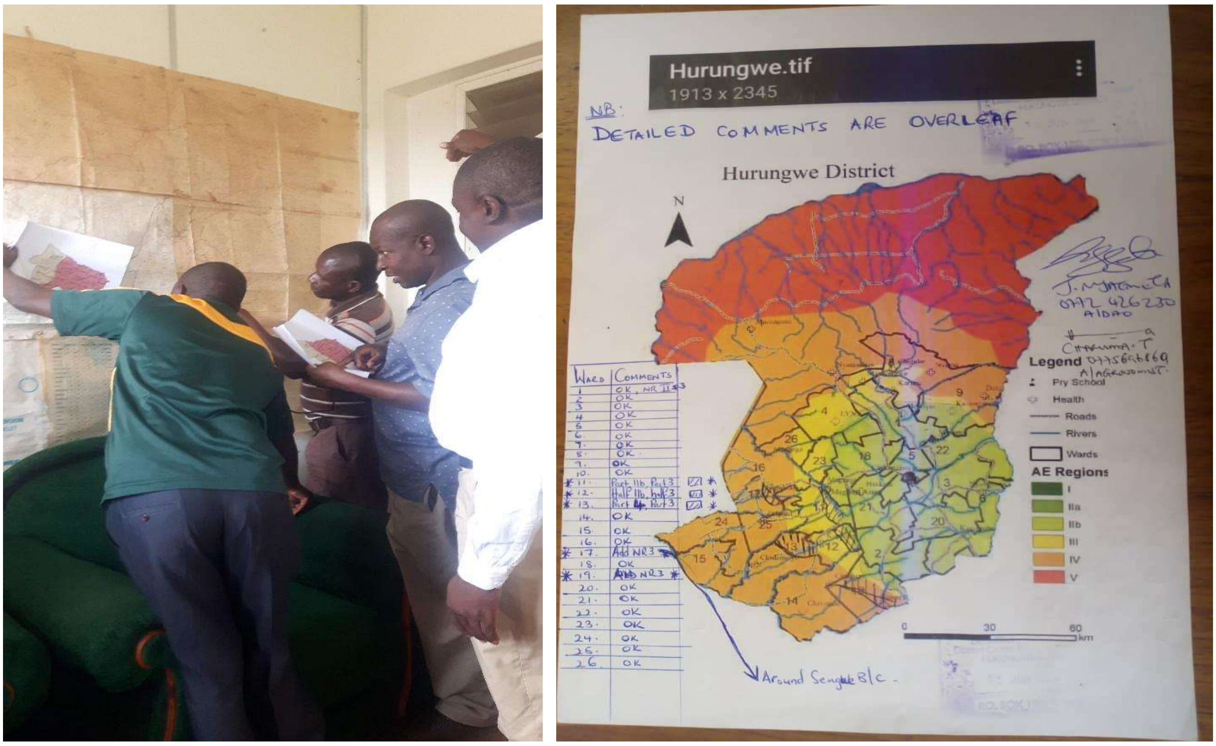

Figure 3.14: AGRITEX officer checking on the concurrence of the boundaries from the automated map with what is observed on the ground (left panel). Hurunge District map indicating a very high rate of concurrence with what was observed in the ground (right panel)

3.6.4 Mashonaland Central Province fieldwork

The province borders Harare province where rainfall is relatively high. Rainfall decreases towards the Zambezi valley where NR V which is the least favorable agriculturally, is located. Mazowe and Bindura are the most agriculturally favorable districts where citrus fruits, maize, tobacco and winter crops like wheat and barley are grown. Although irrigation supplements the rainfall, it is mostly used during the dry winter season. Extensive deforestation took place on the former commercial farms allocated during land reform especially on tobacco farms where trees are cut partly to provide fire wood for curing the crop. Most of the area has been denuded almost entirely of their woody cover. Generally the only trees to survive this onslaught are fruit trees, such as Musau and Mango. As one moves towards the Zambezi valley, the rainfall diminishes. Here bush encroachment, especially by aggressive acacia shrubs, can form impenetrable thickets in overgrazed rangelands in the drier parts of the country (Figure 3.15). Figure 3.6f shows the routes taken during the two field visits to Mashonaland Central as indicated by the positions of the GPS observation points.



Figure 3.15: Images from the Mashonaland Central field trip

Most stakeholders from the district concurred that the NR boundaries had shifted and were happy with the new boundaries presented by the research team. They also advocated for a revision in the crops grown in the province to take into consideration the harsher climate that was being experienced in most of the districts.

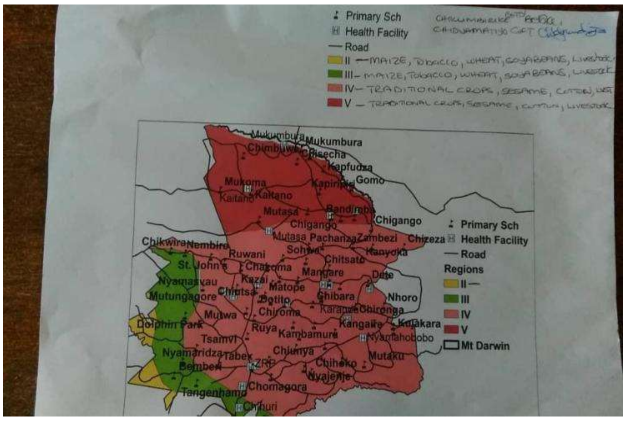

Figure 3.16: Images from the Mashonaland Central field trip

3.6.5 Mashonaland East Province fieldwork

The GPS observation data points in Figure 3.6g indicate the routes that were taken during the three field visits. From the field work observations was evident that the province generally has reliable rainfall and good soils capable of sustaining intensive cropping and livestock production. The cropping systems were found to be based on maize (*Zea mays*), cotton (*Gossypium hirsutum*), wheat (*Triticum aestivum*), soybeans, sorghum (*Sorghum bicolor*), groundnuts and seed maize. These crops are grown under dry land production though structures indicating availability of supplementary irrigation could be seen in the farms. Although irrigation is meant to counter the effects of dry spells within rainfall season it also irrigated winter crops that include wheat and barley grown from colder to predominantly drier months (May-September). Intensive livestock production based on pastures and pen-fattening utilizing crop residues and grain were also found in the region with livestock production systems which include beef, dairy, pig and poultry.

Edaphic factors, those related to the physical and chemical properties of the soil can modify and locally override the effects of climate on the vegetation. A classic example is the contrast woody cover in Figure 3.17 that has an area of plants with stunted growth in the midst of thicker and taller vegetation (Figure 3.17) near Wedza. Here chemically the soils are unfavorable for growth of woody species mainly because of high concentrations of nickel, and an excess of magnesium (Mg) over calcium (Ca). Several open cast nickel mines and nickel ore dumpsites could be seen dotted in the area.

Figure 3.17: Natural region boundary demarcation during the field work (left panel). Typical area where the underlying soil significantly changed the natural vegetation within a region near Wedza.

Stakeholders were happy with the new boundaries presented to them (Figure 3.18, left panel, with no adjustments of boundaries recommended in 8 of the 9 districts (Figure 3.18, right panel).

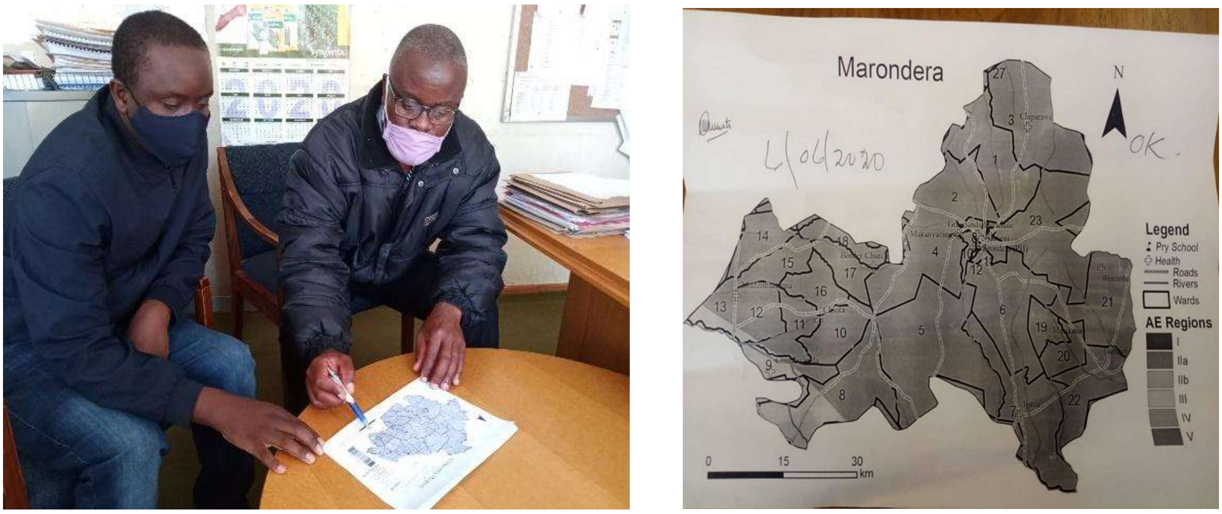

Figure 3.18: A stakeholder from AGRITEX concurs with the district NR map presented (left panel) and was indicated satisfaction by putting OK on the district map (right panel)

3.6.6 Matabeleland North Province fieldwork

Figure 3.6h shows the routes taken during the three field visits to Matabeleland North Province as indicated by the positions of the GPS observation points. An important observation that we made in Matabeleland North region is that the NR V along the Zambezi Valley was somehow different from the other Region V. Here the region receives reasonably more rainfall. However, we noted that it was its uneven topography and poor soils make it unsuitable for crop production. There was evidence of dominance in extensive cattle production and game-ranching. The Provincial Meteorological Officer indicated that the province is generally characterized by highly erratic rainfall with the AGRITEX extension officers reiterating that the province was mostly too dry for crop production. Despite these facts on the ground, households on the communal lands in these regions insisted on growing grain crops (maize and millet) for food security including some cash crops such as cotton. However, except for cotton which is more tolerant to the dry and hot local climatic conditions, these crop yields are extremely low and the risk of crop failure is very high. Hence, cattle and goat production are major sources of cash income. Bulawayo and its environs depicted a wooded savannah which shelters teaks but as one moves towards Lupane and Hwange National Park the vegetation became dominated by teak woodland. The hardy bristle grasses of the genus *Aristida* are common in the west of the province, especially on Kalahari sands. Figure 3.19 depicts vegetation near Victoria Falls (left panel) and Tsholotsho (right panel).

Figure 3.19: Different types of vegetation in region Va near Victoria Falls (left panel) and Tsholotsho (right panel)

As expected, due to the scarcity of observed climate data at high resolution, only three of the seven district maps were found not needing NR boundary adjustments during the discussions with AGRITEX stakeholders (Figure 3.20, left panel). They also recommended new crop varieties which can reasonably withstand the new drier and hotter climate of the province (Figure 3.20, right panel).

Figure 3.20: Discussion of Matabeleland district NR boundaries at the AGRITEX provincial Offices in Bulawayo (left panel) and the new recommended land use per natural region (right panel)

3.6.7 Matabeleland South Province fieldwork

Figure 3.6e shows routes taken and the GPS field observation data points taken during the field visit in Matabeleland South Province. Of note was the confirmation by the Provincial Meteorological Officer of the presence of severe dry spells during the rainy season that are compounded by relatively high frequency of seasonal droughts. AGRITEX officers informed the ZINGSA team that as one goes south-eastwards, the province progressively became unsuitable for dryland cropping. Smallholder farmers grow drought-tolerant varieties of maize, sorghum, pearl millet *(mhunga)* and finger millet *(rapoko)*. Ideally the province is suitable for cattle production under extensive production systems and for wildlife production. Similar to the climate characteristics of regions to the South of Masvingo, the lowlands to the south and southeast are the most arid regions and hottest areas visited by the team. The region appeared not able to sustain any form of rainfed agriculture and was implied by the absence of crop fields along the way. *C mopan*e (is a common tree along with drought resistant *A*. *digitat*a alongside thorny bushes dominated the region (Figure 3.21).

Figure 3.21: Thorny bushes on bare ground in Natural Region Vb in Beitbridge District (left panel) and plants adapted to low rainfall in Matebeleland South Province (right panel)

The general consensus during consultations with the local AGRITEX extension officers indicated that the climatological conditions of the area have now worsened to such an extent that it has become a distinct region in its own where even drought-tolerant crops can no longer thrive. It was suggested that the region be labelled NR VI, a recommendation that eventually led to the creation of regions NR Va and NR Vb.

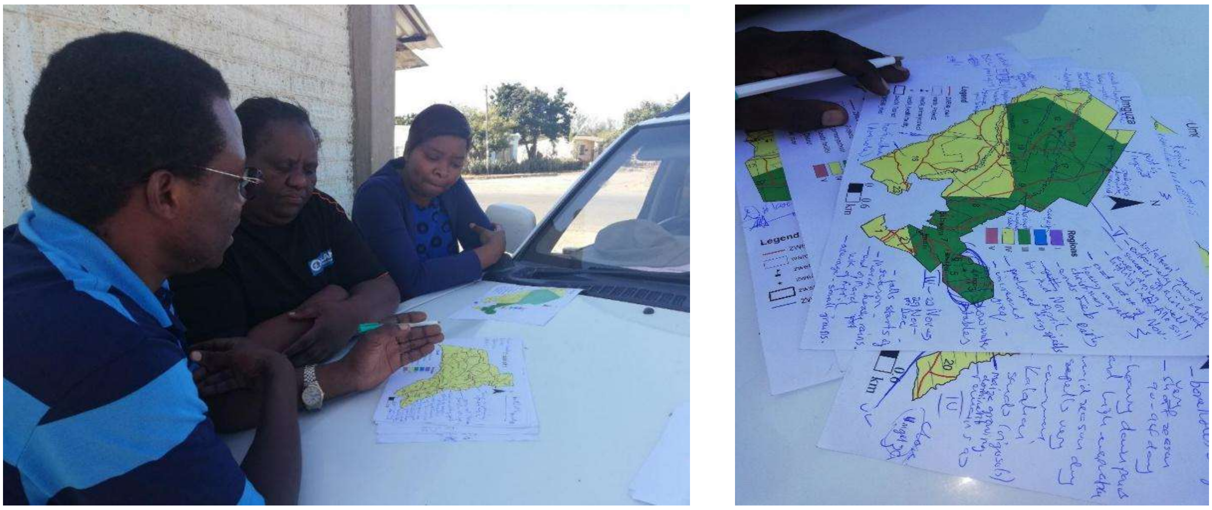

Figure 3.22: AGRITEX extension officers discussing the new NR boundaries (left panel) and recommending new crop varieties so suit the new drier and warmer climate of their districts (right panel)

3.7 Insights from Countrywide Field Visits and Consultations

The AEZs of Zimbabwe especially in the communal areas are rapidly changing primarily due to climate change that is also being compounded by the influences of human activities as overgrazing, deforestation, expansion of settlements and crop cultivation. As such the productivity of the land and its ability to support the local communities is deteriorating as a result of unsustainable land management practices, resulting in land degradation, particularly soil erosion and soil nutrient mining. Therefore, matching crop requirement with resource availability through land suitability analysis and adoption of climate smart agricultural practices is compelling to sustainably increase agricultural productivity while protecting the natural resources (soils; biodiversity and water).

The main limiting factors for land suitability were soil depth, texture, temperature, slope and erosion hazard. The spatial distribution showed that most of the cultivation is currently practiced in marginally suitable land whose suitability potential is still being informed by the climate change degraded original AEZs. These change in the AEZ boundaries has resulted in the seed houses recommending seeds in areas which are no longer suitable for the local conditions. As a result certain types of crops, especially maize is being grown in unsuitable areas. In this regard most of the land is being used against its suitability potential in most parts of the country area. Thus, land-use pattern needs to be updated and modified based on its suitability potential that is informed by a revised AEZ map.

3.8 Incorporation of field survey findings to the development of AEZ map

At least two field validation and stakeholder consultations were undertaken for each province. The findings from the validation exercises were used to improve subsequent boundaries. At each validation stage, the revised version was presented to the experts mainly AGRITEX officers due to their experiences working in the wards and districts of the country. The use of the presence of AGRITEX officers down to village levels also enabled identifying areas best suited for various types of land-use, including rain-fed crops, forestry and protected areas which could be for recommended land-use planning application for the districts. Local expert knowledge was also used to identify localized microclimates which could not be detected at the resolutions of the available data. This served to minimize effects such as data gaps which had potential to misrepresent conditions in some of the places. These iterations ensured that map allocations, field observations and local expert knowledge converged. In the final analysis suggestions for further improvement were minimal given that the improved version had taken into account local effects, biophysical observations and local experts' guidance. Incorporation of these minor inputs led to the production of the final AEZ map.

3.9 Accuracy assessment of AEZ

The accuracy of the redefined agroecological zones of Zimbabwe was determined using validation data (ground truth GPS coordinates of AEZ classes) obtained during field surveys. Figure 3.23 shows the distribution of 411 ground control points which were taken during the project. These points were selected based on their proximity to AEZ boundaries as well as to cover the whole country's regions and to detect intra-class variabilities. Accuracy assessment was performed on AEZ maps produced at different stages to determine the level of agreement with the ground situation and improvement with time.

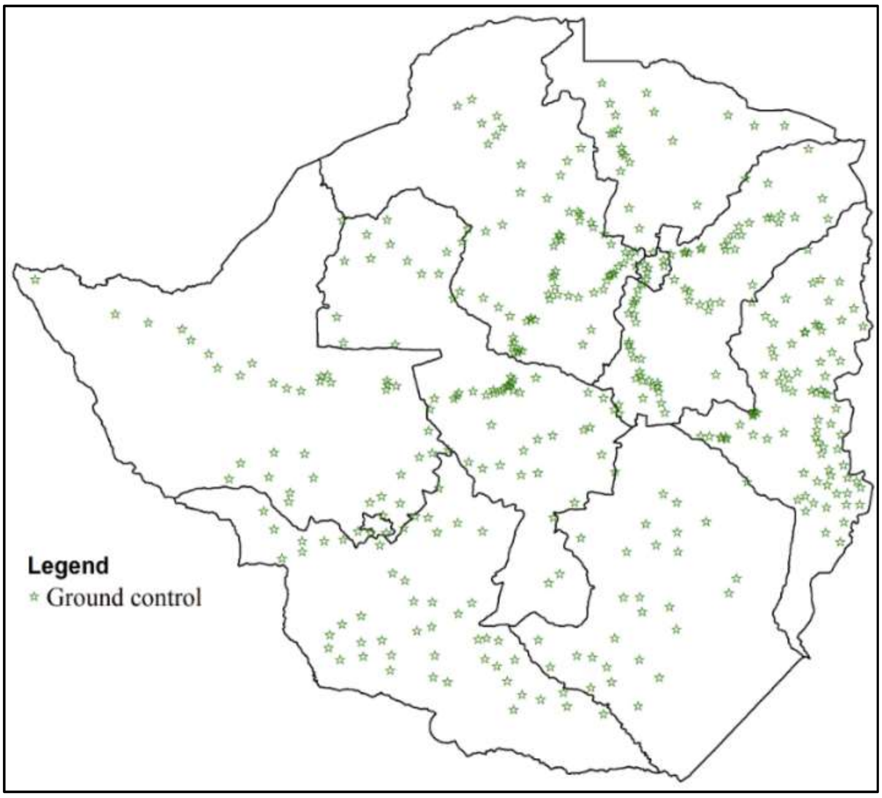

Figure 3.23: The distribution of ground control points used for accuracy assessment and iterative improvement of agro-ecological zones map

3.10 Change detection in the spatial structure of AEZ from 1960 to 2018

Qualitative and quantitative methods were used to analyze changes in the spatial distribution of AEZ between the current and the maps produced in 1960 and in 1984. Overlay analysis was performed to detetermine changes in the spatial extent of AEZs between Vincent and Thomas'1960 map and the ZINGSA (2020) derived AEZs. Sankey diagrams were used to show percentages occupied by each class in the new map as well as corresponding values in past maps. The diagrams also showed the actual transitions which occurred between periods. Visual inspection of the three maps gave a qualitative analysis of the changes in the spatial configuration of AEZs between the periods. Since the Vincent and Thomas effort of 1960 was used as reference in this study, a map showing changes from this to the current was also produced. The map showed places which remained stable as well as where changes occurred between the periods. In addition the old and new value per changed location were also shown on the same map to enable easy assessment of transitions.

3.11 Summary

In this chapter high correlation between remotely sensed and *in-situ* observations of rainfall, temperature and elevation was detected. Accuracy and representativeness of satellite derived variables improved after blending with *in-situ* data. Unsupervised classification using elevation, temperature, precipitation attributes and soil characteristics was not successful in mapping AEZs for Zimbabwe. A conditional statement based approach using the same data and criteria set by Vincent and Thomas was finally selected. This enabled effective detection of changes which occurred between the periods by excluding effect of differences in methodologies. Besides use of conditional statements, stakeholder consultations and field surveys were done iteratively in an effort to ensure high accuracy of AEZ map. Comparison of AEZ maps produced at three different times allowed detection of changes which occurred between the periods. In addition to production of AEZ map, data and stakeholder consultations contributed to the development of an android application for dissemination of AEZ map and area specific advisories.

CHAPTER 4 : REVISED AGRO-ECOLOGICAL ZONES OF ZIMBABWE

4.1 Automatic generated AEZ map

Figure 4.1 shows the first draft AEZ map (after smoothing) generated using conditional statements based on criteria used by Vincent and Thomas. Based on the automated procedure, the AEZ map depicted expansion of NR V from 25.5% to 31.4% (of the country) in the low lying areas to the north and south of the country. Most of the Eastern Highlands areas allocated to NR I by Vincent and Thomas were classified in the same AEZ category. Compared to Vincent and Thomas, NR I was covering a larger area by 0.4%. While the map showed potential to automatically generate AEZs there was need for field validation and accuracy assessment. The map was produced with an overall accuracy of 74% while Region III was mapped with least accuracy (45%) when compared to ground control points. The other classes were mapped with accuracies ranging between 70 and 81%. Improvement of the first draft based on field observations and stakeholder consultations yielded a second draft with an overall accuracy of 88%. Following further stakeholder consultations a final version was produced.

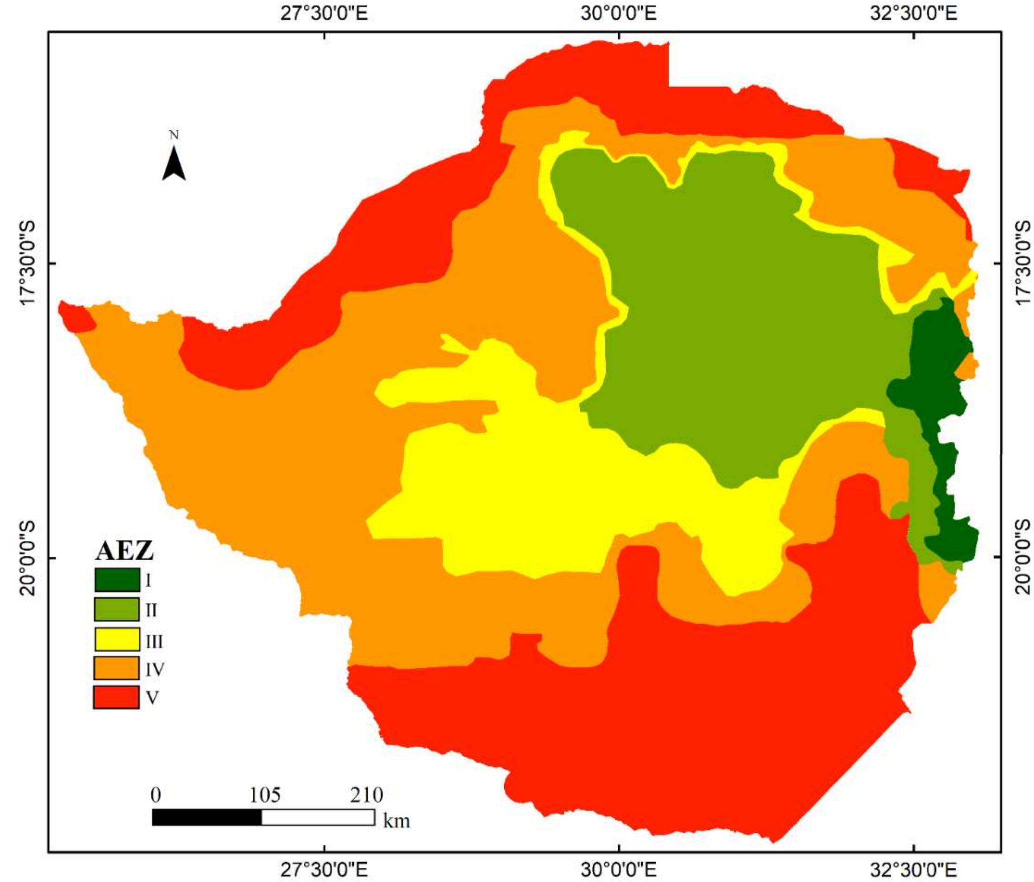

Figure 4.1: Automatically generated first draft of agro-ecological zones map of Zimbabwe

4.2 Evaluation of the new AEZ (ZINGSA AEZ, 2020)

The results of GPS-based field validation across different agro-ecological zones showed that the final AEZ map had relatively high overall accuracy of more than 95%. The accuracy of each region was as follows; Region I: 98%, Region II: 92%; Region III: 95%, Region IV: 97% and Region V: 100%. These results imply that the newly delineated AEZ can be used with confidence as it has been validated.

4.3 ZINGSA AEZ (2020)

Figure 4.2 shows the spatial distribution and proportion of the area occupied by each of the revised agro-ecological zones of Zimbabwe. It is observed that although the revised AEZ map has similar regions (i.e., NRs I to V) to the previous work by Vincent and Thomas (1960) and AGRITEX (1984), the ZINGSA AEZ, 2020 has further been classified into NRs Va and Vb. The classification into NRs Va and Vb is reflective of the increased aridity in this region being mostly driven by climate change. Specifically, the region has experienced a significant reduction in rainfall coupled with increased dry spells and high evapotranspiration which all reduces effective moisture rendering the region too dry for viable agriculture.

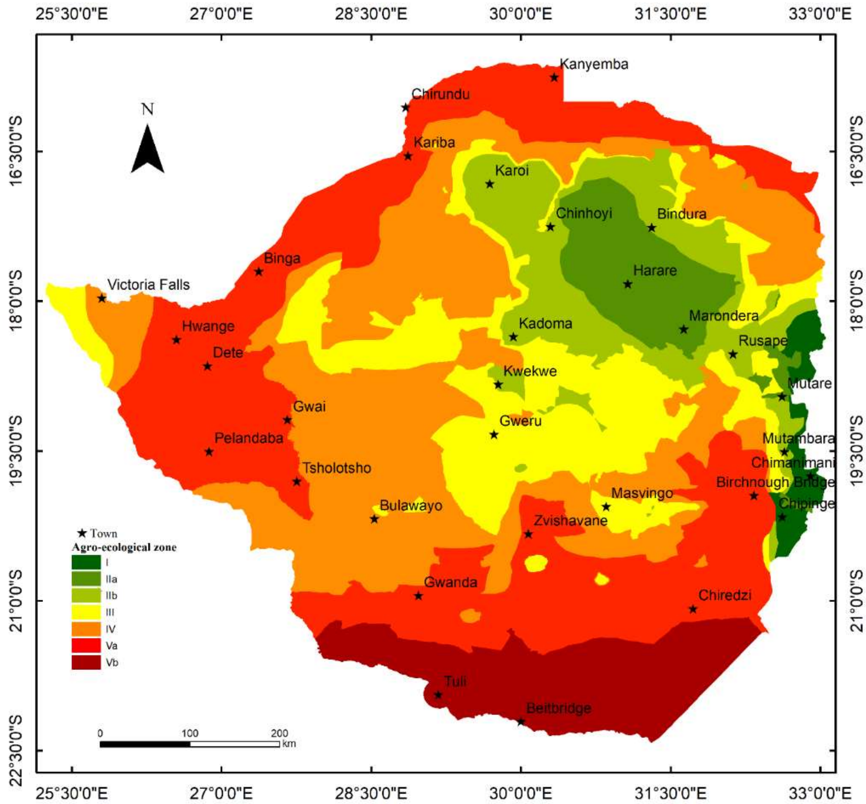

Figure 4.2: Revised Agro-Ecological Zones of Zimbabwe (*ZINGSA AEZ, 2020*)

Table 4.1 illustrates the area occupied by each AEZs of Zimbabwe based on the new classified zones. It is observed that NR I occupies 1.5% of the country and predominates the eastern parts of the country. This region receives the highest amounts of rainfall in the country exceeding

1000mm/year on average. NR II is divided into 2a and 2b which occupy 5.7% and 9.3% of the country, respectively. The main distinguishing feature of the two sub-regions is that NR IIb experiences more dry spells than NR IIa. The region is found within the central, north eastern and eastern parts of the country.

Table 4.1: Area occupied by each of the revised Agro-Ecological Zones/Natural Regions

Region	**Area (km^2)**	**Proportion of country (%)**
I	6008.8	1.5
IIa	22085.4	5.7
IIb	36304.7	9.3
III	63215.2	16.2
IV	113594.9	29.1
Va	115041.2	29.4
Vb	34499.8	8.8
Total Area	**390750**	**100**

NR III is located in the central, western, southern and eastern parts of the country. The region is spread over 16.2% of the country. In terms of area, NR IV is the second most extensive region and occupies 29.1% of the country. It dominates the central and western parts of the country and borders Regions III and V. The most extensive of the AEZ is NR V with NR Va and NR Vb occupying 29.4% and 8.8%, respectively. This NR V is the driest in the country and predominates the major river valleys of the southern, western and northern fringes of the country whilst relative to NR Va, NR Vb is so dry that it cannot sustain any form of rainfed agriculture and is restricted to the southern-most parts of the country.

4.4 Changes in the spatial distribution and extent of agro-ecological zones

Figure 4.3 provides a comparison of the ZINGSA AEZ (2020) with those delineated by Vincent and Thomas (1960) – Figure 4.3a - as well as by AGRITEX (1984) – Figure 4.3b. Results indicate that there is a significant shift in most of the agro-ecological zones although some regions remain within previously defined Regions. Notable changes include the contraction of NR II, NR III and NR IV as well as expansion of NR V. Areas that did not show much change include, Mutare and Harare that have remained in NR IIa while the southern parts of the country have remained largely in NR V. Of significance in the ZINGSA AEZ (2020) is the downgrading of very hot, low lying areas with very short rainfall season in the extreme south (such as Beitbridge) to NR Vb.

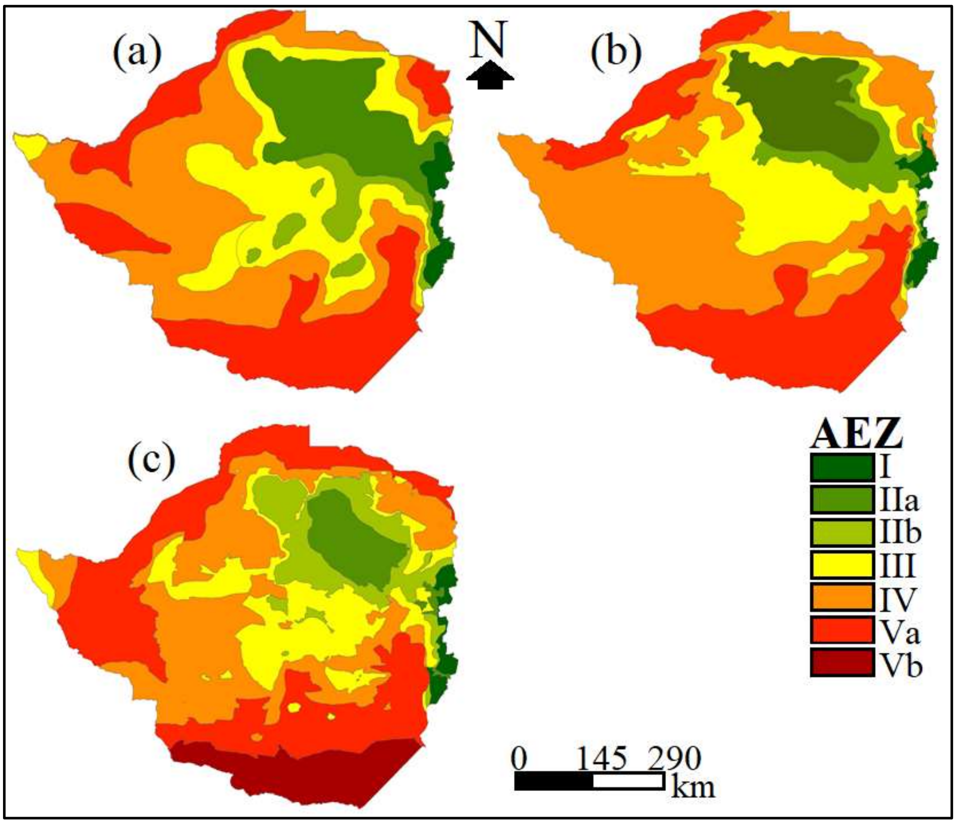

Figure 4.3: A comparison of (a) Agro-Ecological Zone maps by Vincent and Thomas (1960) and (b) AGRITEX (1984) with (c) ZINGSA AEZ (2020)

Figures 4.4 compares the spatial coverage of regions as delineated in the current work and those of Vincent and Thomas (1960) and AGRITEX (1984). The transition matrices accounts for the spatial conversion of regions among the AEZ in each of the maps. A comparison of the ZINGSA AEZ (2020) map and Vincent and Thomas (1960) show that notable conversions occurred between NR IV and NR V. For instance, 12.4 % of NR IV (Vincent and Thomas, 1960) changed to NR Va under the new AEZ. Similarly, 8.6% of former NR V was lost to ZINGSA AEZ (2020) NR Vb. In addition, 8.5% of NR IIIa under Vincent and Thomas shifted to NR IV (7.3%) and NR Va (1.2%) under the revised AEZ. Other remarkable transitions are observed between NR IIa and NR IIb in which the latter gained 9.3% of the region.

Similar conversions are observed between the ZINGSA AEZ (2020) and the Ministry of Agriculture (1984). For instance, 8.5% of NR V (AGRITEX) were lost to NR Vb while 14.3% of NR IV degraded to NR V under the ZINGSA AEZ (2020). However, there were few places that were previously in NR II but are now in NR I under the revised AEZ. A possible mechanism explaining the conversions to a lower NR is change in rainfall distribution across the rainfall season as well as orographic effects in places such as the Eastern highlands where regions on the leeward side are relatively dry resulting in an abrupt transition from NR I to drier regions. The latter case indicates improvement in classification from previous mapping than change due to biophysical environmental factors. Marked differences in biophysical characteristics and agricultural productivity led to the formation of a very hot and dry region covering the extreme southern parts of the country. This led to the segmentation of NR V into a relatively wetter NR Va and a drier and less productive NR Vb. This also enhanced the separation of the NR V characteristics in the northern parts of the countries with the extreme conditions experienced in the southern parts.

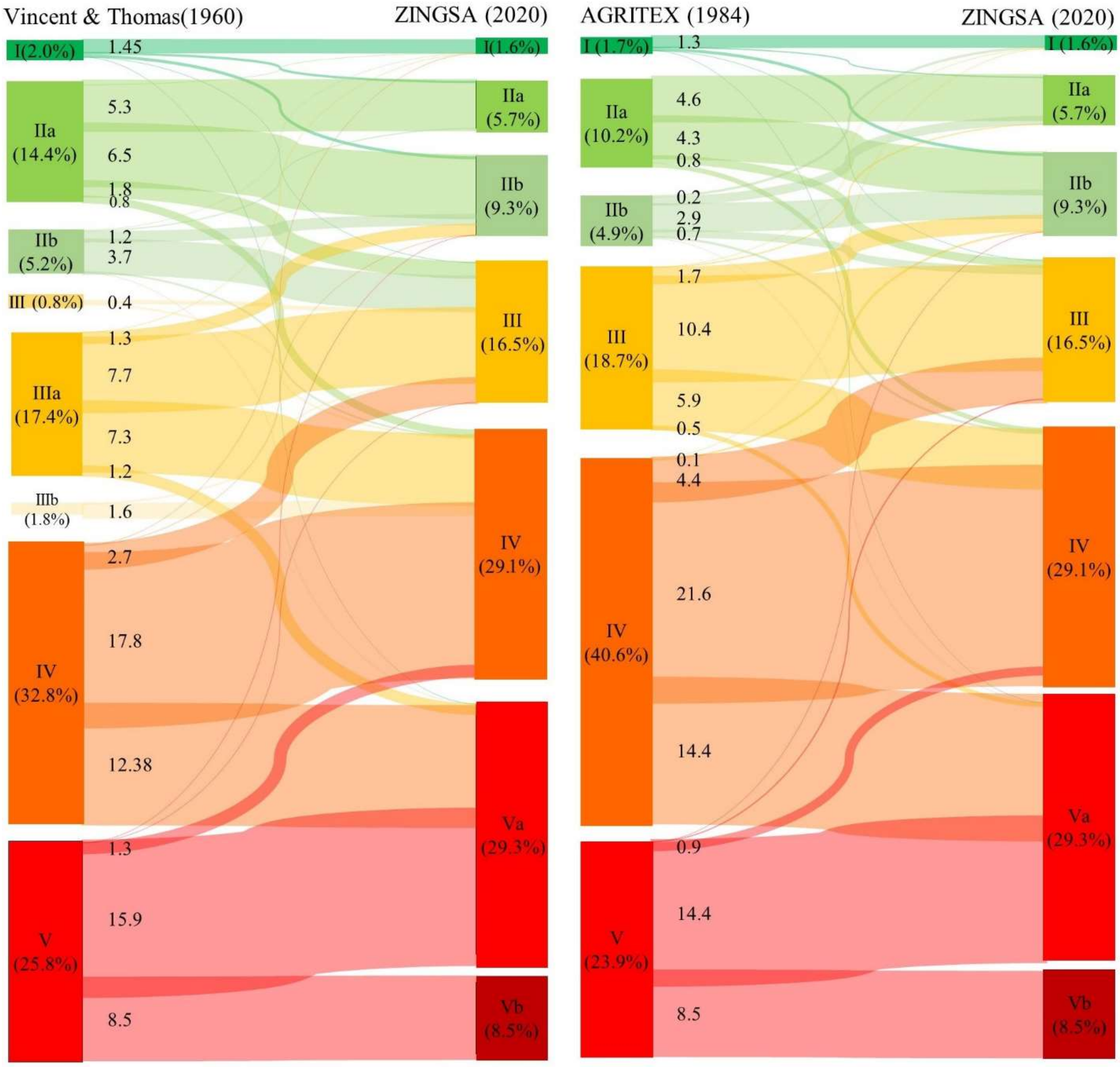

Figure 4.4: Transition matrix between ZINGSA AEZ (2020) and AEZ delineated by Vincent and Thomas (1960) and Ministry of Agriculture (1984)

Figure 4.5.shows the distribution of place where AEZs changed as well as where they remained stable since the previous mapping done by Vincent and Thomas in 1960. Most of the areas previously in NRs I, III and V remained unchanged after the latest mapping. Changes from NR IIa to IIb and from NR IV to V were the most common between the mapping periods (1984 and 2020). Figure 4.5 (left) shows that 49.8% of the country experienced changes in AEZs categories between 1960 and 2020 while the rest remained stable. Of the changed areas, 44.7% experienced downgrading while 5.5% experienced improvement in AEZs over the years (Figure 4.5 – right).

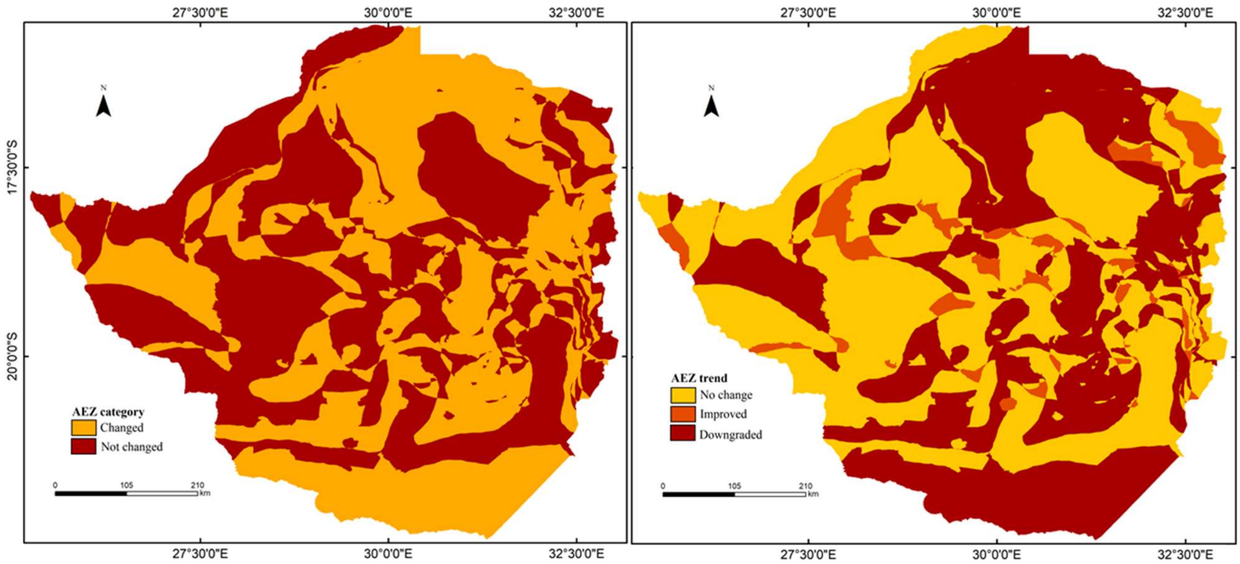

Figure 4.5: Locations with stable and transformed Agro-Ecological Zones between 1960 and 2020

4.5 Characteristics of each Zone and recommended land use

Transitioning from NR I down to NR Vb, mean annual rainfall decreases significantly while the probability of receiving at least 500 mm in a year also decreases from NR I to NR Vb (Figure 4.6 – left). The mean annual rainfall for NR I is about 1250 mm followed by NR IIa with an average of about 975 mm while NR V is the driest with average annual precipitation below 450 mm. Based on precipitation and probability of receiving at least 500 mm in a year, NR Va and the added NR Vb are clearly distinct (Figure 4.6 – right). For example, the mean probability of receiving at least 500mm in a year is below 40% for NR Vb while it is about 65% for NR Va. On average NR IIb has a slightly lower probability of receiving at least 500 mm of annual rainfall than NR IIb although the probability is high in both regions. Cereal crops such as maize which require at least 500 mm of rainfall have at least 30% risk of failure in NR IV, NR Va and NR Vb. The risk of failure for maize (under rain-fed system) in NR Va is at least 40% while it is greater than 60% in NR Vb.

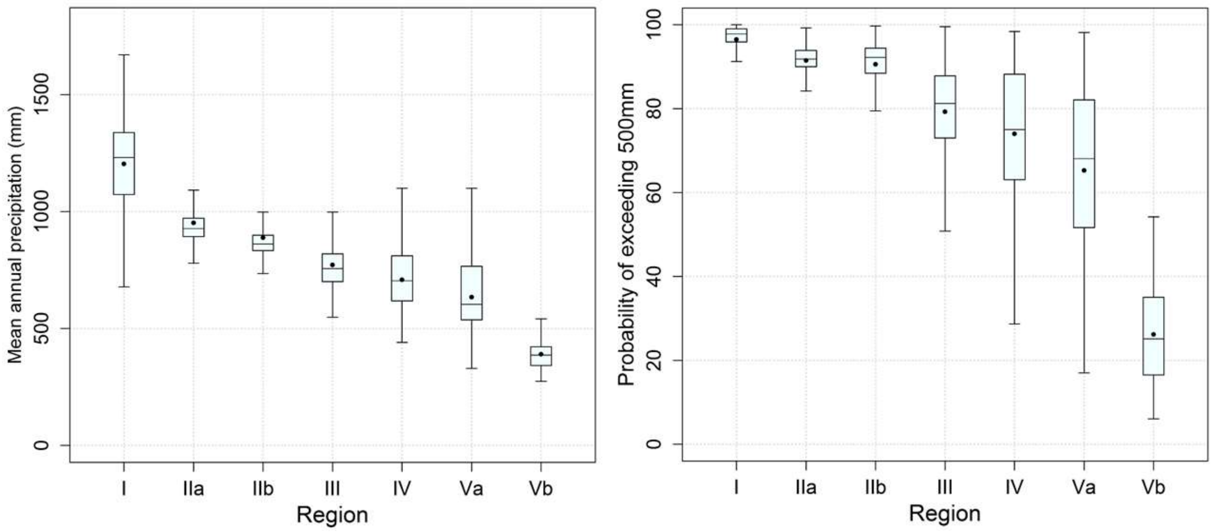

Figure 4.6: Variation in mean annual rainfall and probability of exceeding 500 mm annually in different Agro-Ecological Zones of Zimbabwe

Based on a threshold of 300 mm of annual rainfall, the risk of failure of traditional grains such as sorghum, millet and rapoko was found to be less than 20% in NR I, NR II, NR III, NR IV and NR Va (Figure 4.7 - left). The risk is between 20 and 55% in NR Vb implying that the areas are very dry and not completely suitable for most traditional grains. Except in NR I, risk of failure is high (greater than 70%) for agricultural activities which depend on at least 1000mm of annual rainfall (Figure 4.7 - right). There is need for irrigation to increase productivity of both traditional grains which require less rainfall and other activities which require high amounts of annual rainfall across the country.

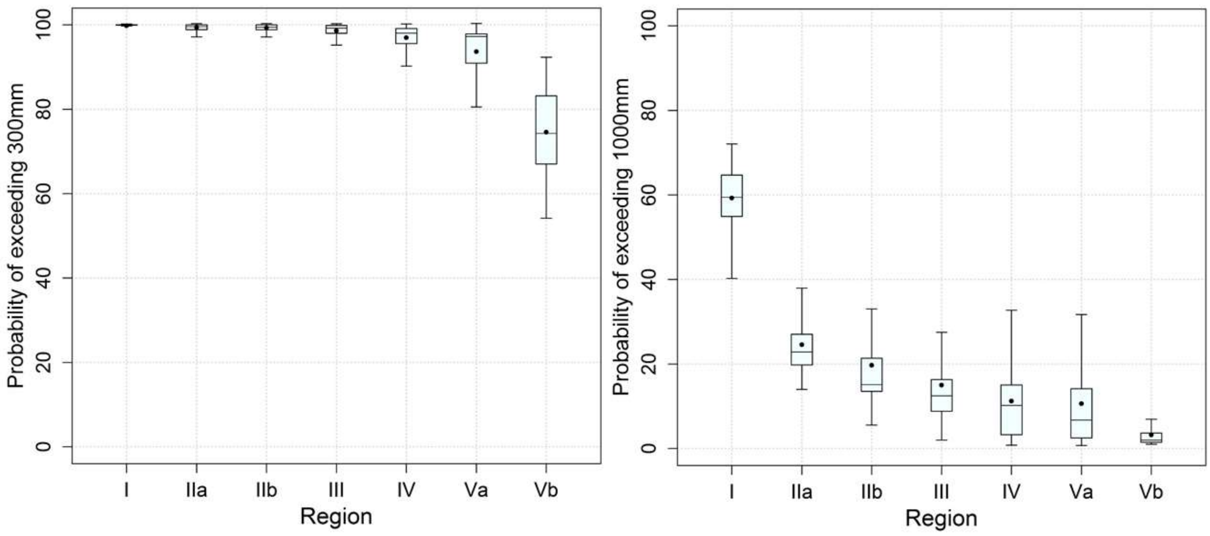

Figure 4.7: Probability of receiving annual rainfall exceeding 300mm (left) and 1000mm (right)

The rainfall season starts very early (about Julian day 158) while the average season is the longest NR I compared to other regions (Figure 4.8). The number of rainy days is also very high (about 55 days) in NR I while NR Vb has an average of about 25 days. NR IIa and NR IIb have approximately the same dates for start of season (around Julian day 162) while NR III and NR IV have same dates for end of season (around Julian day 280).

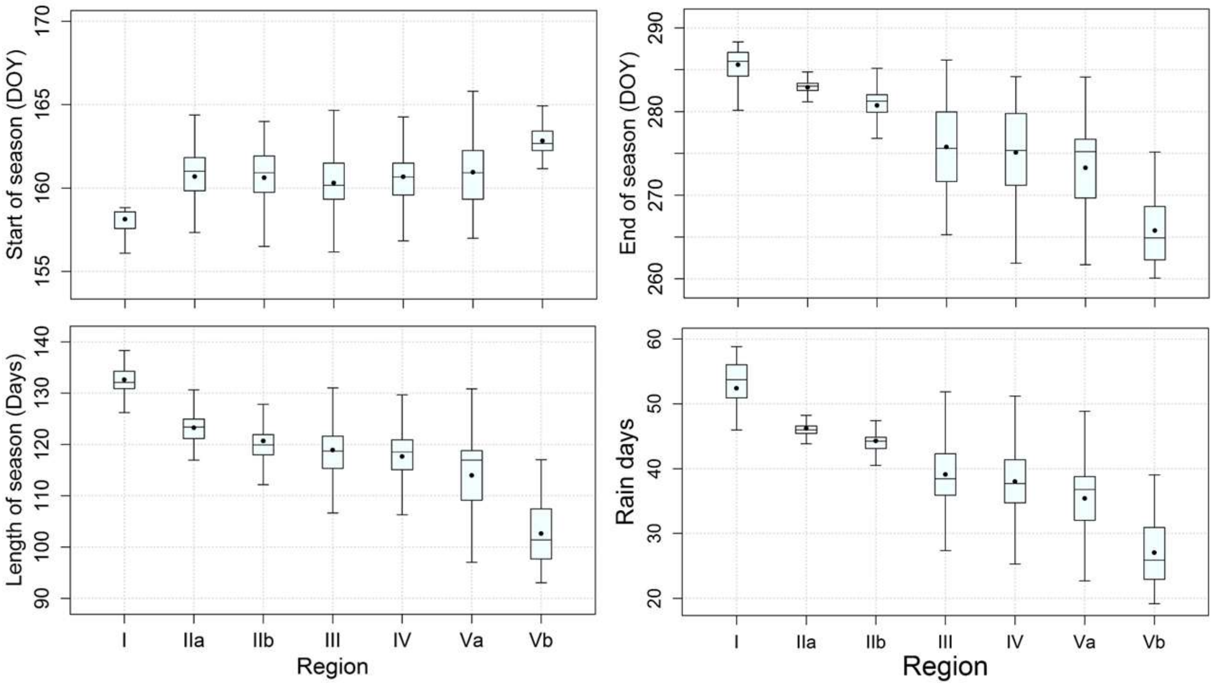

Figure 4.8: Variations in the quality of rainfall season in Agro-Ecological Zones

Although NR IIb and NR III have similar average elevation and mean minimum temperature, they are clearly distinguished based on maximum and mean annual temperature which are higher in NR III than NR IIb (Figure 4.9). There is a general decrease in altitude and increase in temperature moving from NR I down to NR Vb. Therefore, beside low annual precipitation and low probability of exceeding 500 mm, NR Va and NR Vb areas also experience high temperatures.

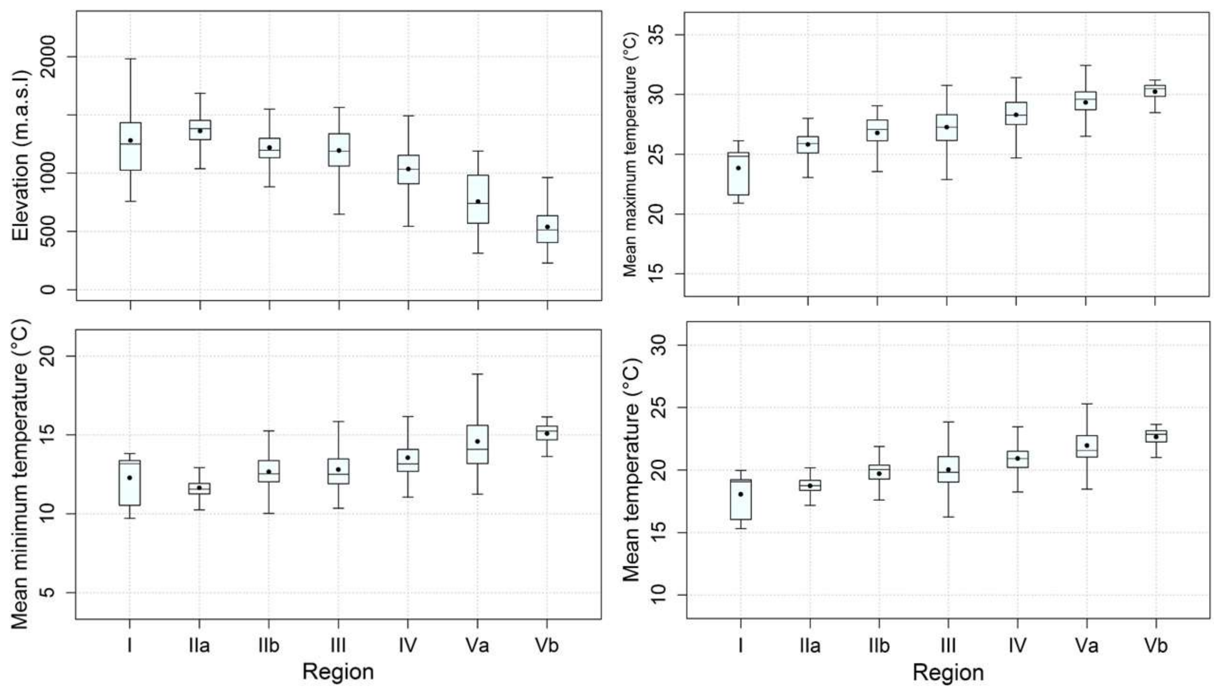

Figure 4.9: Variation of elevation and temperature in Agro-Ecological Zones of Zimbabwe

Table 4.2 provides the detailed characteristics and land-use in each of the AEZs. These recommended land-uses were based on several factors such as climatic and soil considerations among other relevant factors. Further, recommendations were gathered from consultations with experts from AGRITEX and Department of Meteorological Services of Zimbabwe.

Table 4.2: Recommended land use [land management practices] in Agro-Ecological Zones of Zimbabwe

Region	**Climatic Conditions**	**Dominant soil group(s)**	**Recommended Land-use [land Management]**
I	Annual rainfall > 1000mm but possible to get amounts less than 1000, Probability of exceeding 500mm at least 95%, length of rainfall season > 130days and maximum temperature between 21 and 25°C	Orthoferrallitic	Suitable for forestry plantations, banana apples, macadamia nuts, coffee, and tea in addition to intensive livestock production. The region is also suitable for long season (late maturing) maize varieties - requiring >130 days to maturity), Irish potato, field peas and soya beans. [Terracing is highly recommended along steep terrains to minimize soil erosion considering the soils are susceptible to erosion due to a weakly developed crumb structure. The soils require regular soil pH monitoring].
IIa	Annual rainfall between 750 and 1000mm (it is not unusual to get amounts below 750 and above 1000 mm in places), Probability of exceeding 500mm at least 90%, length of rainfall season between 120 and 130days and maximum temperature between 23 and 27°C	Paraferrallitic and Fersiallitic; sporadic occurrence of orthoferrallitic	Suitable for maize varieties requiring 120-130 days to maturity, flue-cured tobacco, groundnuts, Irish potato, cotton and soybean. Barley and wheat are grown under irrigation in the winter and drier months, Intensive livestock production (beef, dairy and poultry) (based on pastures and pen fattening) is also recommended.
IIb	Annual rainfall between 750 and 1000mm (it is not unusual to get amounts below 750 and above 1000 mm in places), Probability of exceeding 500mm at least 80%, length of rainfall season between 115 and 120 days and maximum temperature between 25 and 28°C	Fersiallitic	Suitable for maize varieties requiring 115-120 days to maturity, Cotton, Irish potato, barley, flue-cured tobacco, groundnuts, sorghum, sugar beans, coffee and horticultural crops can be successfully grown. Winter wheat is also grown under irrigation. Intensive livestock production is also recommended in this region.

Region	Climatic Conditions	Dominant soil group(s)	Recommended Land-use [land Management]
III	Annual rainfall between 650 and 800mm while some places may receive amounts exceeding 800mm, Probability of exceeding 500mm between 75 and 80%, length of rainfall season between 110 and 120days and maximum temperature between 25 and 28°C	Fersiallitic	Suitable for maize varieties requiring 110-120 days to maturity. Soybean, groundnuts, cotton and sunflower are also suitable crops in this region. Supplementary irrigation is critical for successful crop production. The region is also suitable for semi-intensive livestock production (beef, dairy and small stock (e.g goats and poultry).
IV	Annual rainfall between 450 and 650mm which may be exceeded in some places within the region, Probability of exceeding 500mm between 60 and 80%, length of rainfall season between 105 and 120 days and maximum temperature between 27 and 29°C	Fersiallitic; sporadic occurences of the sodic, lithosol and the siallitic	Suitable for maize varieties requiring 105-120 days to maturity. However, in the absence of irrigation farmers are advised to grow drought tolerant crops such as sorghum (finger millet, pearl millet, water melons and cowpeas. Extensive cattle ranching, rearing of small stock (e.g. goats and poultry) and wildlife are ideal farming systems for this region. [Rainwater harvesting techniques are required to capture the little moisture in the region].
Va	Annual rainfall less than 650mm in the southern areas while Region Va areas in the Zambezi Valley to the north of the country mostly exceed this amount, Probability of exceeding 500mm between 60 and 80%, length of rainfall season between 100 and 120days and maximum temperature between 28 and 30°C	Fersiallitic; sporadic occurences of vertisol and the siallitic	Suitable for extensive cattle ranching and goat production. The region is marginal for drought tolerant crops such as sorghum, finger millet, pearl millet and cowpeas. Sugarcane is an ideal crop under irrigation, particularly in the vertisol and siallitic soils. Tree plantations, mainly oranges, lemons and lime are also recommended where irrigation is available. This region is also suitable for extensive game-ranching and tourism
Vb	Annual rainfall below 600mm, Probability of exceeding 500mm less than 60%, length of rainfall season less than 110days and maximum temperature between 28 and 32°C	Siallitic; sporadic occurrences of the sodic and regosols	Tree plantations, mainly oranges, lemons and lime are recommended where irrigation is available. This region is also suitable for extensive cattle ranching, goats and wildlife tourism.

4.6 Summary

The objective of this study was to use geospatial technologies and earth observation to revise the AEZs in light of the changing climate since the first attempt by Vincent and Thomas in 1960. Results of the agro-ecological zoning based on methodology proposed by Vincent and Thomas (1960) indicate there have been significant shifts in AEZs. In particular, though the distribution of AEZs in Zimbabwe has been relatively stable, several Regions have contracted owing to shortening of the rainfall season of some stations (areas) in a particular NR. This shortening of season is attributed to a reduction in rainfall coupled with increase in PET, which have not been uniform for stations (areas) in a given NR. . On the overall, results show that NRs III, IV and V,expanded at the expense of NRs I, IIa and IIb. An important development is that NRV, the driest region in the country, has been divided into NRs Va and Vb indicating further worsening rainfall patterns in this region.. These changes are not monotonous over time, but have been characterised by a shift in 1981 which in turn affected the extent and distribution of AEZ. It is therefore concluded that geospatial technologies provide a rapid tool for agro-ecological zoning over relatively large spatial scale such as the national scale. However, results could be improved by using validated and quality controlled station based meteorological data.

Finally, being mindful of the fact that these newly derived boundaries were even going to shift at a much faster rate than before, efforts have been made in ensuring that the map updates automatically the moment more parameters that factor in climate change becomes available. In-order to ensure effective use of modern technologies, information on the map (which includes point data such as fertilizer use, rainfall and temperature characteristics as well as recommended land use) can easily be accessed through an mobile application that is installed on a smartphone with specified minimum requirements. Consequently, accessibility of information on the map through the smartphone will ensure efficient and effective management of land and water resources culminating in enhanced agricultural productivity. Although this is an ongoing process, some of the aspects are being addressed in the following chapter.

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CHAPTER 5 : AGRO ZIM MOBILE APPLICATION

5.1 Introduction

Although the current project used geospatial capabilities to revise Zimbabwe's AEZs which were developed in 1960 by Vincent and Thomas, the benefits of these new zones could be derived by adopting Information and Communication Technology (ICT) in the dissemination and use of the information. In this regard, after the redefinition of the zones, a user-friendly mobile application was developed to enable local and micro-level planning for effective sustainable agricultural development in Zimbabwe. The agro-ecological zoning mobile application is an android mobile application (App) hereby referred to as "Agro Zim App" , that summarizes information about the redefined agroecological zones of Zimbabwe (ZINGSA AEZ, 2020). The Zim AEZ App is map-driven and enables the user to derive on-point resolution data that allows one to get the data pertaining to a specific position or area within Zimbabwe. The App also has a database of Wards, Districts and Provinces in Zimbabwe which assists users in location and reference of retrived data. In addition, the App has a land-use panel where users can be advised or get recommended types of crops and livestock which are best suited to the selected agro-ecological conditions.

5.2 Objectives

1. To develop an interactive mobile application that links the AEZ map to agronomic requirements of major crops and livestock production systems in Zimbabwe.
2. To develop an updatable database of agro-ecological zone attributes (updatable AEZ data as well as input variables).
3. To provide recommendations that lead to an assessment of land-use suitability and potential productivity of a selected area.
4. To provide a user manual for the interactive mobile application (Annex 1).

5.3 Expected Outcomes of the Agro Zim Mobile Application

The interactive mobile application is designed for use in planning and advisory purposes by farmers, agricultural and natural resource management planners and practitioners, rural and urban development actors, health practitioners and high-level policymakers including international research development agencies. Banking institutions can also use the information from the App to assess the viability of projects with potential of funding for farmers. This includes new (revised) agricultural production domains identified for supporting the development of specialized value chains, as well as production of key crops/livestock for household food and nutrition security. In this way, the use of the App has capacity to enhance food and income security at the household and national level.

Research and development specialists may use the map as a basis for the generation and advancement of applications of geospatial and space data and technologies for national development. The App also has potential to trigger research on how to:

- improve the productivity of marginal areas
- reduce risks associated with agricultural activities in marginal areas: and
- use different climate-smart technologies for the restoration of degraded lands.

The map will also function as a dynamic framework for the AEZs planning tool in Zimbabwe that is updatable in future under the changing climate.

5.4 Methodology and Design

This section summarises the mobile application design and development process. The tools and techniques used in the development of this application are listed as follows.

1. MySQL/ Maria Database
2. Hypertext Markup Language (HTML)
3. JavaScript
4. Bootstrap
5. Asynchronous Javascript XML (AJAX)
6. Google maps/ Map box/ osmdroid / picture map
7. Android SDK
8. Java programing language
9. PhP server scripting language
10. MySQL database
11. Retrofit REST client

The application is android driven, thus it runs on Android mobile phones only. The idea behind developing the application was to fuse the ZINGSA AEZ (2020) map of Zimbabwe into the existing world maps in order to make it interactive. Google maps was selected due to the vastness of required resources in the map and other functionalities which we used for reverse geo-coding. Geo-coding was applied for searching and ground_overlay which enabled overlaying the custom ZINGSA AEZ (2020) map within the already existing google maps. The application has a 2-tier architecture which is a PhP driven backend and a native android driven front-end. The data used in the creation of the maps is all kept in a MySQL database (Figure 5.1).

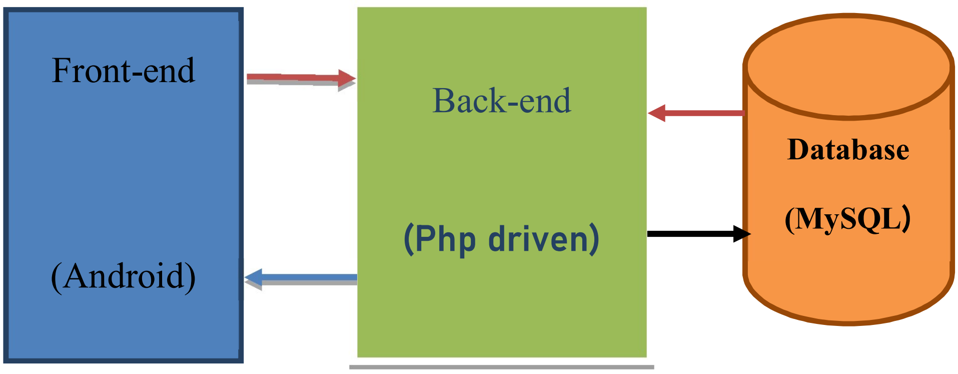

Figure 5.1: Basic System Architecture

5.4.1 Development Method

A prototype software development model was adopted for this work. This method or process involves the building of an initial or first system prototype (an early approximation of a final system or product), which is then tested to further polish the expected user requirements resulting in a second prototype. The working and reworking of prototype versions is an iterative process which is repeated until an acceptable prototype is finally achieved. It is from this final prototype that a complete system or product can now be developed. For the AEZ mobile App, the developers worked closely as well as back and forth with the content experts in Climate Change and GIS in trying to come up with the best system through numerous revised prototypes to ensure that the expected objectives were met.

5.4.2 System Architecture Components

Figure 5.2 shows the architecture and contextual diagram. The architecture has four distinct core elements with various functionalities that make up the overall system. The elements are the database, web services, mobile application, and open Application Programming Interface (API).

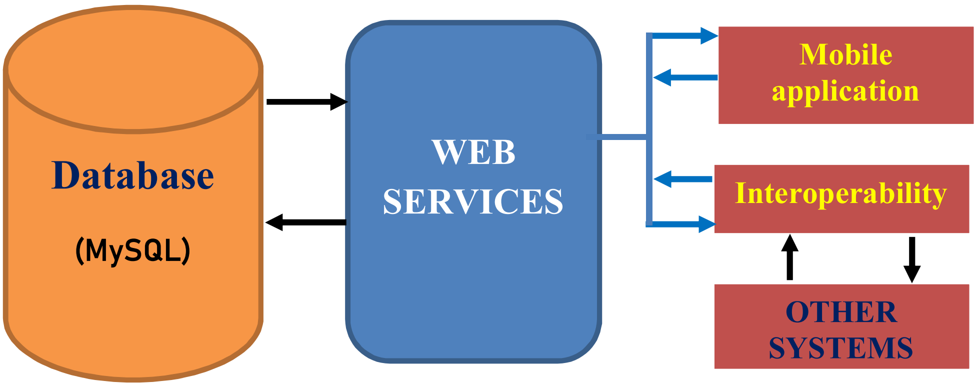

Figure 5.2: Basic Mobile Application Architecture

5.4.3 Database

Database of choice is MySQL which allows the easy use of the Structured Query Language (SQL) to manipulate the data in the database. All the collected data is to be stored and formatted into tables which will be connected according to the relationships between them in the tables. The Database Management System (DBMS) and the web services are hosted live online and they form the backbone of the system. This architecture follows a data-centric approach, which is an approach in which all the system is mainly dependent on the database. The mobile applications access the site via the web services.

5.4.4 Web Services

Web services refer to any piece of software that makes data available over the internet so in general, this is a framework that makes it possible to access information in the database through the mobile application.

5.4.5 Mobile Application

This is also an interface that can be used to access the system on an android mobile phone without using the Uniform Resource Locator (URL).

5.4.6 Interoperability Layer

It can also be called the open Application Programming Interface (API). It allows other developers to access the data in the application (map). The open integration layer extends the capability to get data from the database and permission to edit or update the values in the database, thus giving room for further improvement of the system.

5.4.7 Mobile Application Architecture

The android application is written in android core and Extensible Markup Language (XML) for designs. It utilizes the Google maps API to acquire the required maps and uses map overlay panels to set custom color indicators and other information. The android application is based on the Model View Controller (MVC) architecture illustrated in Figure 5.3.

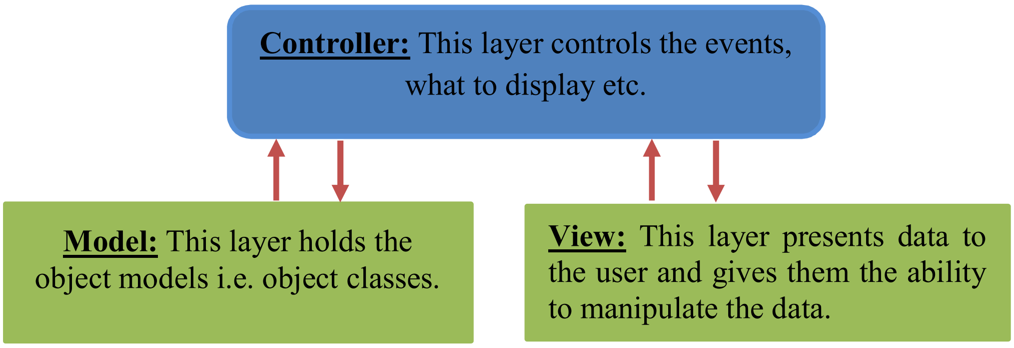

Figure 5.3: Model View Controller architecture

The view mainly uses fragments technology. For Http requests, retrofit coupled with okhttp and Gson Json factory is used.

5.5 System Requirements
This section entails the mobile application requirements.

5.5.1 Functional Requirements of the Agro Zim App

- The system should be able to automatically detect user's current location.

- The user should be able to view any selected attribute and get an attribute summary about the selected location.
- The user should be able to search a location and the system return specified attribute summary about the clicked location
- The user should get results after a click on a certain point on the map, every point on the map should return values.
- The system should display different attribute specific map.
- On click, the system should display the name and province of the clicked location.

5.5.2 Non-Functional Requirements of the Agro Zim App

- Performance– the system should display the required attribute map and show summary information about the clicked location. The system should display the user's current location.
- Availability– users require a service that is readily available at their disposal and ready to respond.
- Accessibility–The use of a web interface allows the system to be accessed by any device given that the main device of use is non-functional or it the one in need of repairs. Also, the system should be easy to access on a mobile application at any time the user wants to access it.
- Usability – the system must be user-friendly; users should feel comfortable using the system. The users will be given user manual to make easy for them to get familiarized with the system.
- Network efficiency–The system must be able to integrate into the services without taking up great amounts of bandwidth.

5.6 System Menu

5.6.1 System Configuration

Users are provided with a Graphic User Interface (GUI) to interact with the database and complete tasks such as data retrieval and display.

5.6.2 Data Flow

Users are presented with an interface from which they can select a variety of forms. Data is retrieved from the database by the user after clicking the buttons in the menu (Figure 5.4).

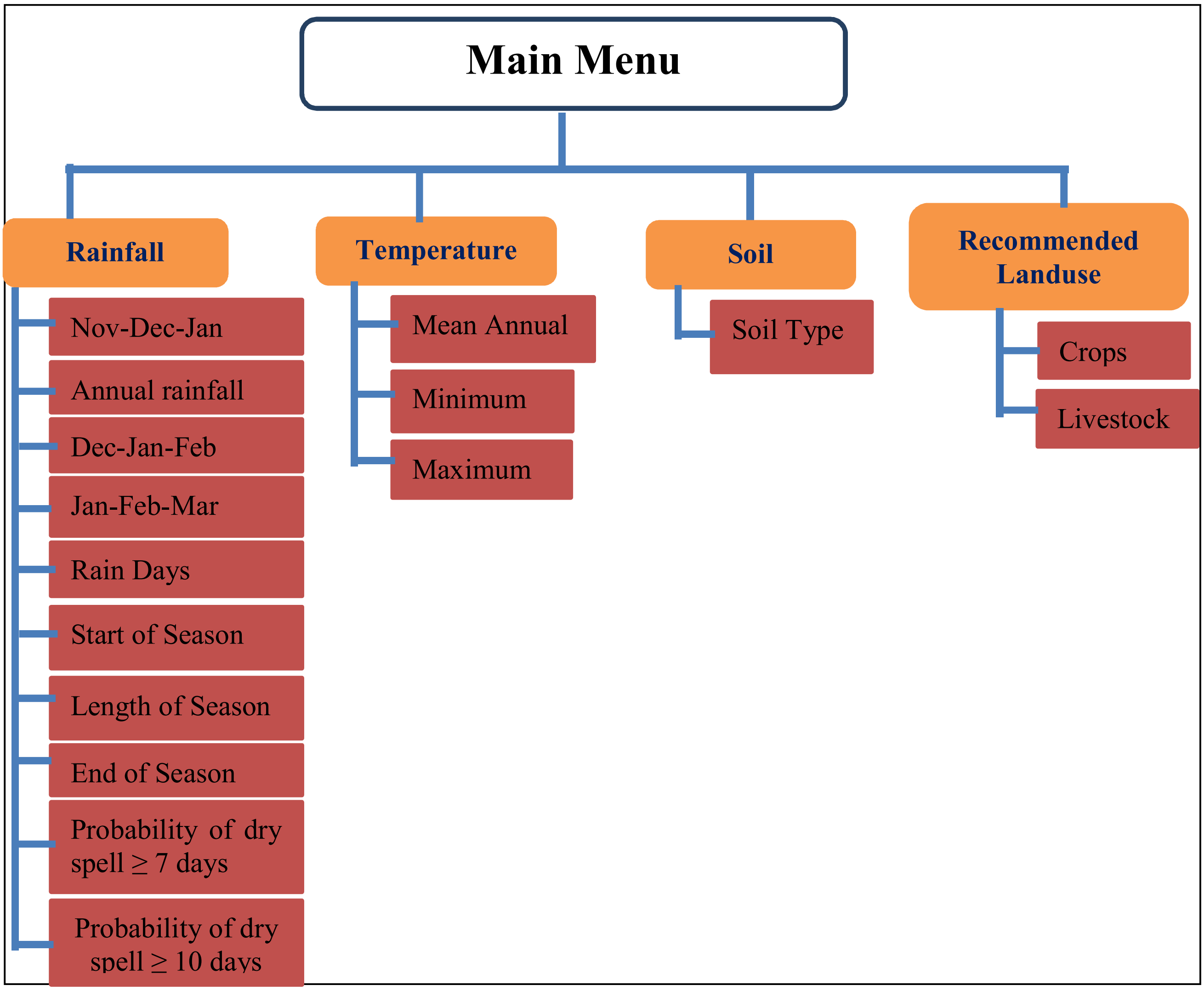

Figure 5.4: Data Flow Diagram for AEZ Map attributes

5.7 Summary

The Agro Zim mobile application is used as a planning and advisory tool by farmers, agricultural and natural resource management planners and practitioners, rural and urban development actors, health practitioners and high-level policy makers including international research development agencies. Additionally, the App makes it easy for institions such as banks and financial houses to assess viability of projects presented by farmers applying for loans. The overall project is expected to increase food and income security at household and national level. Research and development specialists can use the AEZ map to generate applications of geo-spatial and space data and technologies for national development. The Agro Zim Mobile Application to support the ZINGSA AEZ (2020) map functions as a dynamic framework for agricultural realated planning. The tool is updatable for future changing climate. Annex 1 is a user manual which provides more details on how to use the App.

CHAPTER 6: RECOMMENDATIONS

Resources should be availed to support the following research and activities designed to enhance the effectiveness of the current ZINGSA AEZ (2020):

- Although the agro-ecological regions generated through an automated procedure were more than 70% accurate, the method still needs further improvement so as to eventually achieve 100% and to minimize costs and time through extensive field visits.
- Inclusion of factors such as vegetation dynamics should be further tested for improving mapping of the AEZs.
- There is also need, after improving automated mapping procedure, to use statistical and dynamic models to predict future spatial configuration of zones under different land-use, land management and environmental change scenarios (including climate change scenarios).
- The next update should be done timeously before the ZINGSA AEZ (2020) efforts are rapidly eroded due to the high sensitivity of the AEZs to climate change.
- The developed dissemination app needs continuous updating and improvement to suit the needs of different levels of stakeholders over time. This includes addition of other important information such as area specific fertilizer application recommendations.
- The developed app also need to be extended to other platforms like apple devices and desktop PCs.
- Agricultural practitioners need to be trained on the new agro-ecological regions and recommended activities as well as on using the developed mobile application to access area specific information.
- Establishment of more weather stations around the country so as to have more empirical data to use in the improvement of the ZINGSA AEZ.
- Improvement of the Zimbabwe soil map through regional soil surveys at scales larger than 1:250 000 so as to improve resolution of soils data that can be used to improve the ZINGSA AEZ.

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LIST OF ANNEXES

Annex I: Agro Zim Mobile Application User Manual

i) System Overview

This user manual gives a practical overview of the main features of the Zimbabwe AEZs Map and how to navigate through the interactive mobile application. The manual comprises the menu page with the navigation buttons namely, the AEZ Map, the Rainfall Map, the Temperature Map and the Land-use recommendations Map. The soil type for each area are embedded in all the four maps and are displayed on click. In the same way rainfall and temperature attributes are also displayed on click in their respective maps. When a point is clicked, the required information is fetched from the database and displayed. The interface allows point data visualization, and download of data in both space and time. You will learn how to visualize historical and present conditions based on proven meteorological and hydrologic forecasts. This manual provides a general walk-through guide to the system, from beginning to exit.

Help Desk

In the event of a question pertaining to the operation of the program, users should contact:
Dr. L. C. Sakala- Mobile (+263 772 352 551)- Email: lsakala@gmail.com and
Mr. L. H. Ali   Mobile (+263 784 548 051) – Email: leohassanali905@gmail.com

ii) User Interface

The AEZ map has four major attributes: rainfall, temperature, soil and evapotranspiration. Each attribute has tuples which constitute the attribute summary. Thus each location has an attribute summary. The user should be able to retrieve attributes about a certain location.

iii)Home Page

Figure 1 shows a basic display of the access menu of the AEZ map. The basic home page shows by default a detailed map containing all the layers across attributes. The buttons for the access menu allows for the navigation from the home page to specific attribute maps such as the main map - AEZs, rainfall, temperature and land-use maps.

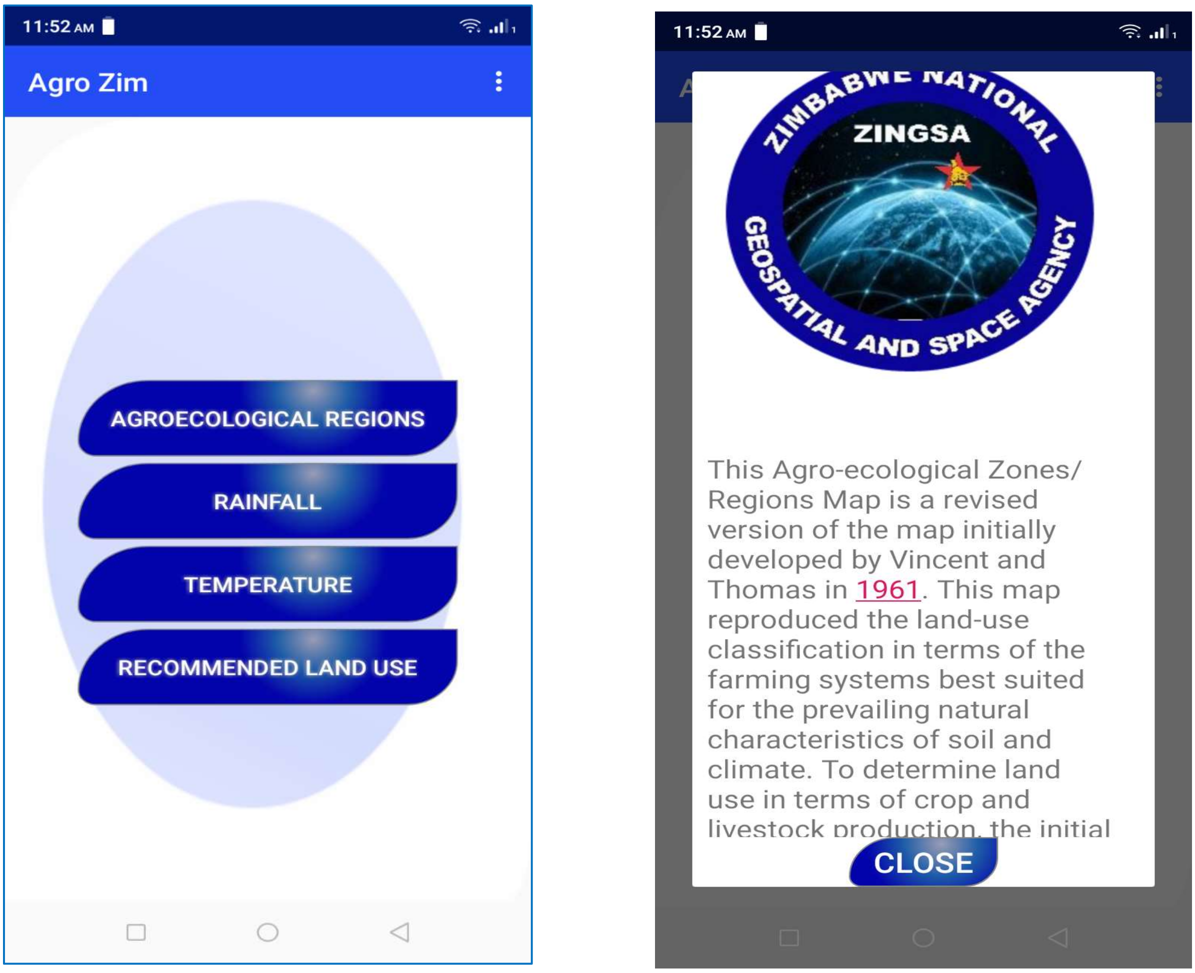


Figure 1: Access Menu of the Mobile Application (Front Page) and the "About" Section

'The About' section of the App comes up as a drop-down after clicking the three dots on the upper right side corner. This is where information about the purpose of the App is displayed.

iv) Agro-ecological Zones Map of Zimbabwe

The rainfall and temperature attributes will be shown in the AEZ map with varying summaries and maps visualization as per each region. On clicking the 'my location' button, the App will automatically detect and retrieves your current location on the map in line with Google location services. The user clicks a point on the map and retrieves the attribute summary of the on-point location at the bottom of the map. The scale at the bottom of the map is to be used when the map has been reset.

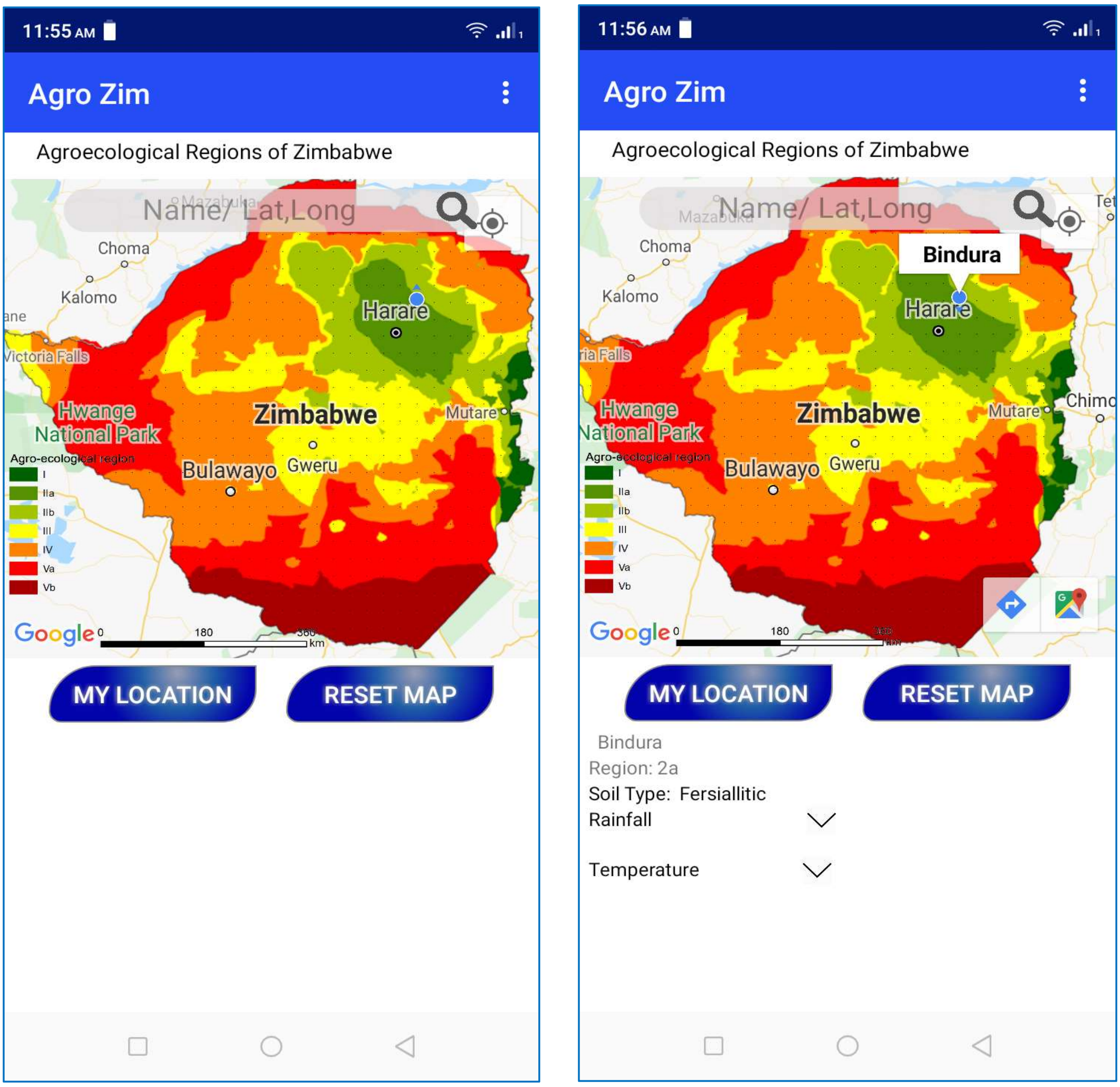


Figure 2: Agro-ecological Zones Map of Zimbabwe

The ‘**My Location**’ button searches through the map show the current location of the user. For example, if a user is in Bindura and they click on ‘**My Location**’, then the current Bindura location is displayed. Additionally, if the user clicks on the ‘**RESET** map’ button, then the map readjusts itself.

v) Search function by District name or Longitude & Latitude points

The search function can be used as an option by typing in the District name and the required attributes of rainfall and temperature will be retrieved as shown in Figure 3 on the left panel where Gweru District was typed in the space provided and Temperature attributes were selected and displayed.

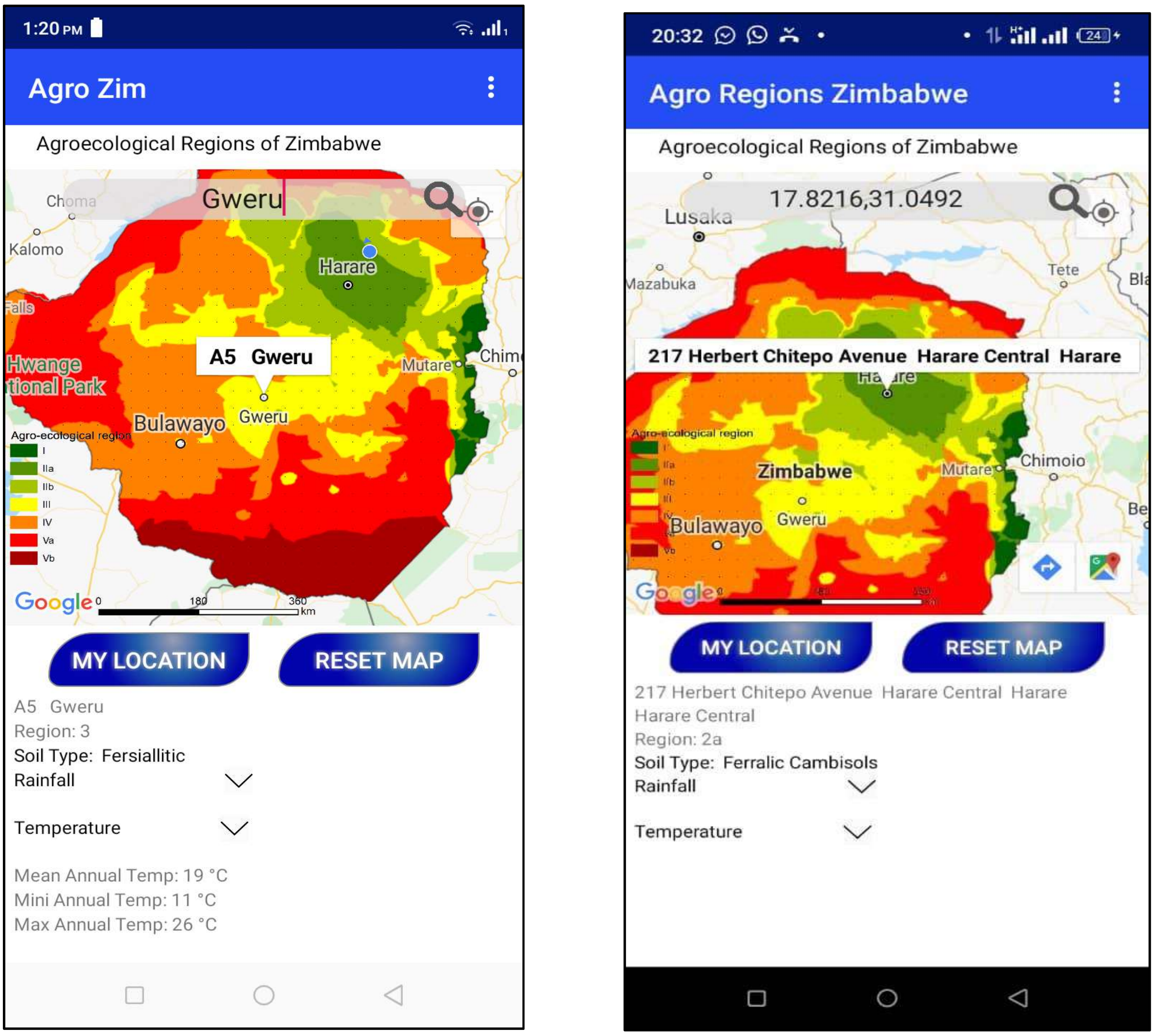


Figure 3: How to search by District name (left panel) and by Longitude & Latitude (right panel)

Additionally, researchers who are well-versed geocoordinates could also use Latitude and Longitude values to search for a specific point of their choice. For example, if you enter ***[17.8216, 31.0492]*** values the Harare Central location is retrieved as shown on the right panel. Users can play around any correct figures in Zimbabwe to locate different areas with their corresponding attributes.

vi) Rainfall attributes

When a user selects the Chegutu District point, the following Rainfall parameters are visualized. Since there are 10 parameters under rainfall they cannot all be displayed at once, rather the user has to scroll up and down to navigate through all the parameters. Figure 4 shows all the parameters displayed in two maps.

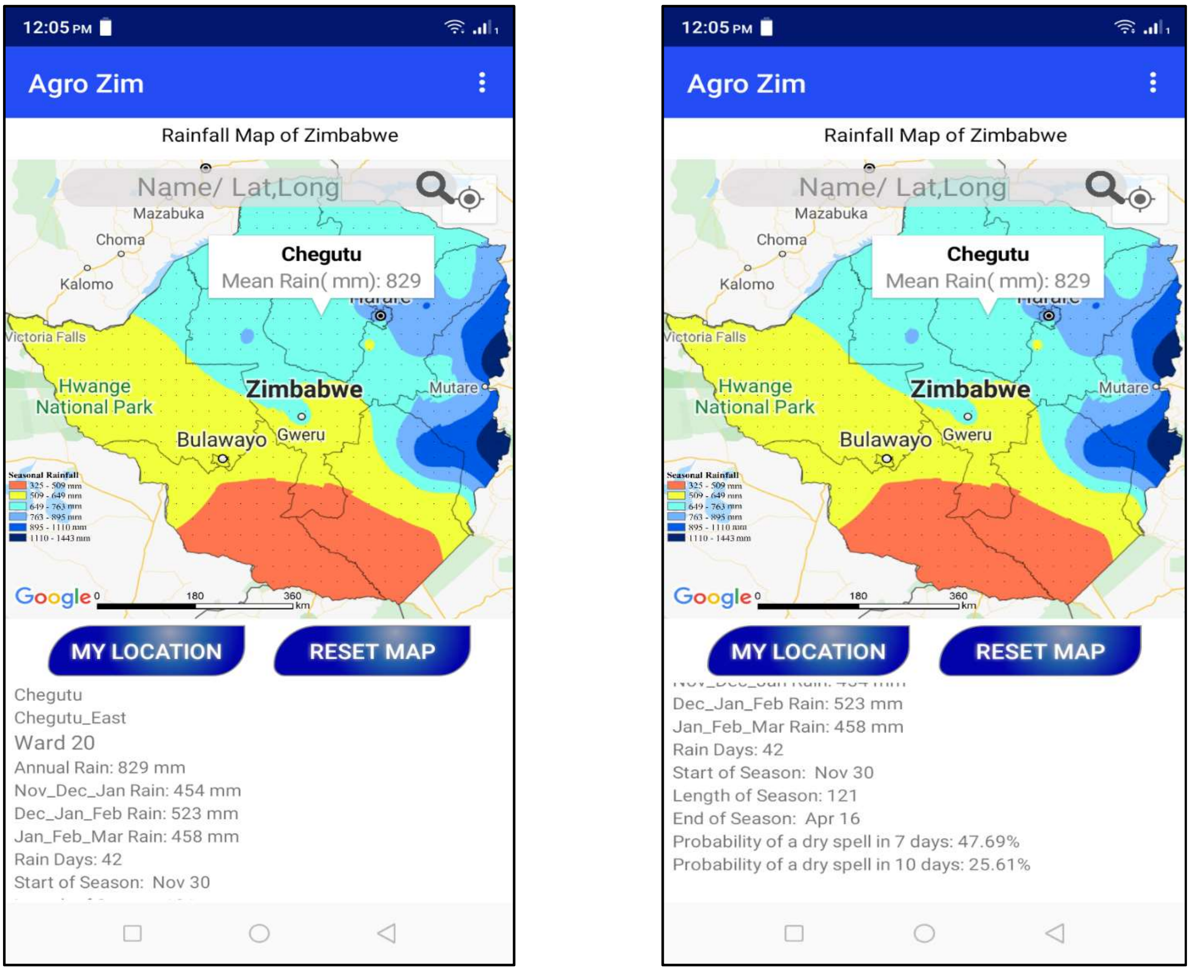


Figure 4: Rainfall attributes for selected District (Chegutu)

The relevance of the meteorological parameters to agriculture for Chegutu illustrated in Figure 4 show that it receives a seasonal rainfall amount of 829mm; over 42 days (i.e. number of rain days). The start of the season for the same place is shown to be on 30 November, lasting for 121 days (i.e. length of the season), and ending on 16 April. The rainfall amount received during the months of Nov-Dec-Jan, Dec-Jan-Feb, and Jan-Feb-Mar is shown to be 454, 523, and 458mm respectively. For the same place, the probability of a dry spell that lasts at least 7(10) days is 47.69% (25.61%).

vii) Temperature attributes

The Temperature Map of Zimbabwe in Figure 5 has the following attributes: Mean Annual Temperature, Minimum Annual Temperature, and Maximum Annual Temperature.

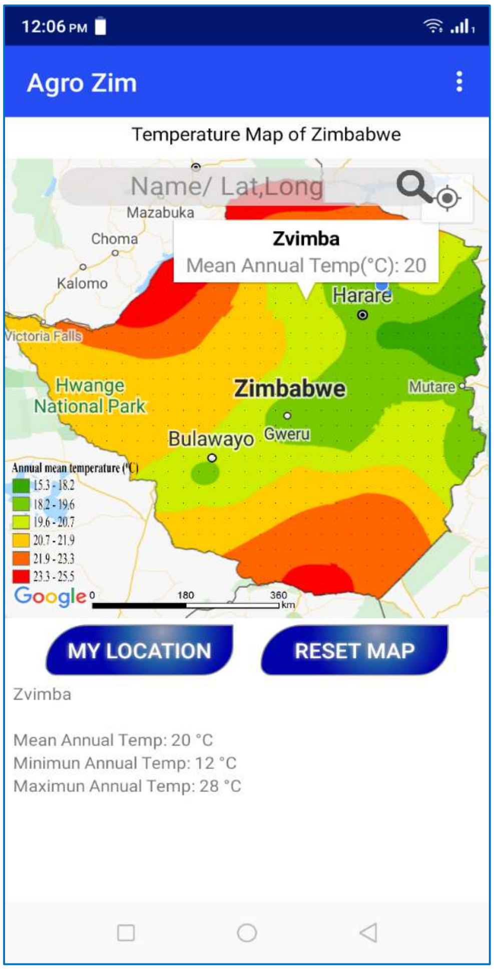


Figure 5: Mean Annual Temperature

When the user clicks inside the map it is the Mean Annual Temperature that is displayed. For example, for Zvimba District the Mean Annual Temperature is 20 degrees celsius.

viii) Recommended land-use

The landuse of Zimbabwe is illustrated in Figure 6. Hwange District is displayed under Region Va and the soil types is Eutric Cambisols. The recommended land use in Hwange is goat, sheep, beef cattle rearing and pasture grasses. Nyanga District is displayed under Region I and the soil type is Stagnic Phaezems. The recommended land use is growing of tea, coffee, bananas and macademia nuts.

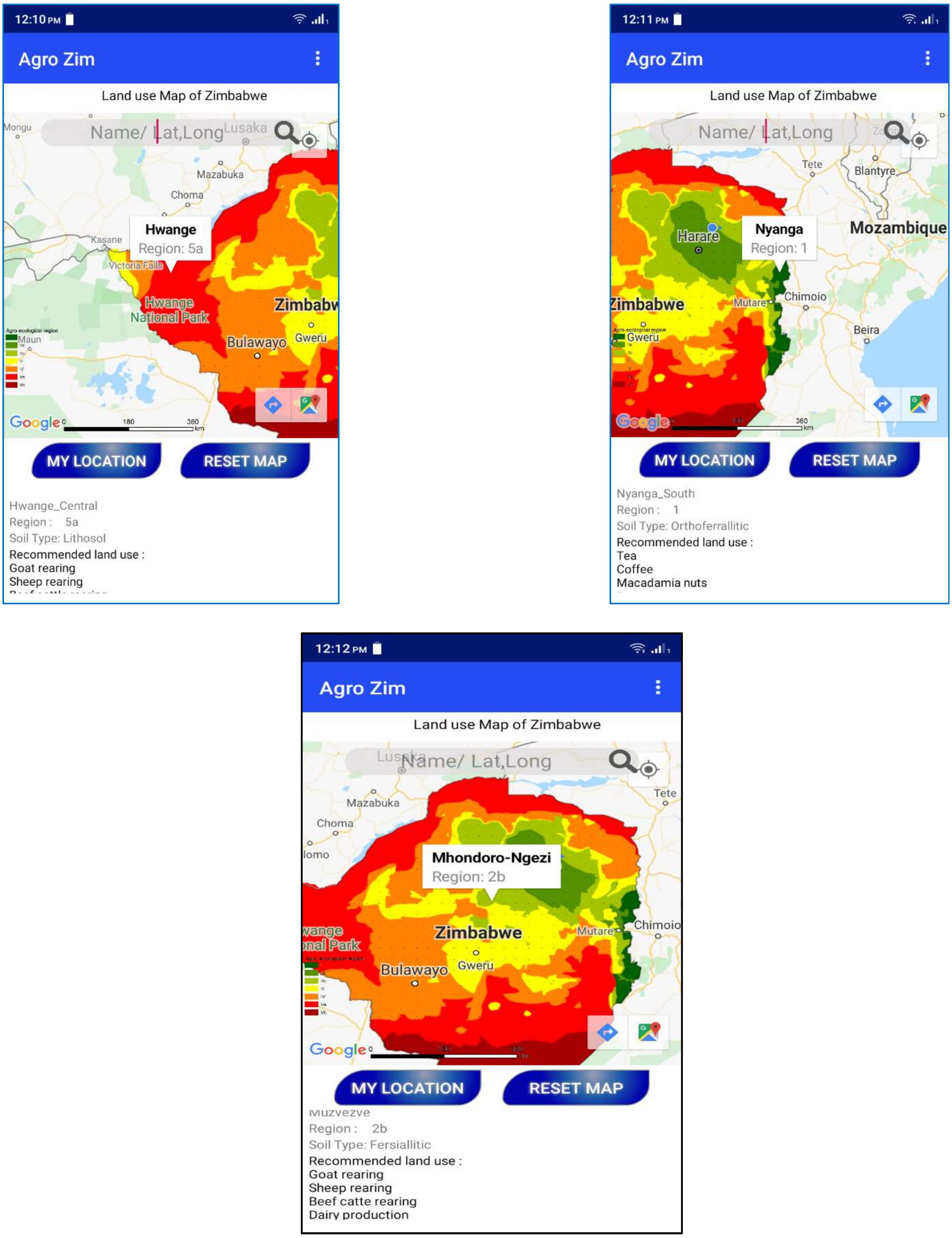


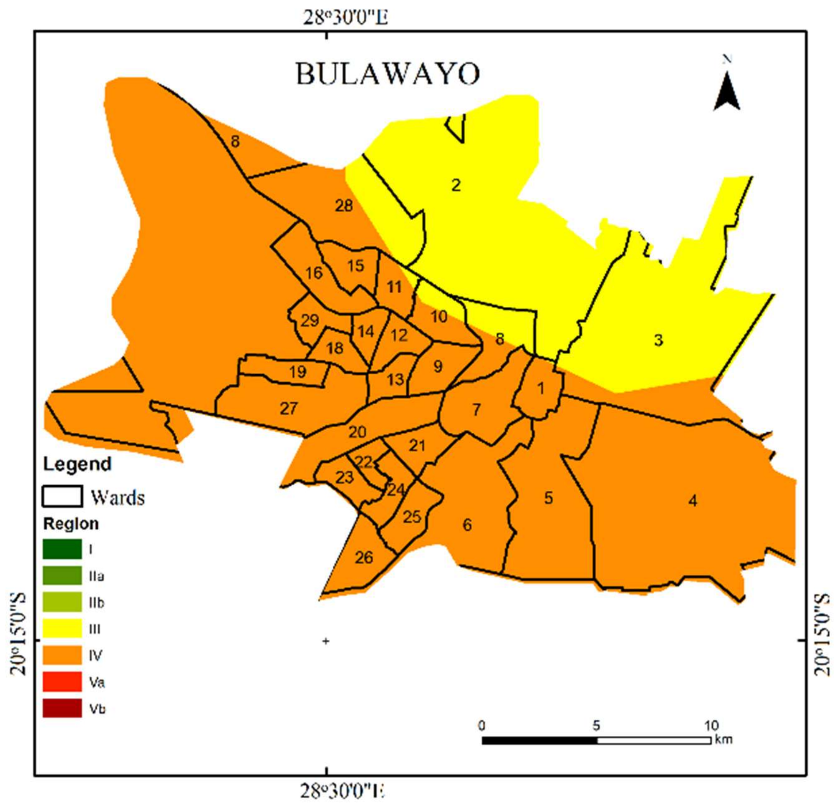
Figure 6: Recommended Landuse for Region Va (top left), Region I (right panel) and Region IIb (bottom left)

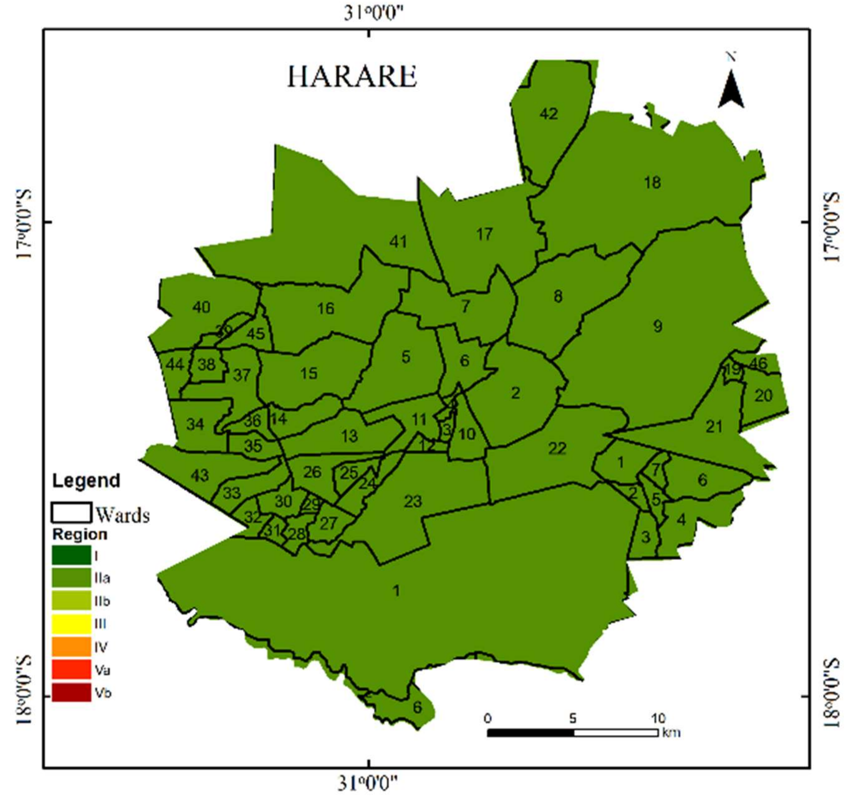
Mondoro-Ngezi District is displayed under Region IIb and the soil type is Fersiallitic. The recommended land use is growing of tea, coffee, bananas and macademia nuts.

ix) Exit System

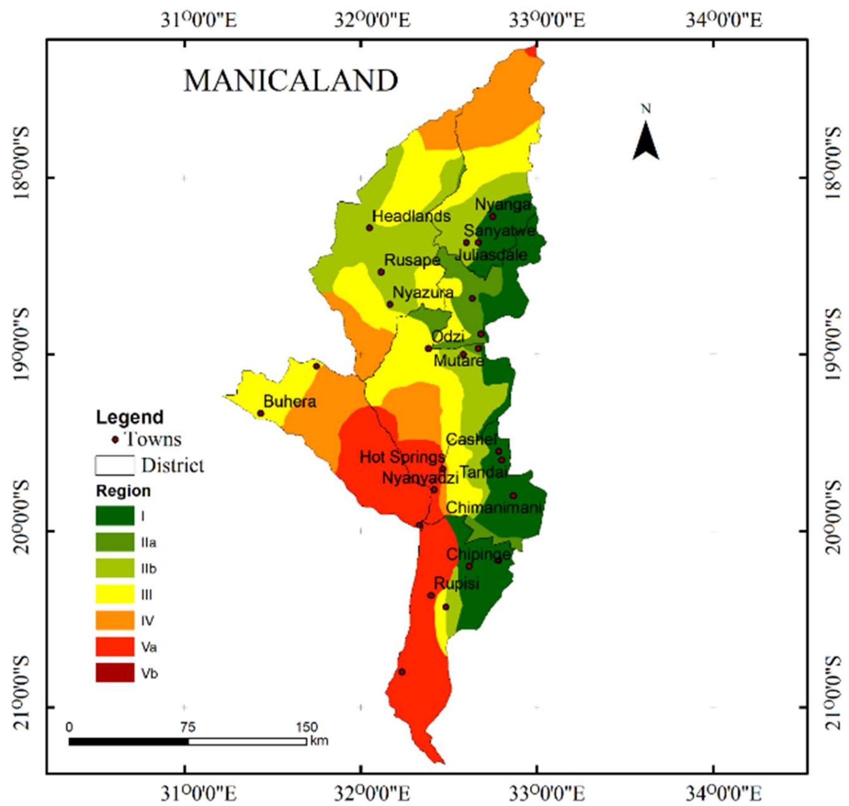
For the user to exit the system they just click on the normal back option once or repeatedly depending on which map is displayed and they are exited from the App.

Annex II: Provincial maps of the Revised Agroecological Zones

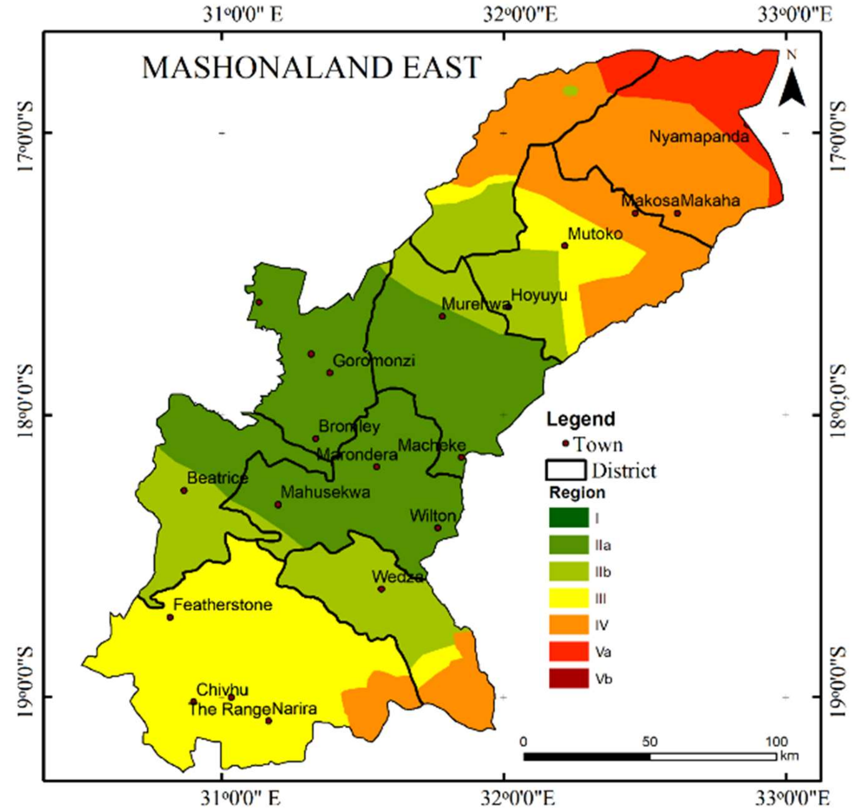


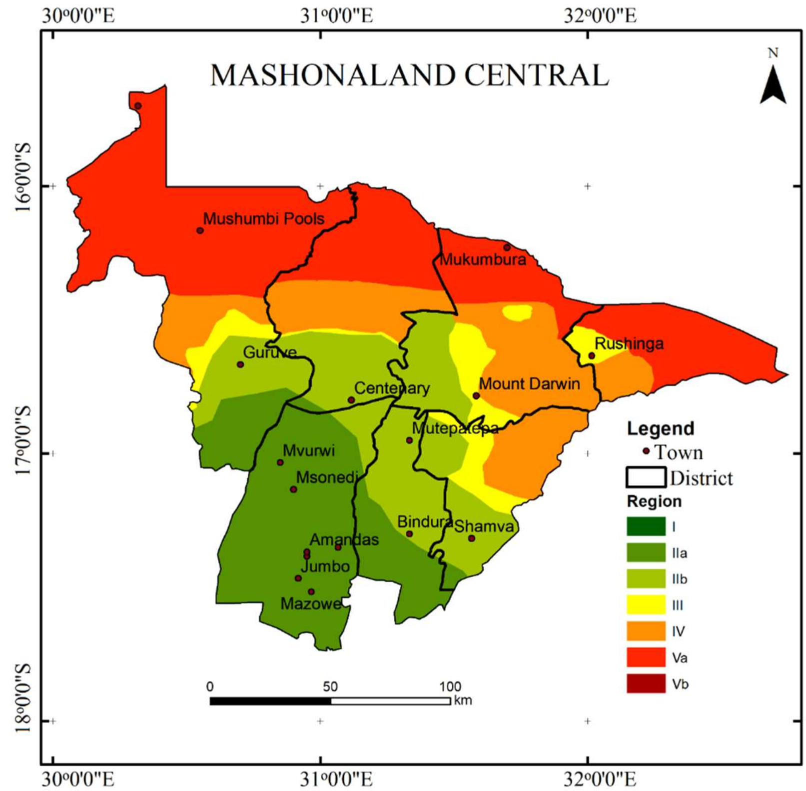


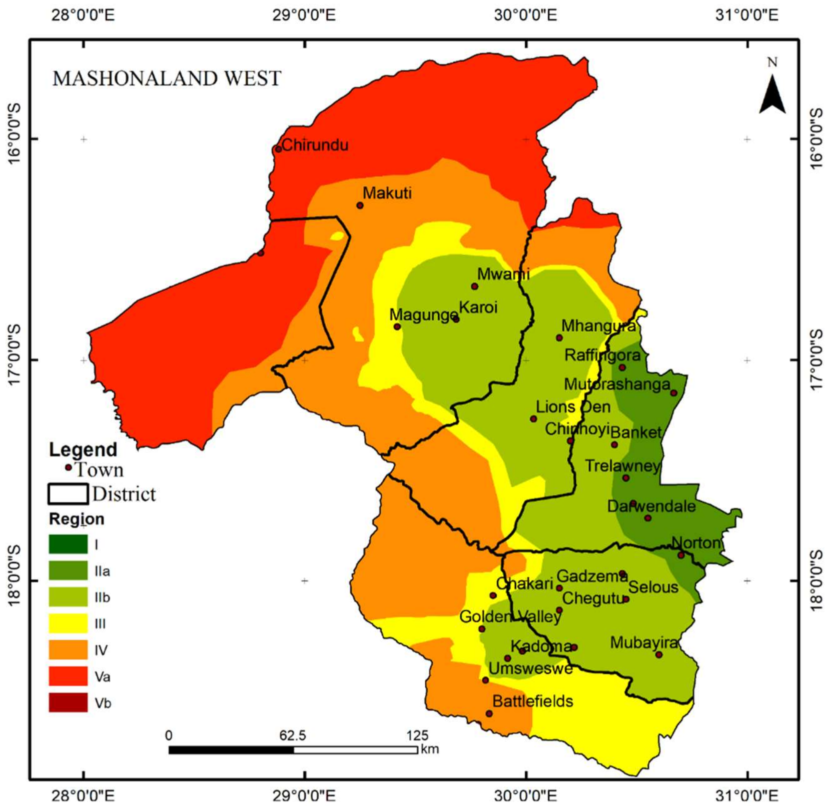
31°0'0"
HARARE
17°0'0"S
18°0'0"S
Legend
Wards
Region
I
IIa
IIb
III
IV
Va
Vb
0 5 10 km

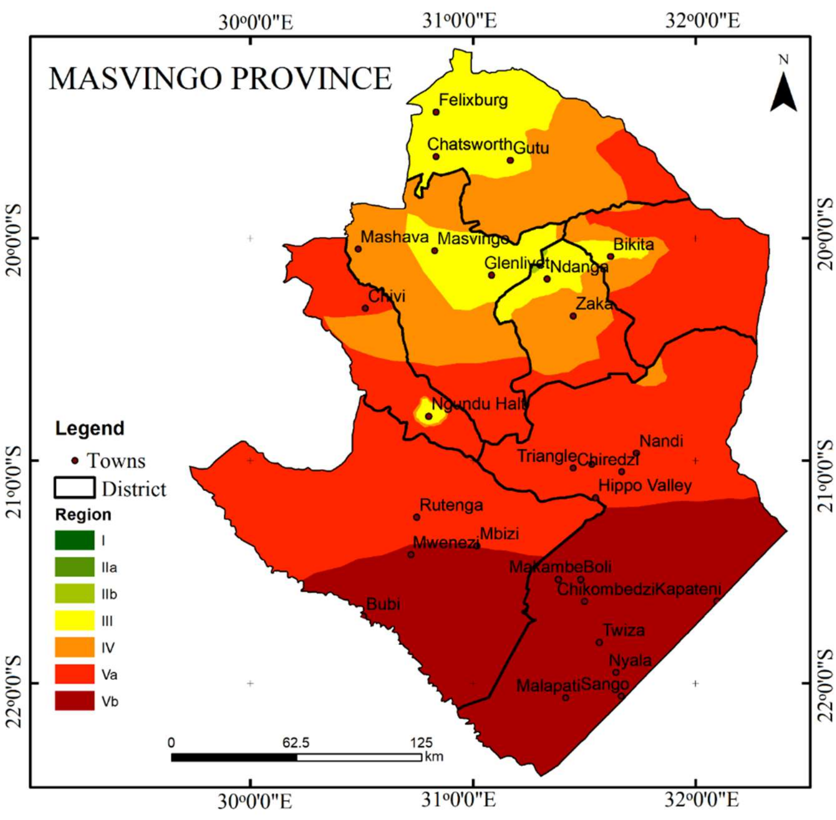


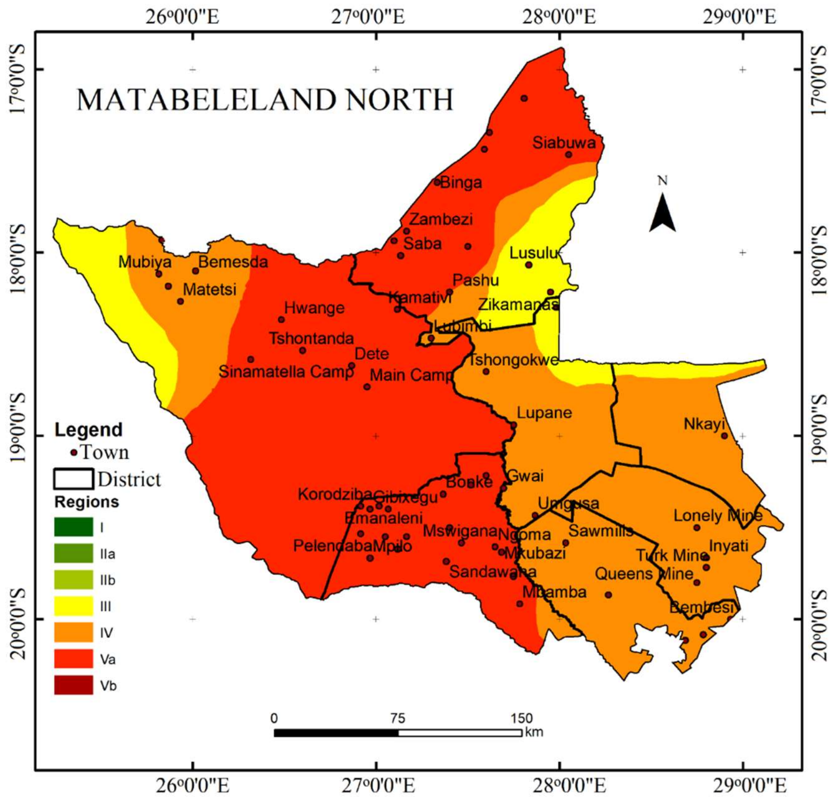
31°0'0"E
32°0'0"E
33°0'0"E
34°0'0"E
MANICALAND
18°0'0"S
19°0'0"S
20°0'0"S
21°0'0"S
Headlands
Nyanga
Sanyatwe
Juliasdale
Rusape
Nyazura
Odzi
Mutare
Buhera
Cashel
Hot Springs
Nyanyadzi
Tandai
Chimanimani
Chipinge
Rupisi
Legend
Towns
District
Region
I
IIa
IIb
III
IV
Va
Vb
0 75 150 km


MASHONALAND EAST
31°0'0" E
32°0'0"E
33°0'0"E
17°0'0"S
18°0'0"S
19°0'0"S
N
Nyamapanda
MakosaMakaha
Mutoko
Hoyuyu
Murehwa
Goromonzi
Bromley
Marondera
Macheke
Beatrice
Mahusekwa
Wilton
Wedza
Featherstone
Chivhu
The RangeNarira
Legend
Town
District
Region
I
IIa
IIb
III
IV
Va
Vb
0
50
100
km

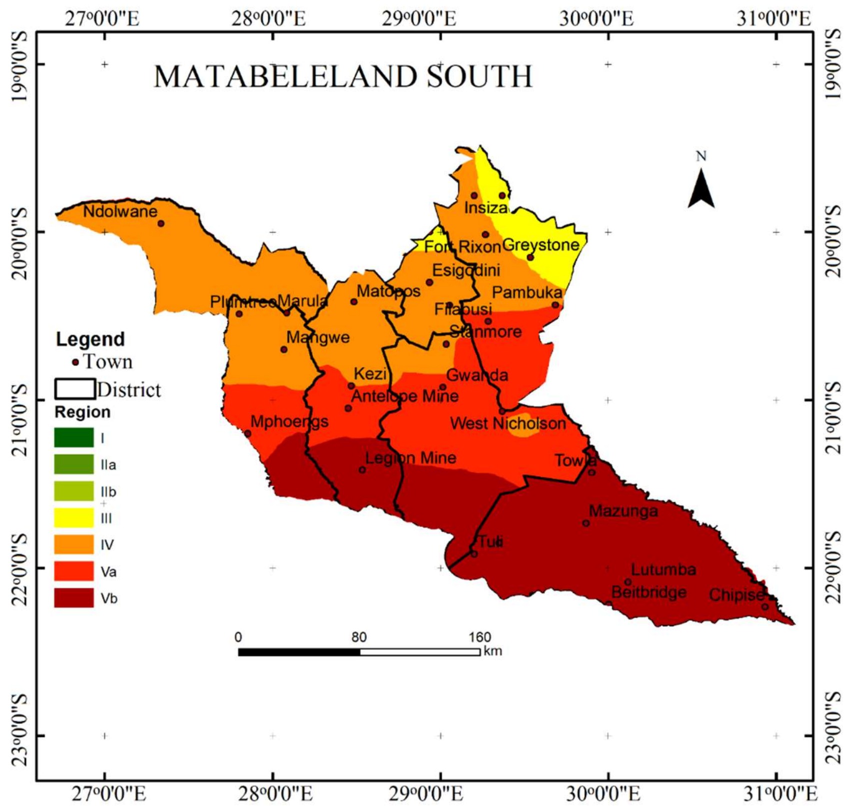

MASHONALAND CENTRAL
30°0'0"E
31°0'0"E
32°0'0"E
16°0'0"S
17°0'0"S
18°0'0"S
N
Mushumbi Pools
Mukumbura
Rushinga
Guruve
Centenary
Mount Darwin
Mutepatepa
Mvurwi
Msonedi
Bindura
Shamva
Amandas
Jumbo
Mazowe
Legend
Town
District
Region
I
IIa
IIb
III
IV
Va
Vb
0
50
100
km


MASHONALAND WEST
28°0'0"E
29°0'0"E
30°0'0"E
31°0'0"E
16°0'0"S
17°0'0"S
18°0'0"S
Chirundu
Makuti
Mwami
Karoi
Magunge
Mhangura
Raffingora
Mutorashanga
Lions Den
Chinhoyi
Banket
Trelawney
Darwendale
Norton
Chakari
Gadzema
Selous
Chegutu
Golden Valley
Kadoma
Mubayira
Umsweswe
Battlefields
Legend
Town
District
Region
I
IIa
IIb
III
IV
Va
Vb
0
62.5
125
km

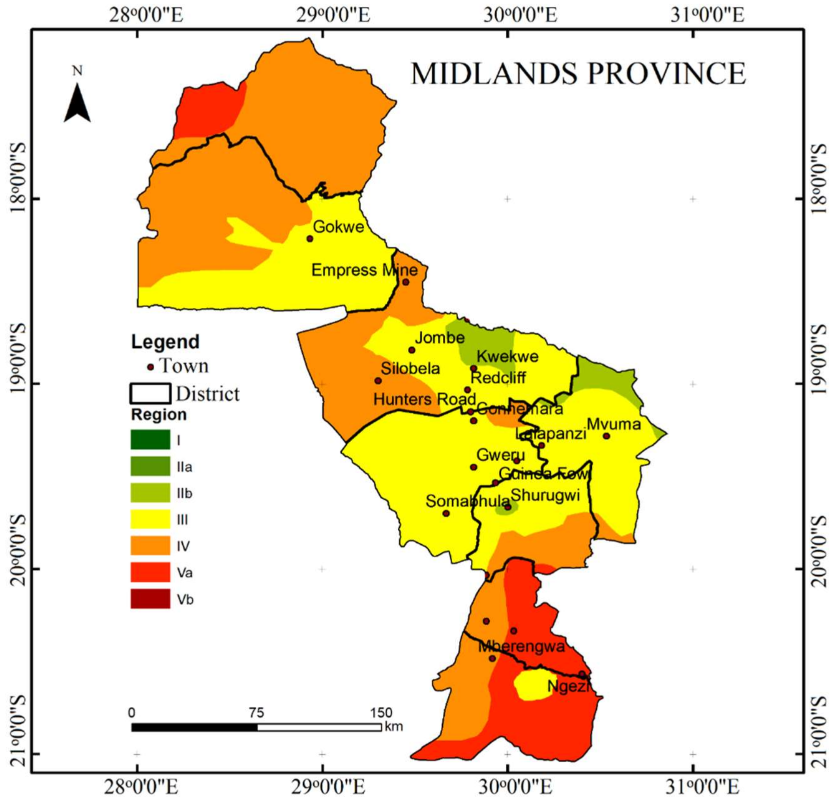

MASVINGO PROVINCE
30°0'0"E
31°0'0"E
32°0'0"E
20°0'0"S
21°0'0"S
22°0'0"S
Felixburg
Chatsworth
Gutu
Mashava
Masvingo
Bikita
Glenlivet
Ndanga
Chivi
Zaka
Ngundu Halt
Nandi
Triangle
Chiredzi
Hippo Valley
Rutenga
Mbizi
Mwenezi
Makambe
Boli
Chikombedzi
Kapateni
Bubi
Twiza
Nyala
Malapati
Sango
Legend
Towns
District
Region
I
IIa
IIb
III
IV
Va
Vb
0
62.5
125
km



MATABELELAND NORTH
26°0'0"E
27°0'0"E
28°0'0"E
29°0'0"E
17°0'0"S
18°0'0"S
19°0'0"S
20°0'0"S
Siabuwa
Binga
Zambezi
Saba
Lusulu
Mubiya
Bemesda
Matetsi
Pashu
Kamativi
Zikamanas
Hwange
Lubimbi
Tshontanda
Dete
Sinamatella Camp
Main Camp
Tshongokwe
Lupane
Nkayi
Gwai
Boake
Korodziba
Gibixegu
Emanaleni
Mswigana
Ngoma
Mkubazi
Pelendaba
Mpilo
Sandawana
Umgusa
Sawmills
Lonely Mine
Inyati
Turk Mine
Queens Mine
Mbamba
Bembesi
Legend
Town
District
Regions
I
IIa
IIb
III
IV
Va
Vb
0
75
150
km
N



MATABELELAND SOUTH
27°0'0"E
28°0'0"E
29°0'0"E
30°0'0"E
31°0'0"E
19°0'0"S
20°0'0"S
21°0'0"S
22°0'0"S
23°0'0"S
Ndolwane
Insiza
Fort Rixon
Greystone
Esigodini
Pambuka
Plumtree
Marula
Matopos
Filabusi
Stanmore
Mangwe
Kezi
Gwanda
Antelope Mine
West Nicholson
Mphoengs
Legion Mine
Towla
Mazunga
Tuli
Lutumba
Beitbridge
Chipise
Legend
Town
District
Region
I
IIa
IIb
III
IV
Va
Vb
0
80
160
km
N



Annex III: List of Stakeholders Consulted in the Provinces

Table 1: List of Stakeholders from Manicaland Province

Name of Stakeholder	Designation	Work Station
Mashayamombe Bertha	District AGRITEX Head	Mutare
Mukanjani Joseph T.	AGRITEX Officer	Chimanimani
Majoe Shupai S.	District AGRITEX Officer	Chimanimani
Mabodo Tobias	District AGRITEX Officer	Mutare
Mashayamombe B.	District AGRITEX Officer (Irrigation)	Mutare
Mubonami R.L.	District AGRITEX Officer (Agronomist)	Buhera/Chipinge
Mufukidze P.S.	AGRITEX Officer (Agronomist)	Buhera/Chipinge
Chowafa M.	AGRITEX Officer (Agronomist)	Makoni
Chipere J. T.	District AGRITEX Officer	Makoni
Muisvikiri F.	District AGRITEX Officer	Mutasa
Makupa S.	District AGRITEX Officer	Mutasa
Murambi Lucas	Provincial Meteorological Officer	Province

Table 2: List of Stakeholders from Midlands Province

Name of Stakeholder	Designation	Work Station
Nyamweda Sydney	AGRITEX Head (Machanisation)	Province
Mandebvu Vimbai	AGRITEX Officer (Agribusiness)	Province
Matore Zivanayi	AGRITEX Officer (Livestock)	Province
Majoni Taziva	AGRITEX Officer (Irrigation)	Province
Machingambi R.	AGRITEX Officer (Irrigation)	Province
Rera Mark.	AGRITEX Officer (Agronomist)	Province
Manjoma Albert	AGRITEX Extension Officer	Gokwe North
Chigududze Ndakazivei	AGRITEX Extension Officer	Mhondoro Ngezi
Ndoro Evelyn	AGRITEX Extension Officer	Sanyati
Joseph Daniel	AGRITEX Extension Officer	Gokwe South
Zinyowera Tafirenyika	Provincial Meteorological Officer	Province

Table 3: List of Stakeholders from Matabeleland South

Name of Stakeholde	Designation	Work Station
Simanga Ngwabi	AGRITEX Officer	Province
Ndlovu Bhekimpilo	EMA	Province
Rogers Munyira	Provincial Meteorological Officer	Province
Donzi Madonana	Min of Lands	Province
Thebe Thubelihle	Dept of Irrigation	Province
Muchemwa Hatitye	AGRITEX Officer (Livestock)	Province
Victor Gwibi	Dept of Mechanisation	Province

Table 4: List of Stakeholders Consulted from Masvingo province

Name of Stakeholder	Designation	Work Station
Muchazovepi Aaron	AGRITEX Provincial Head	Province
Edwin Machokoto	Forestry Commission	Province
Chikata Darlington	Sustainable Agriculture Technology	Province
Mwale Abraham	Provincial Meteorological Officer	Province
Chaduka Sabina	AGRITEX Officer (Agronomist)	Province
Chihombori John	AGRITEX Officer (Agronomist)	Province
Mudzi Tawanda	AGRITEX Officer (Eng. Mechanisation)	Province
Musadaidzwa Justice	AGRITEX Officer (Eng. Irrigation)	Province
Chari Douglas	AGRITEX Officer (Eng. Irrigation)	Province
Dahwa Everton	Lecturer Wildlife Science	GZU
Mudzengi Clarice	Lecturer	GZU
Samakonde Nyaradzo	Epidemiologist	Province

Table 5: List of Stakeholders Consulted from Mashonaland West

Name of Stakeholder	Designation	Work Station
Shambare E.	Principal AGRITEX officer	Province
Ndoro R.Evelyn	AGRITEX Officer (agriculture)	Sanyati
Munyani Charles	AGRITEX Officer (agronomist)	Sanyati
Chigudugudze Ndakazivei	AGRITEX Officer (agriculture)	Ngezi
Jimu M.	AGRITEX Officer(Livestock)	Ngezi
Makaza Siyena.	AGRITEX Officer (agronomist)	Province
Chikomo Abigail	AGRITEX Officer(Agribissiness)	Province
Nyagwesa Joseph	AGRITEX Officer (agriculture)	Hurungwe
Chiwawa Moreblessing	AGRITEX Officer (agriculture)	Makonde
Charuma Tawanda	AGRITEX Officer(agronomist)	Hurungwe
Mupariwa Joel	AGRITEX Officer(agronomist)	Kariba
Marovora Tenias	AGRITEX Officer(agronomist)	Makonde
Marumbwa Nola	AGRITEX Officer(agronomist)	Chegutu
Katanda Jesilina	AGRITEX Officer(agronomist)	Zvimba
Sengayi Godfrey	AGRITEX Officer (agriculture)	Chegutu
Fortunate Marara	AGRITEX Officer (agriculture)	Zvimba

Table 6: List of Stakeholders Consulted from Matabeleland North

Name of Stakeholder	Designation	Workstation
Masendeke Davison	AGRITEX Officer	Province
Nyoni Dhumisani	AGRITEX Officer	Province
Ndlovu Zenzele	AGRITEX Officer	Province
Ngulube Chiposi	AGRITEX Officer	Province

Table 7: List of Stakeholders Consulted from Mashonaland Central

Name of Stakeholder	Designation	Work Station
Torevasei Bernard	AGRITEX Officer	Province
Chireka Moffat	AGRITEX Officer	Bindura
Witness Nezandonyi	AGRITEX Officer	Bindura
Garati Joseph	AGRITEX Officer	Mazoe
Muvhuringi Prosper	AGRITEX Officer	Mazoe
Zhou Johannes	AGRITEX Officer	Muzarabani
Dube Hanzi	AGRITEX Officer	Muzarabani
Kahari Dori	AGRITEX Officer	Shamva
Tungawana Darlington	AGRITEX Officer	Shamva
Mafuzhe Andrew	AGRITEX Officer	Rushinga
Tsoriro Melody	AGRITEX Officer	Rushinga
Loki Cain	AGRITEX Officer	Guruve
Chikotomere Misheck	AGRITEX Officer	Guruve
Chikumbirike Betty	AGRITEX Officer	Mt. Darwin
Gift Chidyamatiyo	AGRITEX Officer	Mt. Darwin
Murena	AGRITEX Officer	Mbire
Vivian Ngwezuka	AGRITEX Officer	Mbire
Chifunha Jonathan.	Provincial Meteorological Officer	Province

Table 8: List of Stakeholders Consulted from Mashonaland East

Name of Stakeholder	Designation	Work Station
Munamati Leonard	AGRITEX Officer	Province
Munyai Watson	AGRITEX Officer	Chikomba
Guti Boston	AGRITEX Officer	Goromonzi
Muwishi DUmusayo	AGRITEX Officer	Hwedza
Manga Tsitsi	AGRITEX Officer	Marondera
Chidziso Benny	AGRITEX Officer	Mudzi
Makuvire Douglas	AGRITEX Officer	Murehwa
Makonyere Lawrence	AGRITEX Officer	Mutoko
Matinhira Teclar	AGRITEX Officer	Seke
Zvirevo Manenji	AGRITEX Officer	Uzumba Marambapfungwe (UMP)

Annex IV: Location, elevation and Station Code of Weather Stations where data used in this Project were obtained

Station_Name	Station_Code	Longitude (°)	Latitude (°)	Elevation (m)
Banket	67769	30.23	-17.24	1300
Beitbridge	67991	30.00	-22.13	460
Bikita	*****	31.37	-20.05	920
Binga	67755	27.20	-17.37	620
Buffalo_Range	67977	31.35	-21.20	430
Buhera	67875	31.26	-19.19	1190
Bulawayo_Goetz	67964	28.37	-20.90	1340
Chimanimani	*****	32.52	-19.48	1470
Chinhoyi	67771	30.12	-17.22	1140
Chipinge	67983	32.37	-20.12	1130
Chisumbanje	67985	32.14	-20.48	420
Chivhu	67871	30.53	-19.02	1460
Concession	*****	30.57	-17.24	1280
Gokwe	67861	28.56	-18.13	1280
Guruve	67773	30.42	-16.39	1180
Gweru	67867	29.51	-19.27	1430
Harare_Belvedere	67774	31.01	-17.50	1470
Harare_Kutsaga	67791	31.10	-17.60	1480
Henderson	67785	30.58	-17.35	1290
Hwange	67853	26.57	-18.44	1080
Kadoma	67869	29.53	-18.19	1150
Kanyemba	67767	30.25	-15.38	330
Kariba	67761	28.53	-16.31	520
Karoi	67765	29.37	-16.50	1340
Kezi	67961	28.27	-20.55	1020
Kwekwe	67865	29.50	-18.56	1220
Lupane	67855	27.48	-18.57	1010
Makoholi	67879	30.47	-19.50	1200
Marondera	67877	31.28	-18.11	1630
Masvingo	67975	30.52	-20.04	1100
Matopos	67963	28.28	-20.24	1340
Mount_Darwin	67779	31.35	-16.47	970
Murehwa	*****	31.47	-17.39	1380
Mutare	67898	32.4	-18.48	1110
Mutoko	67898	32.13	-17.24	1250
Mvuma	*****	30.11	-19.17	1380
Mvurwi	67789	30.51	-17.02	1480

Station_Name	Station_Code	Longitude (°)	Latitude (°)	Elevation (m)
Nkayi	67863	28.54	-19.00	1130
Nyanga	67889	32.44	-18.13	1880
Plumtree	67951	27.49	-20.29	1390
Rusape	67881	32.08	-18.32	1430
Tsholotsho	67857	27.46	-19.45	1100
Victoria_Falls	67843	25.5	-17.56	930
Wedza	67899	31.34	-18.37	1380
West_Nicholson	67969	29.22	-21.03	860
Zaka	67979	31.28	-20.2	770
Zvishavane	67971	30.04	-20.19	980

***** *Stations without codes are not World Meteorological Stations (voluntary Stations)*