Embedding Climate Futures in Spatial Planning for Subsistence Agriculture in The Angolan Central Highlands

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DEDICATION

This work is dedicated to the fond memory of my father Timoteo Adelino, my mother Monica Garcia Kiala. Specially gratitude for all my family, my wife Elga Kiala, my children Isbelkia Kiala, Flavio Kiala, Sudy Kiala and Ligia Kiala, my sister Cecilia “Cila” and brothers Miguel and Timoteo, nephews and nieces.

Abstract

Intensifying climate change is becoming increasingly apparent in Southern Africa with modified precipitation patterns and increases in temperature affecting growing seasons, agricultural production, and food security for small-scale farmers. While there is a strong commitment from agricultural extension services to plan the management of climate change impacts in the region, these endeavors are hampered by a lack of knowledge on how climate scenarios will develop at a scale relevant to local communities. This is especially the case in the province of Huambo in Angola, which is particularly sensitive to climate change with a rainy and dry season, and with over 85% subsistence farming is typical of many areas of the southern African region.

Developing local climate date sets from 1960 to the present day, trend detection, climatic variability, and temperature and precipitation projections were determined by statistical reduction methods using regression, correlation, and time series analysis; statistical prediction methods included integrated autoregression models and moving average (ARIMA). The outcomes indicate the emerging irregular distribution of rainfall and water scarcity issues that will be a challenge for subsistence agriculture producers. This will be further exacerbated by soils with structure and textures that have limited water holding capacity. Furthermore, evidence of soil erosion and depletion of soil nutrients associated with climate change may be additional factors contributing to a significant reduction in productivity and yield of many crops.

Work on the social aspects of subsistence farming community adaptation highlights that environmental changes threaten the livelihoods of local subsistence families even when adopting different strategies and techniques of agricultural production practices to the new climate scenarios. However, rural communities that depend on subsistence

agriculture can adapt to changing conditions using practices that conserve agro-ecosystem resilience, e.g. by changing soil cultivation by systems using intercropping of two or more crops, maintaining soil moisture. Integration of crop and plant residues into the soil is another fundamental tool for mitigation and resilience in the conservation of soil physical characteristics that can provide organic matter to the soil and offer a variety of mechanisms for recycling nutrients. These best practices may maintain agro-biodiversity and provide smallholders with an ecosystem that supports livelihoods' well-being. Further resilience may be built through extension services interventions that include making available agro-meteorological information and to encourage many micro-irrigation systems.

In summary, these findings give a locally nuanced assessment of climate change, suggesting a continuing increase in temperature, decline in rainfall, increase in the length of the dry season, and reduction in the number of rainy days. The impact of these changes will vary with soil water holding capacity and agricultural land management mitigation measures.

Setting the Scene: Climate Change and Agriculture Futures, The Angolan Central Highlands

1.1 Climate Change in Spatial Planning of Land for Agriculture Futures

Climate change has implications for Africa that vary widely from region to region. The impact of climate change in Africa is likely to be severe due to the direct adverse effects of its economy's exposure to climate change, its high agricultural dependence, and limited adaptive capacity. The direct effects vary widely across the continent, with some areas projected to become wetter, while much of southern Africa is anticipated to be drier and hotter (Magadza, 1994; Jury, 2013). Exposure to what may be exceptionally severe effects is likely to impact agricultural production and subsistence family farming in particular. Anthropogenic activities in Africa have contributed negligible amounts of greenhouse gases to the atmosphere. Consequently, Africa's main issues in the global ‘climate emergency’ concern the adaptation of production practices to the new environmental scenario while keeping natural resources sustainable. (Collier, Conway and Venables, 2008)

Sub-Saharan Africa (SSA) is the most vulnerable part of Africa to climate change with the persistent occurrence of natural disasters such as droughts and floods, and agricultural systems that are deeply dependent on rainfall, all of which accentuate the incidence of extreme poverty (Montle and Teweldemedhin, 2014). Southern Africa is one of the regions facing challenges to improve food security in the face of multiple climatic pressures. The impact of climate change and the consequent increase in climate stresses can compromise the ability of subsistence agriculture to adapt and sustain agricultural production and so constrain food security and development (Lotz-Sisitka and Urquhart, 2014). This is a particular concern in the projection of future climate changes related to extreme rainfall, drought, and temperature. High temperatures can lead to a more unpredictable hydrological cycle variability, increasing the prospect of severe droughts or floods in some parts of the region (Archer *et al.*, 2007).

Influenced by changing marine currents, Angola is susceptible to climate change and related variability and the implications that this carries for agricultural economies (Boko, 2007). Understanding and responding to the multifaceted challenges of climate variability and change on the regional and local scale requires robust assessments of the current state of the climate and prediction of climate futures (Davis, 2011, Singh *et al.*, 2017) and how this may relate to local communities. For planning and prediction applications, surface parameters are the most important data sources and require as many long records as possible of high-quality and spatially specific data. Improving the provision and delivery of climate information to support adaptation for subsistence agriculture, particularly in Angola, has been identified as an urgent need based on future climate projections (Field *et al.*, 2007). However, strategic forecasting and dissemination of climate information as a contribution to mitigating current and future climate risks have yet to be acted upon and have not yet contributed to planning adaptative strategies in support of agricultural production and food security.

Because of its vital significance to sustaining large numbers of families and its vulnerability to climate change, the agricultural land use focus of this thesis is family-based subsistence farming. Subsistence agricultural production in Angola is wholly dependent on climatic conditions and is based on a single rainy season. It is a traditional model of a productive, socioeconomic, cultural, and environmental organization in which agricultural activities are developed by the family as a labour force and is a style of self-sufficiency to support almost all the essential needs of the family. The agricultural season usually starts from September to December in most of the national territory on an average of 1.4 to 2.00 ha per household often with two or more land units. Generally, however, subsistence farming obtains a low yield, which is insufficient for family consumption, and there is no surplus for commercialization and trade with climate change – with precipitation and associated soil water holding capacity limitations in particular - accentuating these issues (FAO, 2012; Carranza and Treakle, 2014; Balgah *et al.*, 2016).

1.2 The Research Problem

Ad hoc adaptation of land use management to climate change already in progress has resulted in damaging physical and social effects that are often irreversible. Spatial planning of land use for agriculture in human settlements, particularly in southern Africa, has yet to take into account the phenomena of climate change and has always assumed as climate in which episodes of heavy rains or prolonged drought were unusual situations (Roder *et al.*, 2015). Knowledge about climate changes and the prediction of future scenarios will offer a more robust basis from which to assess new land capabilities and appropriate agricultural land management in the future (Pandey *et al.*, 2015).

For the sustainable use of the agricultural resource base in a climate-changed future, it is necessary to have an evaluation of the main characteristics and basic properties of the soil, its water holding capacity, and how land management may influence the storage of soil water. To respond to the spatial planning of subsistence agriculture and the viability of rural development, research has a responsibility to predict the impacts of climate change with useful data and information that indicates where the greatest impacts might be felt, and which facilitates sustainable land and water planning. This will take into account soil water holding capacity, soil moisture deficits, local community knowledge, and the incorporation of climate futures in land use planning for subsistence agriculture in the central highlands of Angola.

Agriculture has been constantly challenged over time to produce enough food for a growing population (Charles, Nzunda, and Munishi, 2014). Concepts, original interpretations, and solutions that contribute to the economic viability of the subsistence agro-ecosystem and which respond to current climate change conditions are now timely (Charles, Nzunda, and Munishi, 2014). All of this requires a holistic view of the evolution of complex systems in the food production process rather than fragmented aspects that give only partial understandings (Thornton *et al.*, 2011). It is therefore important to emphasize existing or future approaches based on the idea of modulating and predicting the subsistence agroecosystem that offers a dynamic balance with perspectives and solutions based on innovative concepts and methodologies. Technical adjustment to soil and water management aims to adjust the process of obtaining agro-food products in complex systems that consider climate changes and the prognosis for the proper use of land resources in Angola. This thesis seeks to contribute to these discussions through evidenced climate, soils, and land management assessments.

1.3 Objectives and organization of the thesis

This study evaluates major factors influencing the productivity of Angolan subsistence agriculture in a climate-changed future. Given the emerging challenges of climate change to subsistence agriculture in Angola, this thesis focuses on defining changing temperature, precipitation and soil water holding capacity and soil moisture content and the implications this carries for subsistence agricultural systems in Angola. Focused on the important agricultural region of Huambo Province in Angola key objectives are to:

- Project future precipitation, temperature, and evapotranspiration patterns to establish the range of different climate scenarios,
- Classify soils according to their water holding capacity and the implications that this carries for sustainable subsistence agricultural productivity in a changing climate setting,
- Establish the current characteristics of subsistence farming and identify any current and recent land and water management practices that are sensitive and adapted to climate change,

The structure of the study is organized into five chapters with its major and inter-related themes reflected in Figure 1.1. these include local scale assessments of climate change, temperature, and precipitation, and its significance to subsistence agriculture. In light of these changes, soil water holding capacities have a greater significance and these are considered in relation to the soil properties of texture and structure as a way of highlighting inherent land limitations. The nature of agricultural land management within the subsistence farming community is also evaluated and endeavors to evidence adaptability and resilience to impacts of emerging climate scenarios. In the integrated assessment of these themes, the vulnerability of Angolan subsistence agriculture in a future of climate change is made and a new agenda for the management of subsistence agriculture systems in Angola is presented.

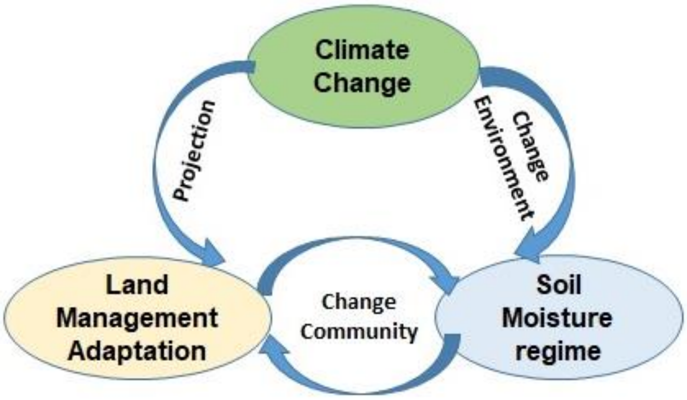

Figure 1.1 - Thesis themes: Interlinking climate change with soil water holding capacity and land management adaptation regime.

The first and second chapter gives the purpose and importance of the thesis. This is based on an assessment of the literature related to the main themes of the thesis and from which the aims and objectives emerge. This chapter highlights the importance of climate change, soil water holding capacity, and subsistence farmer land management, together with the complex interactions between these themes and the challenges of integrating these elements into future land planning scenarios.

The third chapter will discuss the evidence for climate change and climate change futures in Southern Africa, and Angola in particular. It focuses on the collections of historical meteorological data from the study area, including precipitation, temperature, and evaporation over an extended period from 1960 to 2017, statistically assesses climate changes that occurred during this time in the study area, the relationships between climate factors, and how they influence each other, and well as predicts future climate scenarios for the next 60 years. In doing so these analyses indicate the possible intensities of climate change and the implications that this carries for subsistence agriculture.

The fourth chapter focuses on soil survey, field sampling along selected catena transects, and the assessment of soil water holding capacities in the various soil classes of the region. Explanation of soil water-holding capacities is sought in the physical analyses determining soil texture, structure, and infiltration. Assessment is then made of the agricultural capabilities in light of changing precipitation patterns.

The fifth chapter presents questionnaire-based data that seeks to identify and assess different strategies and methods within local agricultural practices that adapt soil and crop management to water availability. These analyses contribute quantitative and qualitative information related to the management of soil and water together with the perception and knowledge that small farmers hold on the impact of climate change on householder's dependence on subsistence agriculture. It also seeks to identify the current roles and possible future roles, both positive and negative of agricultural extension services from the perspective of the subsistence farmer.

The sixth chapter discusses the integration of the analyses and findings. Climate, soils, and social data are integrated as spatial water availability for agriculture across Huambo province using selected future climate change scenarios. The chapter presents conclusions and recommendations from the study, making suggestions for future work that will further deepen the debate on the problem of future agricultural water resource management in developing nations. Planning tools will be suggested for better utilization of natural resources contributing to increased productivity of subsistence agriculture and small family farms.

1.4 Study Location

This study is carried out in the central plateau of Angola, Huambo Province (Figure 1.2), and a major subsistence agricultural area in Angola. This program of research focuses on defining changing climate and the consequent changes in water availabilities for agricultural systems in Angola. For the first time in Angola, it is a study integrating weather data statistics, field and laboratory data, and social and population analyses to give a comprehensive assessment of agricultural land and water management futures and associated risk assessments. In doing so, it creates a basis for the proper sustainable management of land resources in the context of future climate change.

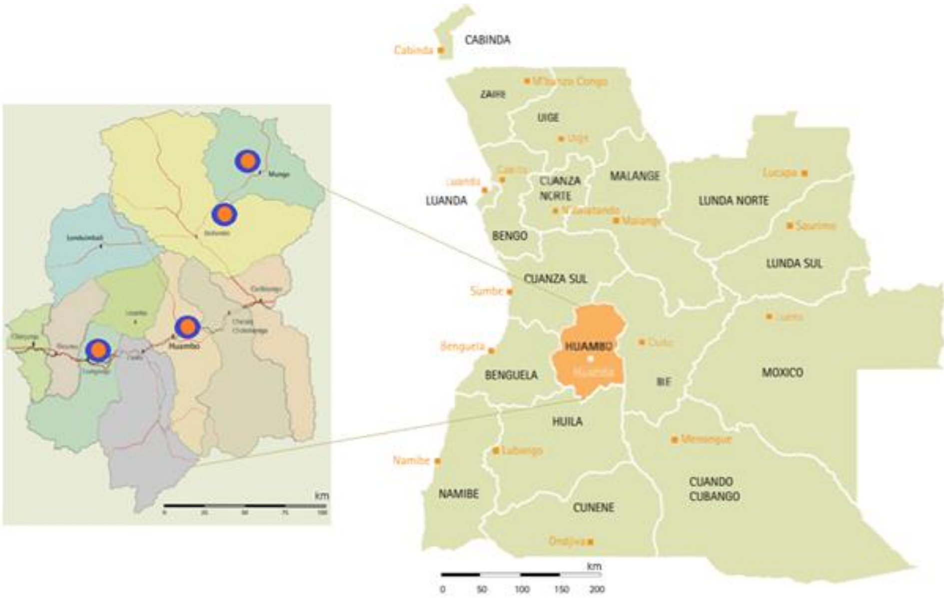

Figure 1.2 - Study for agriculture practice and soil survey location (Atlas of Angola)

Angola is a country with a heterogeneous demographic of various ethnic groups with cultural traditions. The cultural and demographic characteristics of the province of Huambo, the areas under study, are predominantly of the Umbundo ethnic group. The total population of the province is 2,019,555 people, of which 47.7% live in urban areas and about 52.3% in rural areas. According to the National Institute of Statistics (INE 2016), in terms of gender, Huambo has a slightly greater female population of 52.7% of the total population resident in the province. This does however vary between local areas.

The selection of Huambo province as a study area is due to its importance as an agricultural production province within Angola. It is the second province by population density in Angola, with more than 60% of the population dedicated to agricultural production; over 90% of this is subsistence agriculture with the use of rudimentary production technologies. Huambo as well other parts of Angola are located in the tropical climate zone and have two main seasons per year, the rainy season and the dry, or winter, season. The rainy season has typically had an average of 8 months of rain with the possibility of rain starting in September and ending in mid-May.

The current average annual precipitation is estimated to range from 1200 mm to 1500 mm while the average annual temperature is currently estimated between 22°C and 24°C. The choice of the Angola central highlands zone over 1700 meters serves as a starting point to allow evaluation of subsistence agricultural land capacities in climate change settings and it is anticipated that the approach and methods adopted in this study may be applied by the wider land resource user community to help to inform future planning strategies for the sustainable use of water by subsistence farmers and agricultural producers across Angola (Figure 1.1 above) and in the wider southern Africa region.

1.5 Research Approaches

In nature nothing works in isolation, everything depends on factors present or absent. High yields are the result of a complex interaction of factors climate, plant and soil. One of the frequent criticisms being made in the management of land in recent decades is the emphasis on chemical soil attributes that determine fertility, relegating to the side-lines the physical and biological attributes of the sum, also important for high yield. Environment factors, which include climate factors, factors related to biodiversity and soil physical and chemical processes interact in the agricultural production process and affect crop yield. The challenge for subsistence farming (and all farming) is to optimise these interacting factors through management practices that enhance the functioning of the agro-ecological network of living organisms in the production system (Lal *et al.*, 2016). The challenge for the researcher seeking to understand these systems is to ensure an integrated synthesis of the relevant factors.

This program of research adopts a holistic approach integrating climate change data, soil attributes and land management to indicate new potentials for agriculture under climate change scenarios.

1.5.1 Key Definitions used in this Thesis

The key definitions giving foundations to this thesis are:

Climate change can be considered as the variability of average temperature and precipitation over a period of time in a region. The changes caused in interaction dynamics between the atmosphere, the oceans, biosphere terrestrial, the sea currents and the changes in the cover of the surface of the soil, due to human activities, are responsible for current global warming (Mubaya *et al.*, 2012; Joshi and Maharjan, 2013; IPCC, 2014).

Land resources are referred to as a delineable area of the earth's surface covering all attributes of the biosphere's surface, that includes the climate close to the earth's surface, soil forms and hydrology surface such as rivers, bogs and marshes used by subsistence farmers to water crops. Land resources are associated with critical processes that affect the functioning of the planet, such as climate change, biosphere integrity, and biochemical flows (Van Zanten *et al.*, 2018).

Family farming in Angola is a traditional model of productive, economic, social, cultural and environmental organization, in which subsistence agricultural activities are developed by the family as a labour force (FAO 2012). It is a style of self-sufficiency to support almost all essential needs and is the main source of income and food production in the family (Maharjan and Joshi, 2013). Due to the low productivity of crops in general, no surplus can be used for commercialization and is due to the use of techniques that often do not adapt to current climate change conditions and that negatively affect crop yields. In general, each family has one or two fields with an average area between 1.4 and 2 hectares (O'Brien *et al.*, 2000; Wani *et al.*, 2009).

1.5.2 Climate Data Sets and Climate Prediction

Precipitation, temperature, evapotranspiration, humidity and wind speed are the main climatic variables used for crop yield forecasting (Oettli *et al.*, 2011). In this first phase of the climate analyses, a survey of the project area will be carried out to collect the available meteorological data and to develop the meteorological data sets, including precipitation, temperature, and evaporation, so their analyses over an extended period of years can be undertaken. It is important that data reliable can be integrated as a space and time multi-scale forecasting system. The key climate data set is from the 1960s to the present, using daily historical data obtained from the Meteorological Service of Angola (INMATE) at the terrestrial Chianga weather station in Huambo Province, located at a latitude of (-12.74349), longitude (15.82923) and altitude (1696 m). This data set is supported by data from the Huambo airport weather station located at a latitude of (-12.4800), longitude (15.4500) and altitude (1700 m).

1.5.3 Soils Data Sets

Soil survey and sampling will be undertaken on a catena basis reflecting the undulating topography of the region and to allow classification of the various types of soil in the region (Figure 1.3). Soil sampling and assessment will allow physical analysis to indicate agricultural capacities. As is well known, soil properties gradually change direction both vertically and horizontally, boundaries will be defined and mapped in the field based on the following soil physical characteristics:

- Landscape and relief topography
- Soil with a predisposition or not to erosion
- Field observed soil texture and structure

And further refined in the laboratory through assessment of:

- Soil texture class and structure (through thin section micromorphology)
- Soil bulk density
- Soil water holding capacity (through volumetric method)

The results of these analyses will provide a basis for the determination of soil water holding capacity in the landscape and assessment of potential future soil-water-plant relationships and land-use constraints.

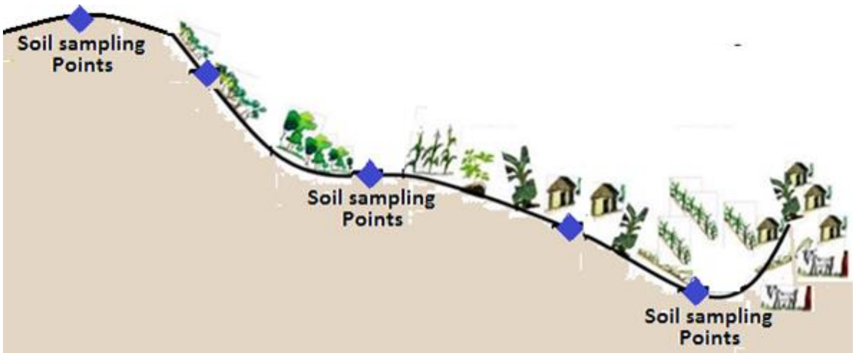

Figure 1.3 - Schematic diagram showing positions of soil sampling points on the catena landscape transects.

1.5.4 Subsistence Agriculture Practice Data Sets.

Farmers, local agricultural extension workers and local authorities in the region will be involved in the research programme, contributing quantitative and qualitative information related to the agricultural land management of the province. These data will be processed and analysed to draw out information on rural development and agricultural pathways within the different localities of the study locality. An assessment of social facts about agricultural techniques, land preparation, and soil and water management will be collected using qualitative methods, (Figure 1.7). In relation to agricultural production, a questionnaire-based approach to data and information collection will include:

- Subsistence farm population attributes
- Main crops used in the region and the productivity of the main crops that, over time, subsistence farming in the region have sowed
- Period of seedlings, seeding made in the rainy season and dry or without rainy season
- Tools used
- Fertiliser practice
- Adaptations to climate change

1.5.5 Integration and Analyses of Data Sets

Integration of climate, soils and land management data sets recognizes the pressure brought to bear on subsistence agriculture as climate changes, the resilience to these changes that might be found in the capacity of soil to hold and store water, and the adaptability of the subsistence farming communities to the emerging climate change realities in Angola. The analyses provide a basis for, and a guide to, identifying the variable levels of risk to subsistence farming as climate changes together with operational solutions that can include a new mapping of land capabilities as a basis for supporting farmers in Huambo Province as well as the wider Angolan regions. The integrated analyses will provide a comprehensive assessment of the future of land and water management, as well as assess the environmental risk associated with climate change.

Literature Review of Research Themes

The chosen research themes are not straightforward to review. The academic literature on climate change and its anticipated impacts in Angola is limited, although increasing, still tends to be generalised and lacks regional specifics. Similarly, details of soil water holding capacities in the landscapes of the study region are very limited and lack local scale analyses together with an explanation of the factors regulating soil water. Details of subsistence farming practice for the region again are very generalised and lack village community and individual householder farm-scale of analyses required for agricultural planning in a climate changed future. It is into this setting that the thesis seeks to contribute. To give a literature-based foundation to the thesis from these limited sources, the approach adopted is to synthesise the available information on the locality with the broader, generic, literature on the themes considered. In this way, a substantive literature review is created that helps contextualise the research findings.

2.1 Angola Localization and Physical Geography Attributes

2.1.1 Climate Conditions

The African continent is characterized by a great diversity of climatic regimes, the average climate being modified by the presence of great contrasts in the topography of the continent. This basic climatic state is further modified by continental asymmetry and the circulation of adjacent ocean basins. The global circulation that produces the observed continental climatology with the annual cycle is strongly determined by the position of the intertropical convergence zone (ITCZ) and El Niño-Southern Oscillation (ENSO) (Haile, 2005, Collier, Onway and Venable, 2008, Stringer *et al.*, 2009).

Climate change is expected to intensify regional differences in Africa's natural resources and exacerbate the continent's vulnerability as a consequence of rising temperatures and significant changes in rainfall regimes (Carvalho, Santos and Pulqué0rio, 2017). Precipitation is one of the most important natural resources for many subsistence agricultures systems in Africa and the inter-annual and intra-annual rainfall variability is perhaps the key climatic element that determines the success of subsistence agriculture on this continent. Considering climate control of soil water availability through rainfall and evaporation, and when precipitation is low, droughts can occur, given dry years even so, high rainfall or even for short periods in years of low rainfall can result in flooding. The impact of drought on African agriculture-dependent economies can be large and can impact between 4% and 9% of GDP on the continent.

Climate has a strong influence on agricultural production systems in the Sub-Saharan African region, particularly subsistence agriculture (Oettli *et al.*, 2011), which in many cases is exposed to high risks of climate variability in tropical and subtropical regions, due to monsoons and El Niño-Southern Oscillation (ENSO) that increase the risk and impact of natural disasters. Dynamic interactions between the atmosphere, oceans, marine currents, terrestrial biosphere, cryosphere and land surface determine the global variability of the Earth's surface climate (Githeko *et al.*, 2000) and temperature in driest regions will increase faster than the global average temperature (Niang *et al.*, 2014, Almazroui *et al.*, 2020). General circulation models (GCMs) estimate that global mean temperatures will have increased by 1.0^{o}C to 3.5^{o}C and for Africa the average annual temperature could increase by 3°C to 6°C by 2100, temporal and spatial changes in temperature, precipitation and humidity are expected to occur under different climate change scenarios (Almazroui *et al.*, 2020).

Global projection of rises in temperature and uncertainty on rain pattern and distribution will directly affect ecosystems and biological behaviour with consequences that included melting snow, retreating glaciers, desertification from drought, flooding, frequent fires, rising sea levels, and emergence of various pests and diseases in different regions of the world (Chaudhary and Aryal, 2009).

Uncertainties in climate projections strongly influence the quantification of impacts and strategic approaches to adaptation and mitigation. The minimization of uncertainty in the projection of climate change is considered one of the biggest challenges in the Southern African region in particular and in different regions of the globe in general (Deser *et al.*, 2012, Salman *et al.*, 2020). According to regional climate projections (RCP) for Africa the indications are that the uncertainty of precipitation and Earth surface warming is likely to be greater than the annual average global warming. It is also reported that annual precipitation in southern Africa is likely to decrease across the region during the annual seasons (winter and summer) causing spatial and temporal changes in current climate zones (Baron *et al.*, 2005). Rainfall projections are more uncertain than temperature projections and show greater spatial variability and seasonal dependence, particularly in North Africa and southwestern parts of Southern Africa region whit uncertainties remaining due to a lack of knowledge of cloud formation and feedback on oceanic and hydrological circulation (Chakraborty, Tiedemann and Teng, 2000).

The southern African region, of which Angola is a part, stretches approximately from the parallels 6’00.00°S at its northern extent to the southernmost part of the continent at 35’00.00°S. This vast area covers climatic regimes that include tropical humid, subtropical, arid semi-arid (Collier, Conway and Venables, 2008). Intensifying climate change is now beginning to evidence itself by changes in precipitation patterns that include reduction in rainfall and extremes of rainfall that are severely affecting subsistence agricultural production, agricultural practices and broader socio-economic development in sub-Sahara Africa generally and Angola specifically. This has already led to increasing food insecurity in the region (Hulme *et al*., 2001; Sivakumar, Das and Brunini, 2005; Thornton *et al*., 2011; Serdeczny *et al*., 2016; de Clercq, *et al*, 2018). Socioeconomic development in the Huambo region is also hampered by the availability of water due to the high variability and reduction of precipitation observed and projected over time (Sivakumar *et al*, 2005). Population growth in the urban and rural sectors and the inability of governments to maintain agricultural and agro-industrial infrastructure, as well as lack of information and monitoring of climate change impact, are additional and related factors limiting the sustainable management of land and natural resources for social and economic development (de Clercq, *et al*, 2018).

The diverse climatic conditions of Angola results from many atmospheric, oceanic and topographic driving forces. Its geographical position is located on the west coast of the African continent in southern Equator to the Tropic of Capricorn (Huntley *et al.*, 2019), occupying the area formed by the coordinates: 4º22' and 18º02' south latitude and 11º41' and 24º05' east longitude (Figure 2.1). Angola occupies a land area of 1.246.700 km^2 (Roosbroeck, de Bettencourt and Huongo, 2006) and the relief is characterized by five large geomorphological units (Figure 2.2), namely: Coastal Strip, Escarpment zone, Transition Zone (Intermediate Surfaces), Mountain Ridge and Ancient Plateau (including Zaire Basin or Congo peneplain, Zanbezi-Cubango peneplain), which influences more localised climatic conditions.

The population of Angola, on which the climate influences, is estimated to be approximately 25,789,024 inhabitants in 2016, of which 16,169,987 live in urban areas, representing 63%, while the remaining 9,635,037 (37%) live in rural areas. It is estimated that about 46% of Angolan households practice some form of subsistence agricultural activity (INE- Instituto Nacional de Estatistica, 2016) and as such are heavily reliant on consistent and Predictable rainfall.

Figure 2.1 - Study site and Angola geography localization and boundaries (Atlas of Angola)

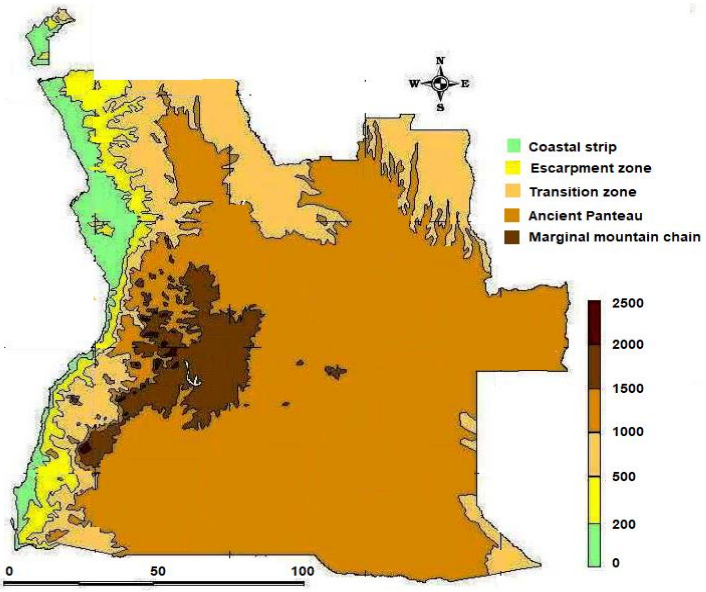

Figure 2.2 - Relief characterization and main geomorphological and landscape units of Angola (Atlas of Angola)

The climate of a particular zone is the result of a succession of various weather conditions throughout the year (Charles *et al*, 2013) and Angola's climate has three notable zones: tropical climate in the north, the subtropical climate in the south, and temperate climate in the higher areas (Figure 2.3). The significant climatic diversity in Angola is further accentuated and strongly influenced by a set of factors that include latitude range, altitude, orography, the cold Benguela currents and the Zaire, Zambezi, Cuanza and Cunene watersheds. Contrasts in climatic conditions within the Angolan territory are also influenced by the Intertropical Convergence (ITC) occurring between Equator and the Tropic of Capricorn and by the Pacific El Niño Southern Oscillation (ENSO) which is the main source of abundant rainfall during the warm season (summer) (Roosbroeck, de Bettencourt and Huongo, 2006; Jury, 2018). This results in contrasts across the country between dry and hot weather, mild coastal rainfall and milder, wetter climate, and more abundant rainfall on the interior plateau.

The area of the central plateau of Angola - and the focus for this study - has a subtropical climate and is a locality where the impact of climate change is increasingly evident. Here, the climate is strongly seasonal with a dry or cool winter, locally called "cachimbo", that has typically begun in the middle of May and extends until the end of September, and the rainy season that occurs in the warm season (wet summer) which typically has run from September until the middle of May. The average temperature is influenced by altitude and ranges between an annual average maximum that is currently 27ºC and the annual mean minimum that is currently 15ºC (Figure 2.3) (Huntley *et al.*, 2019).

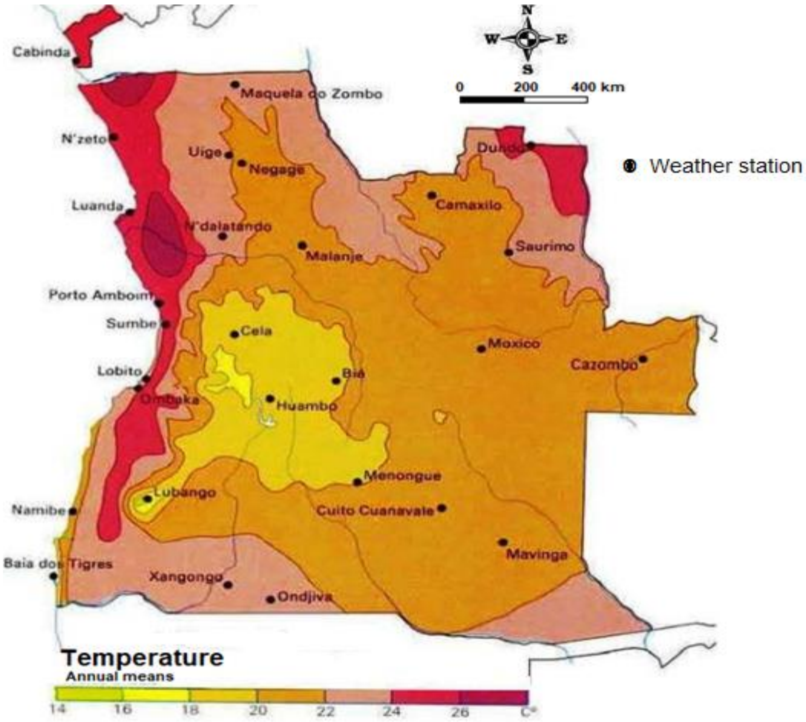

Figure 2.3 - Mean temperature distribution of Angolan territory (Atlas of Angola)

The precipitation patterns of greatest importance are convective in origin, with orographic precipitation occurring in the transition zone at intermediate altitudes and in the Mountain Ridge, which dominates central and southern Africa. Rain distribution is in line with the country's temperature variability, annual average rainfalls are more homogeneous on the central plateau, with average rainfall peaks reaching 1400 mm per year on the Huambo-Bié axis. In comparison, the long terms average of highest rainfall records are found in the northwest and northeast Angola, where the climate is tropical humid and can reach maximums of up to 1600 mm per year, while the minimum of 50 mm per year is observed in the extreme southeast of the country in arid and semi-arid climate (Figure 2.4), (Kalahari or Namibe desert) (Roosbroeck, de Bettencourt and Huongo, 2006).

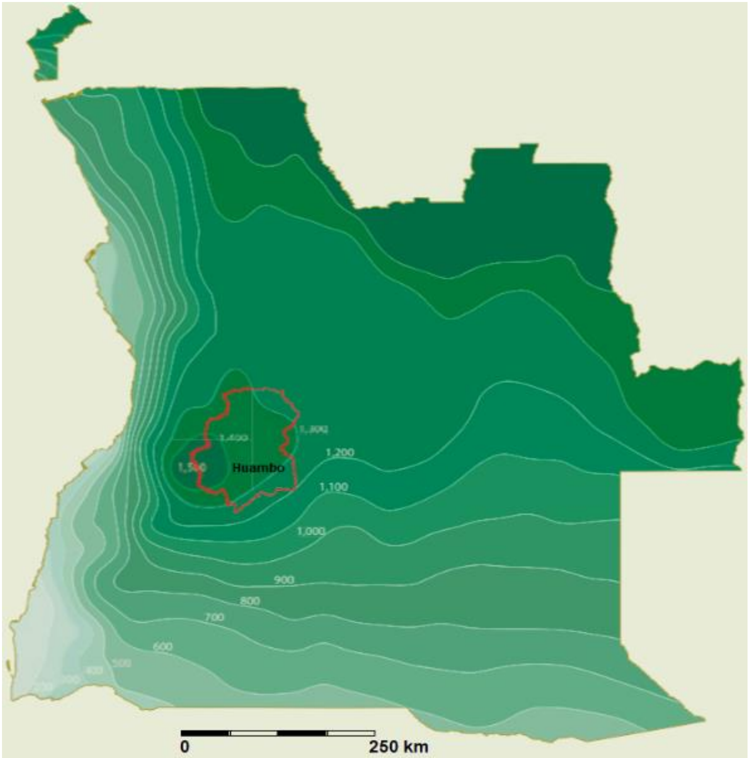

Figure 2.4 - Average annual rainfall in Angola. Most of Huambo (outlined in red) receives more than 1,300 mm per year (Atlas de Angola)

2.1.2 Soil Types

Soil has its origin in the varied interaction of various forces, including climate, relief, parental material, living organisms, acting over time. The development of soil takes many years to form. However, profound changes that may occur in some climatic factors and vegetation means that most soils are under continuous development and change in Angola (Karmakar *et al.*, 2016. Morison, J., Matthews, 2016).

Rain, drainage, evaporation and wind are climatic factors that contribute to Angola's complex soil genesis where, following the FAO WRB classification system, the predominant soils are arenosol and ferralsol, and are classed as entisols, ultisols and latosol in the USDA system (Huntley, 2019). The predominant soils in the central highlands of Angola according to Huntley (2019) correspond to red and yellow ferrasols (MPA, 1961), to the order of Oxisols (SSS, 2010) or the Main Group of ferrasol (WRB, 2006) (Madeira, Ricardo and Neto, 2015).

Morphological assessment of the ferric soils group of the central plateau of Angola has A, B, C horizons as their profile. The B horizons generally have medium or fine textures and in most cases with hue and chromatic colours that vary from yellowish to reddish; they are weakly structured with granular aggregates of very friable consistency. These soils have clay clusters dominated by low activity and high sesquioxide clays; the soils can be of great depth and are generally well-drained. These controlling profile attributes result in low organic carbon, low chemical fertility and low water holding capacity. Their distinguishing chemical characteristics are the strong occurrence of iron and aluminium oxides originating from weathering of kaolinic minerals. In some cases, these soils may have lateritic concrete dispersed along the profile or concentrated in layers with varying depth (Osman, 2013). Regions with higher humidity, precipitation and temperature tend to form deeper soils, due to the direct action of water and temperature on weathering bedrock material and, indirectly, promote greater biological activity, which in turn also contributes to weathering.

2.1.3 Climate and Soil Interactions

Climate is a key factor in balancing soil formation and degradation (Julius, 2008) and is a vital factor in land management and assessment (Guo *et al*, 2008). Temperature change, rainfall and wind all contribute to the weathering of the rock parent material. Likewise, climate affects the occurrence and distribution of plants, which keep the soil intact, provide organic matter and with increasing temperature, enhance micro-organisms activity (Backlund, 2008). For this reason, soil organic matter decomposes faster in the tropics and contributes to nutrient release.

Rain and wind are the main climate-causing agents of soil erosion. Soil degradation is also aggravated by anthropogenic activities, such as deforestation, inadequate soil management for agriculture and forestry and which has especially been the case in Angola (Julius, 2008, Charles *et al*, 2013).

Climate plays a dominant role in changing soil moisture content, the hydrology of river basins, flowing rivers, lakes, ponds and groundwater, (Parmesan, 2006). It can directly influence the various components of soil water holding capacity and subsistence agricultural activity that affect above-ground crops, along with interactions with soil properties and nutrient availability (Douglas, *et al*, 2008; Pende, Ringler and Magalhaes, 2004). Precipitation is the most important climatic factor in Angola influencing soil moisture content and its distribution may vary according to storm characteristics in turn influencing soil moisture conditions, and, resulting in spatial and temporal variability in soil moisture (Binayak *et al*, 2016) as well as influencing patters of soil erosion.

2.2 Climate Change, its Recognition and Emerging Significance to Subsistence Agriculture in Angola

Important climatic factors to consider in agriculture systems include precipitation, solar radiation, temperature, wind and humidity, all of which contribute to the space-time dynamics of soil moisture and the resulting water flows (Douglas, *et al*, 2008). Climate is considered variable over extended periods (Douglas *et al.*, 2008). To reduce the negative impacts of climate change on subsistence agriculture, it is becoming increasingly important to define climate limits on a consistent scientific basis and assessed against sustainable agricultural practices and different crop varieties used by subsistence farming. There is also an increasing need to recognise that the understanding of these limits could be improved and adapted to new technologies of farming practices according to the nature of climate change affecting Angola’s subsistence farming (Oyekale, 2016).

Detailed consideration also needs to be given to local effects with any national scale of climate classifications adjusted according to regional and local variations (Cline, 2008). There are however large uncertainties in climate change analyses in Angola particularly because there is a lack of information on many specific local regions as well as uncertainties in the magnitude of climate change (Carvalho, Santos and Pulquério, 2017), the effects of technological changes on productivity, and changing global food demands that may mediate or accentuate climate change impacts, (Fatecha, 2004).

Most agronomists believe that agricultural production will be significantly affected by the severity and pace of climate change and less so by gradual trends in climate change, although, gradual trends could also harm agriculture in many countries, including Angola and especially those that are already suffering from poor and degraded soils (Pontelli 2006).

Adequate provision and collection of climate information to support adaptation needs to be seen as crucial in guiding future dissemination of land management techniques that will bring resilience to climate change; these should have greater prominence in sustainable land management research,(Roggema, 2014). Improving the availability and access to high-quality data for climate observations need to be linked to practical guidelines for the use of climate information in agriculture and land management, as well as its systematic documentation and widespread dissemination of good practices in terms of land management techniques (Yanda and Mubaya 2011). Understanding climate change and predicting successive scenarios is increasingly being recognised as providing a more rigorous assessment of water and land management for agricultural use in the future, (Oyekale 2016).

According to IPCC (2014), the predicted temperatures in the region of the central plateau of Angola in the next 20 years could be average annual temperatures of around 25.5ºC with the warmest months being the months of October and September, whilst May is be considered as the month with the highest average temperature increase of 5 ° C. (Figure 2.5).

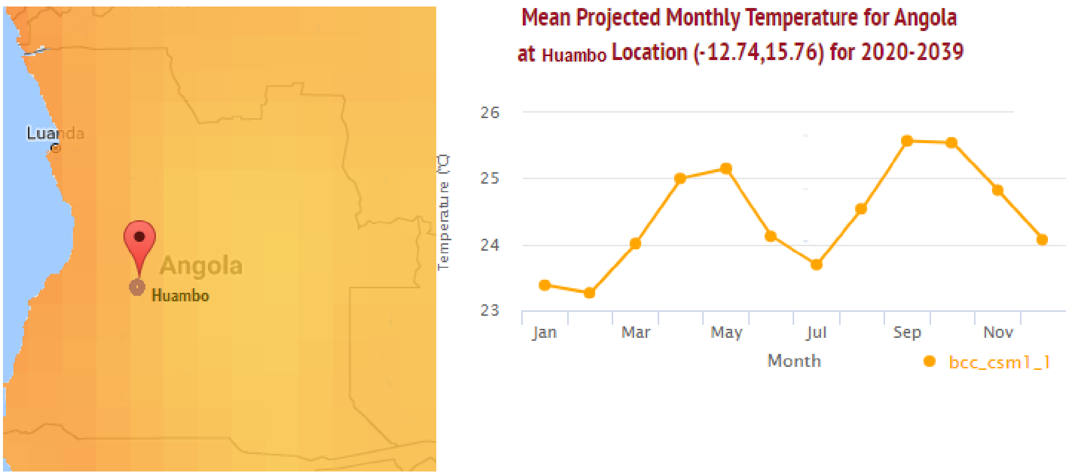

Figure 2. 5 - IPCC temperature prediction for Huambo next 20 years.

Prediction of changes in the precipitation regime is however more complex and requires a deeper knowledge of the influencing factors together with an ability to synthesize their interactions across space and time (Borchardt, *et al*, 2016). However, measurement of many of variables reflecting the outcome of precipitation changes, such as soil moisture and soil water holding capacity, can be considered spatially restricted and is traditionally measured and provided by terrestrial meteorological stations (Savva and Frenken, 2002; Lakshmi, 2016). Occasionally, in the case of Angola, this information is available, but the absence in most regions of weather stations results in a lack of reliable, comprehensive and detailed spatial understanding in many rural localities, severely restricting information available for the subsistence farmers who rely on rainfall.

The reduction of agricultural productivity observed in many soils in diverse areas across Angola may be influenced by several factors including misuse and inadequate land and natural resources management (Fallon *et al.*, 2018). Additionally, research practices and how programs are directed may not have allowed favourable policies to strengthen the sustainable management of natural resources and land for agricultural growth and the need to provide sustainability to the shocks and threats caused by climate change.

Liebig, *et al* (2012) reported that unsustainable agricultural practices used by farmers in agricultural production are considered as causes of degradation of land resources and should be viewed with concern. In Angola, although all regions show some degree of degradation, the central plateau is the most affected by land degradation. According to (Hahn, 2013) a high degree of deforestation and the unsustainable use of forest resources, soil loss through erosion leads to reduced soil water holding capacity and soil fertility. Increased susceptibility to changes in precipitation has negative impacts on agricultural productivity, which requires effective and efficient country-led sustainable land management practices, (Jonger and Ferguson 1991). Furthermore, the irrational and unsustainable use of agroforestry resources in Angola in general, and Huambo in particular, has resulted because of difficulties in applying legal instruments that have a sustainable management emphasis for the protection of natural resources; the resulting devastation of forests is an important factor to be considered in land degradation and its effects on soil water holding capacity and soil moisture for agriculture in Angolan subsistence farming (Hurni 2000). Increased soil erosion resulting in depletion of soil nutrients and depletion of water holding capacity associated with climate change may be a new and additional cause that contributes to a significant reduction in soil water holding capacity and decreases in productivity in many crops.

Within this complexity of factors and the so far limited disentangling of environmental processes feedback loops, it is emerging that climate change is accentuating land degradation in Angola and is superimposing itself on an already degrading land resource base. To face this situation, it is necessary to make future predictions of climate change and soil water holding capacity so that adequate sustainable planning of future agricultural land management can be undertaken in a way that sustains subsistence family farming using sustainable agricultural practices, (Hurni 2000). Sustainable land management that embeds climate change requires a strong link between agricultural research, the rural extension system and farmers to develop and disseminated technologies and practical land management practices that respond to the needs of farmers (Thomas, *et al*, 2007). In addition, to develop and implement effective and well-targeted policies for land improvement and appropriate soil fertility practices there need to be an account of the current challenge related to significant degradation and conditions imposed by climate change (Parmesan, 2006). It is vital to consider that, for sustainable land management, effective progress of local capacity is needed to support appropriate techniques to ensure the best management of land, in future climate change scenarios (Prada *et al* 2017).

Understanding and responding to the multifaceted challenges of climate change influences on agriculture requires robust assessments and prediction of climate futures. In Angola integration of long-term climate data and spatial land surface parameters has now become essential so that planning and prediction applications can be developed for agricultural adaptation. Planning and land management support to farmers facing climate change realities are not reflected in the current agricultural advice system and as a result land and water use are not changing appropriately in response to climate change.

2.3 Water in Agriculture and the Regulation of Soil Water Holding Capacities

2.3.1 The Challenge of Water Availability in Agro Ecosystems in Southern Africa.

Water is the main natural resource for the existence of life on Earth (FAO 2012). It constitutes a basic need of humans and animals to survive and is a basic requirement of the subsistence agricultural production system through its contribution to the photosynthetic process (Jin and Young, 2001; Binayak *et al*, 2016). Agriculture is considered the economic sector that uses the largest amounts of water (Wallace, 2000; Molle and Berkoff, 2009).

The emerging changes in rainfall patterns observed in the southern Africa region and, in particular for this study, the central plateau region of Angola, is contributing to an increase in water scarcity for subsistence family farming in Angola and Huambo Province. Furthermore, reduction in the efficiency of water use for the limited irrigation systems and the lack of water management that may otherwise mitigate the impact of climate change is a challenge that needs to be recognised and addressed to sustain the livelihoods of subsistence family farmers and future generations of rural communities in Angola (Thomas *et al* 2007).

The water requirements of each crop differ. Crop water requirements are dependent on each type of agricultural crop, environment moisture, soil moisture, crop planting time, the stage of crop growth and climate (Savva and Frenken, 2002; Wani *et al.*, 2009). For integrated water management, it is important to consider those aspects of water movement that contribute to maximizing the beneficial use of water, through human intervention in water control that influences allocation, conservation, and reuse strategies for sustainable agricultural development (Borchardt, *et al*, 2016). It is also essential to involve the appropriate application of technology and management to provide adequate amounts of water when needed by crops and to prevent salinization and loss of water from the root zone of plants (Challinor *et al.*, 2007).

Climate change is expected to have both negative and positive effects on agricultural production (Borchardt, *et al* 2016). However, impacts will differ depending on regional climatic characteristics, in some regions there may be benefits in terms of agricultural productivity, and in other regions agriculture will be exposed to a greater degree of climate vulnerability (Collier, Onway and Venable, 2008). In Southern Africa, millions of livelihoods are already being affected by changes in precipitation patterns through recurrent drought and flood events, the consequence of climate variability that is creating new agricultural risks throughout the region, (Savva and Frenken 2002). In the Southern African region, one of the most challenging issues in these changing climate circumstances is the creation of farming abilities and water management infrastructures that can contribute to the conservation and management of water and land resources, contribute to the sustainability and intensification of agriculture and in so doing contribute to the reduction of hunger and poverty (Douglas *et al*, 2008).

Currently degradation of agro-ecosystems and related reductions in the availability of water for agriculture by reducing water infiltration and percolation and water holding capacity. This is impeding subsistence farmers from making full productive use of resources and affects livelihoods that are dependent on the use of these resources, (Binayak *et al*, 2016). Gradual degradation of water and land resources is contributing to diminishing the ability of farming communities and individual farmers to make crucial investments required to reverse this degrading agro-ecosystem situation (Wani *et al* 2009).

In Angola, and particularly in the central plateau, soil water resources are an important factor in subsistence agricultural production. However, this type of information is not always available to farmers due to a lack of data and accessible information regarding the soil and its ability to hold sufficient water without irrigation use. Unlike developed nations (see for example Bibby, et. al. 1991), there is a lack of soil and land survey maps in Angola showing in detail the different types of soils, their distribution and location. Neither is their thematic maps showing, for example, texture classes or soil water holding capacities and is a weakness in land use and management in Angola. The development of such maps can contribute to the needs of different users by providing important details showing spatially specific basic soil classes, information that explains to users the individual types of soil on the map, a grouping of soils that behave similarly in response to land management definition of properties that influences the movement and storage of water in the soil (Oyekale, 2016).

Numerous parcels of agricultural land do not have basic information on soil water conditions and need to create possible conditions that allow accurate mapping of soil water retention capacity according to their use for subsistence agriculture and availability for the householder. On the other hand, to estimate soil water retention capacity, integrating all basic and mapped information and made available to all users of soil water resources is a tool required for proper management of natural resources especially given the impact of the current changes happening in the environment (Piedallu *et al.*, 2011). This should be an important tool for the future spatial planning of subsistence agriculture in the use of natural resources under the effect of the climate change scenario.

For the suitable balance of water and land management in Southern African countries, it is now increasingly necessary to create policies based on a participatory approaches, involving landowners, planners and policy makers (Thomas et al., 2007).

This will require strengthening of agricultural research systems to provide appropriate tools for sustainable water use technologies that are within acceptable boundaries of risk of failure and be accepted by farmers; this will require vertical integration in the socio-political sphere rather than the current emphasis on horizontal integrations (Borchardt, et. al. 2016). To achieve this, there are increasing calls for functioning links between agricultural research, farmers and market systems. This means enhanced exchange of technical information in which the priorities of research objectives must be identified and focussed on production systems and users of water and land (Nhira, Mapiki and Rankhumise, 2007). All these worthy objectives do however need to be founded on a thorough understanding of the climate changes facing Angola (discussed in section 2 above) and in what happens to water in agricultural soils, the theme reviewed in this section.

2.3.2 Water in Agricultural Soils: Regulating Factors.

Soil is a dynamic solid three-dimensional natural body that is the uppermost part of the Earth's crust interacting with the atmosphere and is composed of liquids, gases, organic matter and minerals earth (Mendonça, 2006; Osman, 2013). Perhaps more precisely in a further definition, the soil is composed of rock-derived minerals, organic matter, water, air, flora formed by microscopic small plants and fauna, such as nematodes and protozoa, (Karmakar *et al.*, 2016). Climate and underlying geology in particular influence significant regional contrasts in the conditions of natural processes of soil formation and the development of contrasting soil types in different regions of the globe (Várallyay, 2010). Energy and matter transfers and transformations, particularly as a result of weathering of rocks through chemical, biological and physical processes, vary with the interacting factors of climate, geology, landscape relief and living organisms over time to create the horizons of the soil profile (Jenny and Amundson, 1994, Mendonça, 2006; Osman, 2013).

These factors and processes of soil formation can result in differentiation of textures in the soil profile, spatial arrangement and stability of soil aggregates and the content of organic matter in soils (Morison and Matthews, 2016), in turn influencing the dynamics of water in the soil. The development of soil horizons takes many years to form. Regions with higher humidity, precipitation and temperature tend to form deeper soils, as is the case in Angola, due to the direct and intensive action of water and temperature on weathering bedrock material, and by promoting greater biological activity, which in turn also contributes to weathering. However, profound changes that can occur in some climatic factors and vegetation cover means that most soils are under continuous development and change in soil properties and which again influence the water dynamics in soils (Karmakar *et al.*, 2016; Morison, J. and Matthews, 2016; Korres *et al.*, 2015).

At a landscape scale, morphological, physical and chemical properties of soils can form as distinctive associations of soils on specific slope positions forming what is known as a catena across the slope (Borden, Baillie and Hallett, 2020). The distribution of individual soil profiles in a catena varies from the crest of a slope to the valley and has an impact on the pattern of land use, agricultural production and affecting the potential of water movement and the ability to retain water on the slope. (De Alba *et al.*, 2004; Marcin, 2010).

Amongst methods used for the soil classification process, morphology has become a more reliable method for soil classification pedogenesis based approaches. Soil morphology refers to observable attributes of various horizons in the field in which the soil is composed, it is the description of the type and arrangement of these horizons and has the potential to provide long-term information on the ability to contain moisture over a given period as well as other influencing factors including soil degradation (Eze, 2015).

Broader spatial scales of grouping soils involve soil classification, the orderly way of grouping soils based on the measurable and observable characteristics of similar attributes. This allows the exchange of knowledge between scientists, policy makers and other land users. In Angola, there is a reliance on the two most popular in the soil scientific community: World Reference Base (WRB-ISRIC-IUSS, 2006) and USDA Soil Taxonomy and morphological approaches (1999) (Eze, 2015), even though in Angola there has been little attempt to develop thematic mapping, such as soil water holding capacities, form these fundamental classifications.

At a general level, soils within natural systems can be viewed as a regulating part of the hydrological cycle, the continuous transfer of water in nature in the form of precipitation, runoff infiltration and storage, and evapotranspiration (Wright *et al.*, 2013). Soil moisture depends on the rainfall it receives, the water holding capacity of the soil and water loss through evapotranspiration. Precipitation and its duration naturally contribute directly to the surface runoff of rainwater, but does not all remain in its entirety on the land surface, it infiltrates in the ground where it may be 'stored' as part of the groundwater. Surface water is also 'stored' in the form of lakes and rivers, and which eventually drain back to the oceans. Evapotranspiration is a combination of two separate processes, evaporation from the soil surface and transpiration from the plant both of which contribute to the loss of soil water (Savva and Frenken, 2002). These two processes are inseparable and occur simultaneously on vegetated surfaces. The evapotranspiration process is strongly affected by meteorological factors including solar radiation, air temperature, air humidity and wind speed.

The water content of the soil is therefore directly influenced by environmental factors external to the soil including the occurrence of precipitation in the locality and region, the topography of relief affecting the flow and speed of infiltration and percolation of water into the soil and the type of vegetation that covers the surface of the soil influencing evapotranspiration (Mendonça, 2006; Osman, 2013, Négrel *et al.*, 2015 and Balasubramanian, 2017). The amount of moisture already contained in the soil is also important in determining the partition of rainwater infiltration and drainage (Kim, Kwon and Han, 2018).

Soil properties internal to the soil profile that influence water retention capacities include soil texture, soil structure, including porosity characteristics, and the organic matter content in the soil, which itself also influences the structural and textural stability of the soil. In response to these external and internal variables soil moisture is constantly changing in time and space (Vereecken *et al.*, 2014) with the soil acting as a water reservoir that reflects field water balances of precipitation and evapotranspiration, and the soil properties that influence the ability of soils to retain water (Várallyay, 2010; Choi and Jacobs, 2007; Rosenbaum *et al.*, 2012). This interdependence in the continuous movement of the forms by which the soil retains water constitutes a closed sequential dynamic system, based on the physical laws that control the movement, storage and disposal of water in the upper earth surface and atmosphere (Choi and Jacobs, 2007).

In practical terms in Angola, the amount of available water in soils varies with changing seasons, discussed in section 2.1 above, and which increases during the rainy season and decreases in the dry season. These varying moisture contents in soils can serve as a starting point for information based on measuring the variability of hydrological and meteorological processes and for subsistence agriculture, such assessments can be key to successfully managing land to maintain an adequate moist environment in the crop root zone.

Assessments of soil water for agricultural purposes can include the volume and timing of soil moisture levels and water movement both in terms of retention and exit from a soil profile and topography-based soil catenas and include the assessment of available (between field capacity and permanent wilting point) and unavailable water. Continuous assessment based on spatial variations in soil water retention capacity is increasingly (Piedallu *et al.*, 2011; Zhao *et al.*, 2017) seen as essential for the planning and sustainability of subsistence family farming in light of current climate changes, to give clear information that defines the soil's water retention capacity and availability to the plant. The direct measurement of water in the field is however recognised as difficult to achieve from a land evaluation perspective (Mcgarry, 2006).

The distribution of water in the soil is a vital constraint, or limiting factor, on all agricultural systems; it directly affects the development of plants on a spectrum from deficit to an excess of saturation in the soil. More precisely, in landscape terms, the assessment of soil water conditions the inputs, the outputs and the storage of water, is essential for the understanding of agro-ecosystem dynamics in Angola and Southern Africa more generally. Meteorological and hydrological variables together with soils storage of water regulating water availability are now being profoundly influenced as precipitation changes under climate change scenarios (Wright *et al.*, 2013) and so an understanding of the ability of soils to store water is now essential.

2.3.3 Water in Agricultural Soils: The Soil ‘reservoir’ for Subsistence Agriculture.

The maximum rate at which water enters the soil - the infiltration rate - under steady-state conditions is influenced by several factors, such as soil texture, initial soil water content or soil moisture, type of vegetation covering the soil, soil compaction, soil aggregation and stability, desiccation of cracks in clays, cropping practices and whether conventional or conservation planted (Binayak *et al*, 2016).

Water holding capacity, or retention, in the soil is what governs the dynamics between natural infiltration and runoff, as well as storage, percolation, and evapotranspiration (Raghunath, 2006). Once in the soil, soil water determines plant water supply, regulates soil temperature, vegetative productivity, nutrition, soil fauna and flora and, more broadly, impacts on agro-ecosystems development (Várallyay, 2010). It is the source of evapotranspiration water, even when there is only a moderate amount of moisture (Rosenbaum *et al.*, 2012). From soil moisture, water enters the plant through its roots, contributing to the reduction of water content in the soil, moves through the plant's vascular system, reaching up to the canopy of the plant where it is expelled into the atmosphere as evapotranspiration (Feddes *et al.*, 2001; Norman and Anderson, 2005; Choi and Jacobs, 2007). Soil water content balances episodic excesses of rainwater supplied and smooths variations in evapotranspiration. The role of soil moisture in the soil-plant-atmosphere system depends on the amount of soil moisture and the availability of water, which in turn is regulated by the texture and structure, including pore space, of the soil and the characteristics of the plant's root system (Feddes *et al.*, 2001).

The occurrence of water in the soil does not mean that it is accessible for plants to use. Available soil water is the amount of water maintained in the soil between field capacity, where gravity drainage becomes insignificant and the soil is not saturated but with high soil water conditions, and the permanent wilting point of the crops. This is the retained soil water, which can be used by plants, and which is considered the soil water available content beyond which plants cannot recover from water stress, even though there may be a very small amount of water in the soil which is held by the soil and not available to plants (Savva and Frenken, 2002). The ability of the soil to maintain accessible amounts of water for agriculture depends on its texture, the proportion (particle size distribution) of sand, silt and clay particles, which in turn also influences soil structure and pore space characteristics, together with the amount of organic matter within the profile. A higher proportion of clay for example gives very small pore spaces which increase capillary attraction thus reducing available water.

Organic matter in soils is increasingly seen as an important mediator of soil water by increasing aggregation (Reinert and Reichert, 2006; Saxton and Rawls, 2006). Organic matter plays a fundamental role in guaranteeing soil quality, soil water holding capacity, stability of soil aggregates, nutrients, and maintaining soil oxygen circulation capacity (Romaniuk, Giuffré and Romero, 2011, Karmakar *et al.*, 2016). Organic matter influences the physical conditions of the soil in several ways. Plant residues that cover the soil surface protect the soil from sealing and crusting by raindrop impact, thereby enhancing rainwater infiltration and reducing runoff.

Increased soil organic matter contributes indirectly to improved soil porosity and increased soil faunal activity with the immediate result that water infiltrates more readily and can be held in the soil (Li *et al.*, 2007). The improved pore space is a consequence of the bioturbating activities of micro-organisms and macro-organisms and channels left in the soil by decayed plant roots. However, in the case of the Huambo soil, nothing is known about the detailed composition of the organic matter in its soils, which constitutes a challenge for future research

Pores are microscopic and macroscopic spaces that are part of the complex soil matrix, with varying water suction pressures that regulate water availability to crop roots for metabolism. The irregularities of the pore geometry (their size and shape), their degree of discontinuity together with variations in texture and clay mineralogy are properties that all combine to influence soil water retention (Rawls, Gish and Brakensiek, 1991). Pores in the soil are intimately linked to the structure of the organo-mineral aggregate that forms the soil. They constitute a fundamental feature of the soil that influence the circulation and retention of air and water. One issue increasingly evident in agricultural soils is the tendency to develop physical restrictions in the subsoil such as soil compaction, modifying pore space characteristics that can have a negative effect on the circulation and availability of water in the plant root zone. Thus, the degree of saturation, the ability to retain water and the ability to drain water in the soil depend on the size, shape and continuity of the pores (Singh and Sainju, 1998).

Different soil structures and ratios of void volume to the gross volume of dry soil play an important role in regulating the circulation of water (and air) in the soil. This can define the water retention capacity of the soil and is one of the most important properties governing how crop irrigation should be undertaken as it allows defining the actual soil capacity to retain water and water availability at its saturation point (Savva and Frenken, 2002). Whether irrigated or supplied by precipitation, ideal soil moistures from an agricultural perspective are considered to be between 60% and 80% of the water retention capacity (Kannojia, Sharma and Sharma, 2019).

While understanding the overall retention and availability of soil water for agricultural planning is vitally important, there has also been an emphasis on understanding the dynamics of water in the crop root zone. (Liebig *et al* 2012). Water management, precipitation flow processes and the dynamics of ecosystem changes can be considered as spatial-temporal variables that influence the flow of water through the surface or underground and evapotranspiration, influencing water flow in the root zone (Pender, *et al*, 2010). It should also be considered that the soil moisture content of the root zone plays a fundamental role in the individual scale of the plant as well as the whole agro ecosystem (Nhira and Mapiki, 2007). Due to the imbalance in water management and water supply for agriculture, the prediction of soil moisture in the root zone is of vital importance for crops. Irrigation drainage differences and adequate distribution practices should be considered in the development of tools that benefit farmers in improving the prediction of soil moisture deficiencies in the root area of the plant and water stress, (Savva and Frenken, 2002).

2.3.4 Subsistence Agriculture and Soil Moisture

Most of the food that feeds the planet is produced by subsistence householder family farmers and this deserves much more recognition (Nhira, 2005). In the South African region historically, there has been a slow and fragile adoption of sustainable land and water management in response to the risks and uncertainties within the new climatic conditions that affect the region. Rainfall is the source of water supply for rivers, lakes and land moisture. However, this supply is not distributed evenly and depends on the characteristics of each agro-ecological region (Wani, *et al*, 2009). Available land and water resources may be sufficient to produce the amount of food needed to satisfy future demands, (Nhira and Mapiki, 2007). However, for this, it would be necessary to take into account dryland agriculture that depends only on rainfall, and which produces enough food to support the most disadvantaged communities in developing countries. In sub-Saharan Africa for instance, 95% of the cultivated land depends exclusively on precipitation, (Thomas, *et al*., 2007).

Subsistence agriculture is the largest source of householder family income and is the activity that most jobs provide to the rural population in Angola and in particular in Huambo province. Increasing crop productivity can contribute to improving life quality in rural areas and beyond. The need for a consistent perspective on Angola's subsistence agricultural potential means it is essential for research to provide credible information with complete details on the physical, water and chemical characteristics of soils and their ability to sustain sustainable agriculture. There is also a real need to maintain the monitoring of the natural resources that determine householder agricultural potential in relation to climate change. Land use planning depends on reliable data and information on the potential of natural resources. Currently, for subsistence forming farmers, land use planning is rarely based on adequate information about natural resources.

As well as information support on water management, irrigation, both large-scale and micro-scale, may offer another approach to manage climate change driven precipitation changes. Irrigation in agriculture is expanding around the world due to the improved productivity it supports, but this greater water demand must be weighed against hydrological availability and the water requirements of public supply, industry and the environment. In many regions of the world, and particularly in southern Africa and specifically Angola, little attention is given to the needs of the water ecosystem and there has been no effort to predict future requirements for irrigation (Thomas, *et al*, 2007, Wani, *et al*, 2009). To prepare for the future, it will be necessary to create integrated models of agricultural hydrology - including soil water holding capacities -

that can calculate the demand for irrigation and assess the impact of this demand on hydrology and predict future sustainability of expanding irrigation under contrasting climate scenarios (Jin and Young, 2001). Even with a shift to irrigation systems for subsistence agriculture, sustainable land management practices that contribute to increasing the soil's water-holding capacity and conserving soil moisture content will remain essential to maintain crop growth and productivity.

Historically in Angola, there have been no studies to assess changes in soil water conditions based on analyses that are linked to predictions of future climate, no parametrization to local land surfaces and an absence of hydrological and climatic models predicting soil moisture dynamics (Nhira, Mapiki and Rankhumise, 2007). Angola urgently needs to develop its appropriate schemes according to the climate of the region and to create new predictions of soil moisture content and soil water holding capacity, using rural extension services that allow the dissemination of local information about the climate, predicting risks and introducing new agricultural production techniques practices in rural communities that are sustainable in soil management and conserve soil moisture against the impacts of climate change. It is now essential to consider analysing whether the soil's capacity to hold water can offset part of the impact of a decline in rainfall and which soil properties are regulating the soil's water-holding capacity? and how much water can the soil hold to support subsistence agriculture.

Two important physical properties are soil texture, defined by the particle size distribution, and soil structure the aggregation of soil particles (Reinert and Reichert, 2006). Climate influences significant changes in the conditions of the natural processes of soil formation and the development of different soil types in different regions of the globe (Várallyay, 2010). It can result in differentiation of textures in the soil profile, spatial arrangement and stability of soil aggregates and the content of organic matter in soils (Morison and Matthews, 2016).

Regions with higher humidity, precipitation and temperature tend to form deeper soils, due to the direct action of water and temperature on weathering bedrock material and, indirectly, promoting greater biological activity, which in turn also contributes to weathering. Soil has its origin in the varied interaction of various forces, including climate, relief, parental material, living organisms, acting over time. The development of soil takes many years to form. However, profound changes that occur in some climatic factors and vegetation, most of the soils are under continuous development (Karmakar *et al.*, 2016. Morison, J., Matthews, 2016).

2.4 Land Management for Soil Water Holding Capacity in a Climate Change Future.

2.4.1 Enhancing Agricultural Land Management and Water Use Efficiency.

Some crops are highly dependent on specific climate conditions but endeavouring to understand the overall effect of climate change on agricultural production and food supply can be difficult. Increases in temperature and carbon dioxide (CO_2) can be beneficial for some crops in some places, however, to realize these benefits, nutrient levels, soil moisture, water availability, and other conditions must also be met. Changes in the frequency and severity of droughts and floods will also pose challenges for subsistence farming farmers. The effects of climate change also need to be considered along with other evolving factors that affect agricultural production, such as changes in farming practices and technology.

Soil moisture deficiency in the root zone of plants, flooding and prolonged drought can have a negative impact on local, national, or regional agricultural production, (Binayak *et al*, 2016). With emerging climate change, it is important to create sustainable policies that enable decisions to be taken to allocate and manage water resources that offer sustainable strategies for efficient water use and to reduce the potential risk of crop failures caused by drought or flooding (Challinor *et al.*, 2007). Land assessment is the process that involves the selection of land suitability for specific purposes such as irrigated agriculture, adequate land for appropriate crops, and management alternatives that are physically and economically feasible. Adaptation of land and water use management to the climate change that is already in progress, has resulted in damaging physical and social effects that are often irreversible. Spatial planning of land use for agriculture in human settlements has never taken into account the phenomena of climate change and has always assumed a stable climate in which episodes of heavy rains or prolonged drought were unusual situations. Knowledge about climate changes and the prediction of future scenarios will offer a more robust assessment of appropriate agricultural land and water management.

Land resources are used for various purposes in the production of essential goods for humanity. Different uses differentially affect the natural balance of ecosystems and require sustainable management that contributes to local and global environmental benefits. Regardless of their purpose, productive systems must be adequately adapted to the practices that contribute to sustainable agriculture, using good soil management practices and technologies that provide effective adaptations, reforestation, urbanization, and use of water resources guaranteeing the long-term potential of soil productivity and maintaining an acceptable environmental balance.

The land is a fundamental resource for human beings constituting the universal support for all economic activities (Doran and Jones, 1996). A high standard of knowledge about appropriate forms of land use can be an essential part of the sustainable process of land management (Hurni, 2000). Considering the different forms of the basic needs and the dynamics of how land is used requires sustainable management that guarantees long-term productivity (Craswell and Lefroy, 2001). Land production sustainability is however influenced by the potentially limiting effects of climate change, a critical factor to take into consideration in sustainable land management, (Hurni, 2000; Branca *et al.*, 2011).

According to Shukla *et al.*, (2019), most of the extent of dry land in the tropics can be considered fragile subject to degradation by erosion. Unsustainable agricultural practices on agricultural land, the transformation of forests to agricultural land, grazing overgrazing and overexploitation of the natural environment are the main causes of serious land degradation, reducing primary land productivity in the Southern African region. The high impact caused by climate change variability can also contribute directly to land degradation (Pende, Ringler and Magalhaes, 2004). Exposed and unprotected soil to extreme weather conditions contributes to the high degree of soil erosion, organic matter loss and other impacts such as changes in the dynamic of soil flora and fauna microorganisms that contribute to soil degradation.

Combined, climate change and poor land management results in a faster transformation of forest or pasture to unsustainable agricultural uses (Hurni, 2000), exhaustion of fertility and water storage capacities and vulnerability of agriculture productivity and rural population (Prada *et al.*, 2017). However, the appropriate application of land management practices can contribute to the improvement of agricultural production systems and soil water retention. They can increase soil productivity, soil microorganism activities and manage and conserve soil moisture (Keshav Lall. Maharjan and Joshi, 2013).

One of the emerging major problems for large and small farmers facing climate change in Southern Africa is soil water conservation resulting from dramatic changes in rainfall, drought, plant transpiration and soil evaporation (Collier, Conway and Venables, 2008, Stringer *et al.*, 2010). In the southern African region, the annual variability of the rainy season and the dry season is influenced by the El Niño-Southern Oscillation (ENSO) phenomenon that causes an increase in heating between 0.2°C and 0.5°C per decade. Meanwhile, the continent's overall average temperature is projected to increases by about 0.7°C. (IPCC, 2007). Water stress and soil infertility are the main factors restricting the increase of agricultural productivity in arid and dry areas (Kpadonou *et al.*, 2017) and new land management practices are needed to mediate these impacts (Oyekale, 2016).

The most important resource for the economic and social development of a country has always been the land. However, climate, population and economic changes are increasing the use and pressure on natural resources and land use worldwide, and it is necessary to create appropriate management models that contribute to the sustainable management of this resource, (Roggema 2014). Climate variability and land degradation are seen as considerable threats to the livelihoods of millions of people in sub-Saharan Africa, (Fallon, *et al* 2018). However, there are important opportunities for governments to improve the livelihoods of small-scale farmers and users of land resources in Angola, mitigating greenhouse gas emissions, reducing land degradation through efficient management techniques, and addressing planning issues directly related to development that takes account of the impact of climate change and the expansion of international, national and local efforts, thereby promoting sustainable land management and conservation, (Oyekale 2016)

According to FAO (2012) and Fallon, *et al* (2018), the land is considered the most valuable asset in southern African nations and as a consequence, land governance is increasingly considered in terms of legal concepts as a means of contributing to improving land use and management. Despite the existence of legal structures that determine how to access, protect and use the land, Angola still faces significant limitations in the effective implementation of new mechanisms of adequate land management.

For Angolan subsistence agriculture practised for small family farming the most significant sector of the Angolan agricultural system, institutional deficiencies contribute to increasing the complexity of existing rural difficulties, (Beernaert, 1997). The challenges that family agriculture faces over time are linked to the incomplete implementation of legal frameworks related to land incumbency law, the increasing impacts of climate change, food insecurity and conflicts over foreign agricultural investments (Hahn, 2013). Most recently, however, adapting principles based on social dialogue and negotiation between family farmers and legal institutions has been an effective mechanism that has contributed to a paradigm shift in the appropriate methodological approach to the use and management of land and natural resources for agricultural development.

In Angola, agriculture is dominated by thousands of small family farms that practice subsistence agriculture, (FAO 2012). The average area of land planted by each family is about 1.5 ha. In general, agricultural family farmer's production depends exclusively on the rainy season, which begins in September through February in most of the country and can last until April, (Beernaert 1997, FAO 2012). the majority of farmers do not use agricultural mechanization in the preparation and seeding of land;

everything is done manually and uses relatively low levels of inputs, such as improved seeds or the use of chemical fertilizers (Hahn, 2013). A large proportion of these small farmers do not have a technical domain of sustainable land use management, contributing to a significant increase in land degradation, (FAO 2012).

The misapplication of land management techniques can cause considerable land degradation that impedes agricultural growth and other economic sectors, increasing poverty and vulnerability, social tensions and imposing greater burdens on limited natural resources (Hahn, 2013). The existence of few skilled researchers has contributed to a collapse of agricultural institutional capacity at all levels severely affecting, agricultural research and rural extension, preventing the introduction and adoption of improved technologies and practices along the agricultural production chain, (Hurni, 2000).

2.4.2 Smallholder Responses Strategies to Adapt Land Management Soil Water Holding Capacity to the Impacts of Climate Chang.

Environmental changes threaten the livelihoods of local families, who must adopt different strategies to the new climate scenery and techniques of agricultural production practices. For this, the use of cultivars with reduced planting time that accompanies the change in the rainy season affects subsistence traditional farming patterns. These patterns of change must be confirmed during group discussions with traditional authorities, communities, householder farmers as part of the main beneficiaries (Laube, Schraven and Awo, 2012).

Development of several structures that integrate elements that describe adaptability capacity and the relationships between ecological and biophysical driving, natural, social, political and economic processes that influence access to risk exposure (Figure 2.6), contributing to dynamic vulnerability due to environmental stress (Nelson, Adger and Brown, 2007) There is examination required of the economic costs of subsistence family farmers to adapting to the differences between the economic losses associated with changes in the environment and traditional scenarios with new technologies. Among these approaches, the main issue is the identification of successful adaptations to natural resources outcomes of land and water management, to improve soil water holding capacity and soil moisture content (Adger, Huq and Hulme, 2003), developing several structures that integrate elements that describe the relationship between soil management and the improvement of the soil's water-holding capacity and the maintenance of soil moisture content, contributing to the reduction of the dynamic vulnerability of rural communities dependent on the production of subsistence family farming.

The characteristics of the components of the adaptation strategy process result from adaptability capacity of the formers according to the characteristics of the community and system, in management of natural resources and livelihood outcomes which are captured by the concept of resilience (Nelson, Adger and Brown, 2007). The factors that contribute to vulnerability are not assumed a priority but are identified based on householder farming experiences, allowing differentiated vulnerabilities in the community, explaining the multiple underlying political, socioeconomic, and environmental forces that influence how subsistence farmers are exposed and how sensitive they are to them the climate and its ability to adapt to changing conditions (Figure 2.6). It is imperative to develop an integrative adaptive strategy plan that describes the relationships between processes that influence subsistence farming exposure to risks based on the dynamics of the impacts of climate change.

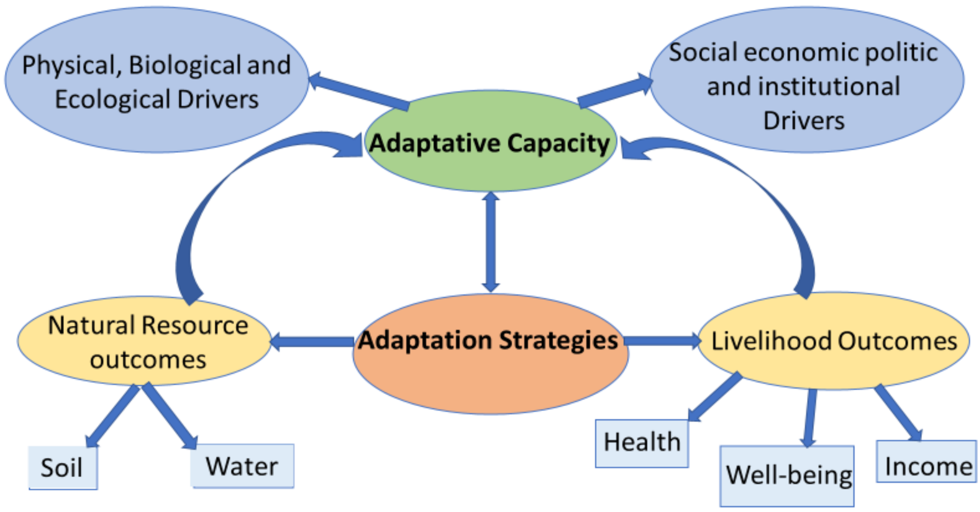

Figure 2.6 - Integrated elements of land management and social adaptative capacity and strategies regime to climate change.

It is extremely important to develop a general sedative strategy of coupled human-environment systems, with links to impacts and adaptations between scales that reflect subsistence farming vulnerability to exposure, sensitivity and resilience. The construction of strategies and actions ranging from short-term variability to more profound and long-term transformations aim to meet more than just the goals of climate change and may or may not be successful in moderating the damage or exploring beneficial opportunities (Moser and Ekstrom, 2010).

Sustainable householder farming approaches are useful in capturing contextual factors that shape adaptive capacity. The adaptability of subsistence farming in managing land resources for water holding capacity and maintaining soil moisture content is a process that occurs when individuals and local communities decide to act and change their habits for a new reality. This can include innovative agricultural practices, sustainable management of natural resources and environmental conservation strategies. This complex process occurs in local communities that share social, economic and environmental interests in search of a shared vision of the development and facilitation of adaptation processes (Oettle, 2015).

2.4.3 Customary Land Management Small Farmers Limitations in Adapting to Climate Change.

The high incidence of vulnerability in sub-Sahara African countries to climate variability, aggravated by multiple tensions at various levels, is one of the main factors affecting various socio-economic sectors on the sub-continent with current environmental sensitivities. This vulnerability is exacerbated by existing development challenges, such as subsistence agriculture that depends entirely on environmental factors (Claessens *et al.*, 2012), associated with endemic poverty, complex governance with uncertain climate policies, the use of obsolete and rudimentary technology and the constant degradation of the ecosystem and natural resource, all of this contributes to the weak capacity of southern Africa subsistence small farmers to adapt to projected climate change (Boko, et.al., 2007)

Land management techniques used by subsistence farmers in the region are the result of attempts to adapt to the environmental pressures and uncertainties experienced over time. These management systems can be considered as adaptive based on an accumulation of observations mechanisms due to climate change (Berkes, Colding and Folke, 2010), where local knowledge contributes to the structure of society and acts as a guardian of ecosystems and expands the empirical techniques to subsistence traditional farming land management that allow the improvement of endemic crops and natural resources.

Therefore, an important approach to be considered in the management of land and natural resources for resilience is adaptive management to minimize uncertainty, which allows dealing with external shocks, in the dynamics of soil water holding capacity and soil moisture content for subsistence householder farming (Nadzirah, Hitoshi and Amran, 2020).

Householder farming that depends on subsistence agriculture use practices that conserve ecosystem resilience, such as changeable soil cultivation systems with intercropping of two or more crops, while maintaining soil moisture and crop diversity. This management system created a productive mosaic where the harmonious interaction between people and nature sustains biodiversity and provides smallholders with an ecosystem that supports various livelihoods and well-being (Nadzirah, Hitoshi and Amran, 2020).

2.4.4 Hydrology and Soil Water Holding Capacity and Moisture Deficit.

The effects of climate change could cause profound changes in soil hydrological conditions, reducing soil moisture content, soil water holding capacity and contribute to reducing subsistence agricultural productivity (Jin and Young, 2001). Sustainable management of natural resources including river and catchment can be a process that supports the formulation and implementation of actions that allow the sustainable manipulation of land resources to provide goods and services without damaging the soil water holding capacity and soil moisture content (Wani *et al.*, 2009). This process includes a range of technologies for the integrated management of natural resources, improving the soil water holding capacity, techniques for the conservation of soil moisture and nutrient management economically and that can be easily adopted by the householder agricultural production practices, (Savva and Frenken, 2002).

The amount of moisture contained in the soil is important to determine the infiltration and drainage partition of rainwater. However, excessive rainfall can flood the soils and, consequently, have a negative impact on the production process in Angola(Rivaldo *et al.*, 2017). Crop losses caused by torrential rains represent about 40% of the total area planted in regions with high rainfall rates (FAO 2012). However, in areas where there is a prolonged drought during the crop growth phase, losses are also considerable, between 60% and 80% of the total planted area. As a consequence, food insecurity and hunger increase among smallholder agriculture (Carranza and Treakle, 2014).

Dry soil receives more water before saturation, while areas with high soil moisture have less rainwater infiltration capacity and are easily saturated. This plays an important role in determining the severity of flooding in areas with high moisture content for long periods. (Savva and Frenken, 2002). It is imperative to have efficient and sustainable management of agricultural water driven by better predictive tools and a better understanding of the water cycle at different scales. These should take into account space-time considerations based on precipitation, temperature, contributing to the sustainability of water resources for agricultural production and health of the terrestrial ecosystem, (Binayak *et al*. 2016).

However, almost no studies of agriculture and land water holding capacity have been carried out in the Angolan productive lands and river basins, these have been studied only in relation to the construction of hydroelectric dams and with limited studies in specific localities on the construction of small irrigation channels. There has been no thorough study in agriculture linked to soil water capacity and current climate change conditions, (Oyekale, 2016).

Agro hydrology is considered the processes and collection of hydrological data to increase the productive efficiency of plants and provide conditions that contribute to the maintenance of soil moisture suitable for crops (Chandrappa *et al*, 2011). However, variability in environmental conditions in which crops grow and the influences and forms of land management and drainage of surface waters have a significant impact on the productive process and the retention of water in the soil (Ian.

Douglas *et al.*, 2008). Soil moisture distribution is affected by soil heterogeneity with considerable influences on hydrologic conductivity and soil water holding capacity through variations in texture, organic matter content, structure and porosity (Shin, Mohanty and Ines, 2012). These factors may affect water transmission and retention properties, soil hydraulic variability, vertical and lateral transmission (Joshi *et al.*, 2011).

The variation in soil particle sizes, as well as in the pores, can determine the transient soil water flows upstream and downstream at very short distances. Another factor that plays an important role in the spatial distribution of soil moisture is scale-dependent topography. The heterogeneity in the distribution of vegetation, variations in radiative incidence, soil texture characteristics, aspects related to slope including curvature also directly affect soil moisture distribution (Gaur and Mohanty, 2013).

Agricultural production in Angola is mainly based on a single rainy season. Subsistence small family farms predominant in the agricultural production process with a subsistence farmer having an average of 1.4 ha to 2.00 ha per household often with two or more land spaces (Carranza and Treakle, 2014). The agricultural season usually starts from September to December in most of the Angola national territory. Land preparation is done mainly by rudimental techniques manually or by animal power, while a small number of farmers use mechanization. Practically, the use of improved seeds, agrochemicals or chemical fertilizers is very low negligible or non-existent across the subsistence farmers. In the dry season and due to the lack of rainfall and irrigation systems farmers tend to carry out production in the valleys on the edges of rivers or ponds (Figure 1.9) where there is acceptable and high moisture content in the soil (FAO, 2012, Carranza and Treakle, 2014).

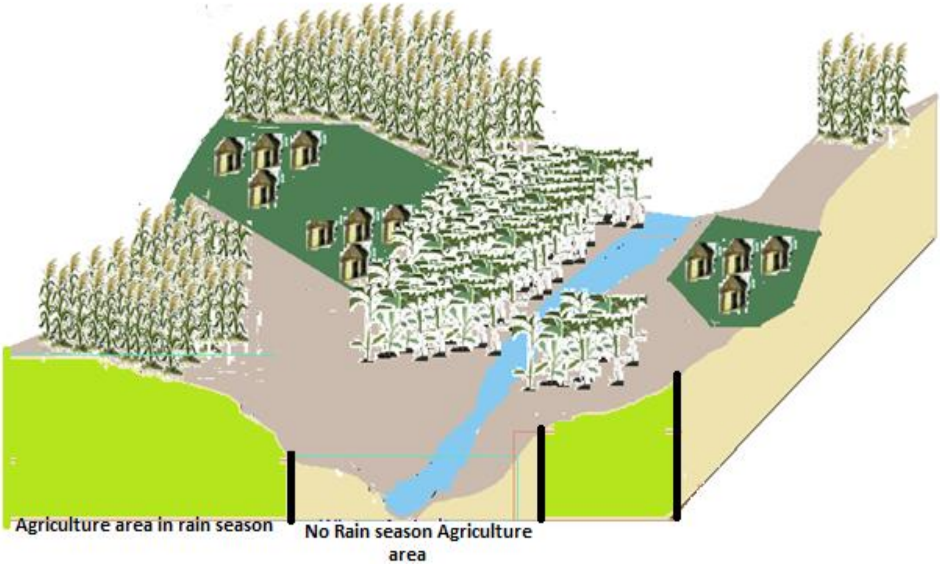

Figure 2.7 - Schematic of the agricultural landscape, Huambo province Angola. Subsistence farmers planting crops following soil moisture according to the slope of the terrain

Subsistence agriculture depends entirely on the soil and the water contained in the soil (Rawls, Gish and Brakensiek, 1991). The quantity and quality of soil moisture depend on its ability to store enough water to satisfy basic functions for sustainable crop development. (Eswaran *et al.*, 1996). Agriculture plays a sustainable basis for the development of the world economy. Throughout the world, there are signs of greater support for the sustainability of the family farmer to alleviate and eradicate hunger that still exists in many parts of the world in general, and sub-Saharan Africa in especially (FAO, 2014). Sub-Saharan Africa has the largest vulnerable and marginalized population in the world, family farming is critical to the sustainable development of subsistence farming, contributing to the stability of current and future food security (Eswaran *et al.*, 1996).

2.4.5 Climate Impact on Crop Productivity and Land Management to Sustaining Soil Water Holding Capacity and Moisture Content.

Subsistence agriculture is an ancient and historic economic activity widely used in sub-Saharan Africa by most of the rural population (Sivakumar, 2006), in which their domestic economy depends on agriculture to survive. It is the socioeconomic activity broadly practised in the region in the process of producing low-cost food for the needy population (Fadda *et al.*, 2020). It also creates the opportunity to continue living in a village, where housing is much cheaper and allows the family to be self-sufficient in food production.

Although householder farming can be sustainable for some rural families, however, in the vast majority, there are still risks of hunger due to the impact of climate changes that occur in the environment and its dependence on natural resources and soil water holding capacity and soil moisture content (Burke, Lobell, & Guarino, 2009, Singh & Singh, 2017). With current climate change, subsistence agriculture is slowly responding to adapt to these changes and is heavily affected by prolonged droughts or floods. In both cases, the harvest can be very limited causing the occurrence of insufficient food to support the family.

In the Angolan context and the Huambo region, in particular, subsistence agriculture, often neglected from a socio-economic point of view, with few financial resources, low agricultural productivity, and an average cultivated area per family of fewer than 2 hectares, use of rudimentary equipment and technology it is a challenge for rural communities to face climate change. The dissemination and sharing of information on climatic conditions in rural areas and the results of research from universities, research institutes and the availability of rural extension services would be relevant for the transference of new technologies and acknowledgement of climate variability and this is the key to promoting the sustainability of agriculture enabling the adoption of new technologies that aim to assist in the adaptation and sustainable management of natural resources to current climate conditions in subsistence agriculture (Mazvimavi *et al*, 2010). In subsistence agriculture, crops generally have low productivity due to the use of rustic technologies and the work is completely manual. The lack of support from financial institutions or credits to support and modernize production techniques, which rarely happens in subsistence family farming, directly affects the productivity of the crop, with low profits for the family, both in the sale of products and in the diet of families.

Climate Predictions and the Impact of Climate Change on Subsistence Agriculture in Huambo: Angola.

3.1 Chapter introduction: Climate and Climate Change Prediction.

Water scarcity caused by low rainfall in the study region is a challenge to social stability compounding problems associated with increased urban and rural population growth and local government's inability to maintain agriculture and agricultural infrastructure. Lack of information and monitoring of the impact of climate change are also limiting the sustainable management of land and natural resources for social and economic development. (Thornton *et al*., 2011; de Clercq *et al*., 2018).

Climate variability is a process related to frequent changes in the distribution of climatic parameters, such as temperature and precipitation in a given period. Change in climatic conditions is currently having a negative impact on food security in the Southern Africa region and in many Angolan households, which are largely dependent on subsistence agricultural production. A better understanding of the impact of climate on food production and how climate variability affects food production systems and subsistence farming sector now and in the future is increasingly needed in Southern Africa to help mitigate its effects on subsistence systems (Parry et al., 2004; Fischer et al., 2005; Joshi and Maharjan, 2013; Niang et al., 2014). A starting point for this is to understand the nature of climate change in the region.

Subsistence agricultural production in Angola is dependent on climatic conditions and is based on a single rainy season. It is a traditionally productive model integrating socio-economic, cultural and environmental organization in which agricultural activities are developed by the family as a labour force to support their essential needs. The agricultural season usually starts between September and December through to May across most of the national territory on an average of 1.4 ha to 2.0 ha per household, often with two or more land units. However, subsistence farming generally gives low yield and is often insufficient for family requirements; furthermore, there is no surplus for commercialization and trade. Climate change influencing temperature and precipitation together with associated soil water holding capacity limitations are accentuating these issues (FAO, 2012; Carranza and Treakle, 2014; Balgah *et al.*, 2016).

Climatic factors directly limit agricultural productivity in subsistence systems. Among the important climatic factors to be considered in agricultural systems, precipitation, temperature, evapotranspiration, and humidity are the main climatic variables used for crop yield forecasting. Although all these factors are extremely important for agriculture, precipitation is the most important climate limiting factor in Southern Africa directly regulating soil moisture deficits and with distributions varying with storm characteristics. Variances in soil properties then influence available water capacity resulting in spatial and temporal variability in soil moisture for agriculture, (Balgah *et al.*, 2016).

Climate factors are variable over the years and by decades in this region of Sub-Saharan Africa. To manage and reduce the negative impacts of climate on subsistence agriculture, it is important to define climate limits on a consistent scientific basis and assess against sustainable agricultural practices and different crop varieties used. These assessments can be applied to give early warning of climate change impacts, help improve spatial planning for agriculture and adapt new technologies of farming practices according to climate changes affecting the region, (Douglas *et al.*, 2008 ; Oyekale, 2016). However, improving the availability and access to high-quality data for climate observations also requires a link to practical guidelines for the use of climate information in agriculture and land management for the household subsistence farmer. Systematic documentation and widespread dissemination of good practices in terms of climate sensitive land management techniques that are easily accessible to the farming family are needed (Yanda and Mubaya 2011). Farmer knowledge and perceptions about climate changes and prediction of future scenarios can also offer a more robust assessment of new land capabilities and appropriate agricultural land management in a climate changed future.

The two main climatic parameters that determine the socioeconomic prospects of householder farming are annual precipitation, its spatial and temporal distribution, and temperature fluctuations (figure 3.1). Adequate availability of water is one of the fundamental factors for the success of subsistence agricultural productivity. For soil moisture, rainfall, rain days and dry spells frequency play an important role in crop production for agricultural livelihoods (Sivakumar, 1992), because it is the input for soil moisture and water supply required by the agricultural plant, while temperature (and humidity) dependent evapotranspiration can be a soil moisture loss to the plant (Parry *et al.*, 2004).

Soil moisture content for agriculture depends heavily on precipitation. The total rainfall per number of rainy days per hour (millimetres) that occur characterizes precipitation intensity. This includes not only the measurement of the interval between the period of high rainfall that occurs from November to March and the period of low rainfall from May to August but also includes the frequency with which these extremes occur and the intensity of the rainfall events. Increasing temperatures can cause changes in precipitation and a possible increase in the frequency of extreme events, such as droughts and floods, which can increase crop production risks and productivity (Fischer *et al.*, 2005)

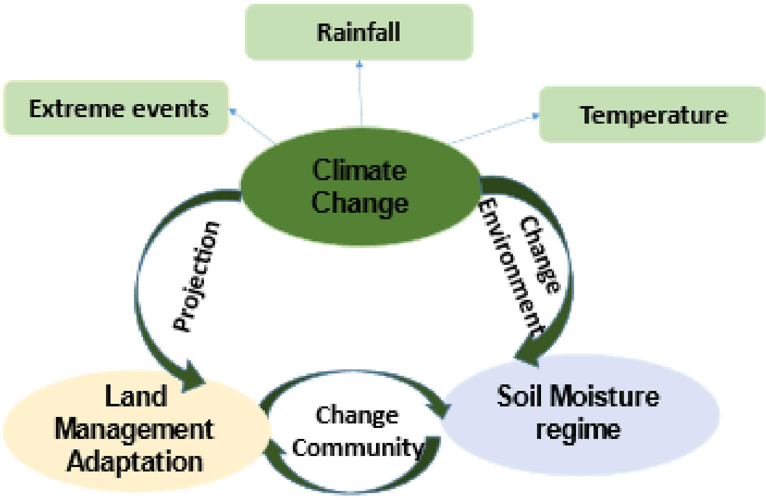

Figure 3.1 - Climate factors intertwined relationship with soil moisture and land management adaptation.

As precipitation and evapotranspiration are the main factors that affect soil moisture and the amount of water in the soil, adequate availability of water is one of the fundamental factors for the success of agricultural productivity, since lack of water can result in soil moisture deficiency and consequently, cause a negative physiological disturbance in crops. Rainfall plays an important role in subsistence crop production because it is the soil moisture and water supply for the agricultural plant, while evapotranspiration acts as a soil moisture loss to the plant.

In regions with less precipitations than evapotranspiration, there is a hydrological deficit. However, rainfall is never uniform in Huambo Province specifically and Southern Africa more generally, and it varies throughout the year (Kusangaya *et al.*, 2014), so the relationship with soil moisture deficits also varies over the year. Local climate data sets specific to particular localities therefore become important as a basis for understanding climate change and offer detailed advice that is relevant to subsistence farming communities. In demonstrating the importance of local climate data sets, and as an example, it is important to understand rainfall and evapotranspiration regimes in the Huambo region using historical weather data set over the years and address the question: - *How have climate – temperature, precipitation and evaporation - and derived soil moisture deficits changed between 1960 and present-day?*

Obtaining information on agrometeorological and climatological data is essential to facilitate the planning of agricultural production. Without adequate information describing the real climate characteristics of the region, it would be impossible to make decisions enabling the proper use and management of land and natural resources. Sustainable land and water use, selection of suitable crops, irrigation control, sowing time, pests and diseases and symbiotic relationships between crops and climate in a given ecosystem depend directly on the climatic conditions presented in a region. However, many agricultural activities can be effectively scheduled in the use of real-time weather information, such as sowing, fertilizing, harvesting and pest and disease control should be applied when climatic conditions are more favorable. Possible climate changes can indicate transformations in the precipitation regime and increases in temperature throughout the region will contribute to increased evapotranspiration. It is important therefore to continuously monitor weather conditions, as they contribute directly to crop production and productivity. As well the possibility of predicting future climate scenarios based on historical data sets, this chapter will also endeavor to explain *how these data and observations can contribute to a future agricultural capability system*?

Soil moisture depends heavily on precipitation (Kusangaya *et al.*, 2014). The total number of rainy days that occur characterizes precipitation intensity. The characteristic of precipitation in the region is based on the relation between the rainfall total and the number of rainy days that have occurred (Sivakumar, Das and Brunini, 2005). This includes not only the measurement of the interval between the period of high rainfall that occurs from November to March and the period of low rainfall from May to August but also includes the frequency with which these extremes occur and the intensity of the rainfall events. Increasing temperatures can cause changes in precipitation and a possible increase in the frequency of extreme events, such as droughts and floods, which can increase crop production risks and productivity (Fischer *et al.*, 2005).

Within these contexts, the purpose of the chapter studies is to construct scenarios of climate change – temperature and precipitation – local to Huambo province, Angola. These analyses are based on historical colonial and postcolonial local climate data sets from between 1960 and 2017 together with statistically modelled projections from these data. In so doing we highlight what analyses are possible from these archived data and the prospects they hold for constructing future climate scenarios. The analysis is also considered as a foundation for local land evaluations and community adaptations. Our objectives are to:

- Identify changes in annual average temperature, annual maximum and minimum temperatures
- Identify changes in precipitation patterns including total annual precipitation and changes to the rainy season period
- Make forward projections of temperature and precipitation change for the Huambo region

It is anticipated that these analyses will help realize future planning for sustainable land use by local agricultural extension services in Angola and translated into mitigating actions for family farming and small farmer producers in a climate changed future.

3.1.1 Study Location

The study was conducted in the province of Huambo, located in the central plateau of Angola, 1700 meters above sea level (Figure 3.2). The selection of Huambo province as a study area is due to its importance in agricultural production within Angola. It is the second province by population density in Angola, with more than 50% of the population dedicated to agricultural production. Over 85% of this is subsistence agriculture practiced on Ferralsols of limited water holding capacity even though there is good rooting depth (Jones *et al.*, 2000; Jones, 2018) and with the use of rudimentary production technologies. Huambo is located in the tropical climate zone and has two main seasons per year, the rainy season and the dry (or winter) season. The rainy season generally has an average of 8 months, with the possibility of rain starting in September and ending in mid-May. currently estimated to range the total annual from 1200 mm/year to 1500 mm/year. while the average annual temperature is currently estimated between 22°C and 24°C. The choice of the Angolan central highlands zone for this first local study of climate change in Angola is as a starting point that will lead a more detailed evaluation of agricultural land capacities integrating soil water holding capacities and land management practices in relation to climate futures in other localities.

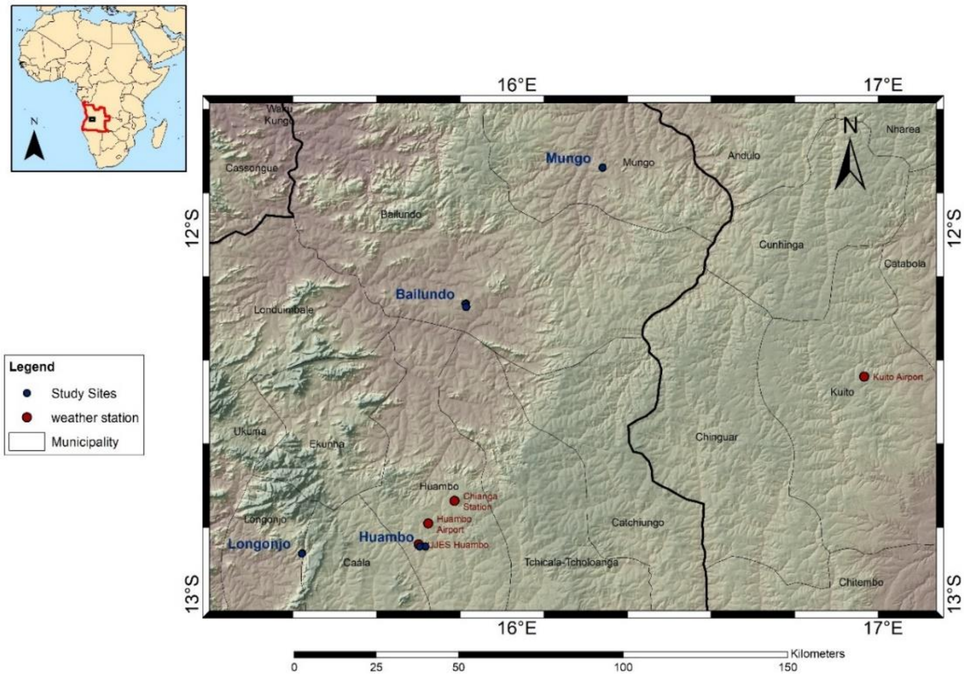

Figure 3.2 - Study site localities and weather stations in the region

3.2 Material and Methods

It is important to emphasize that it was not easy to obtain the data used in this research, with difficulties of access and availability. Most institutes in Angola do not always allow researchers to access climatological data files. This is in part due to the fact that much of the data was recorded during the colonial period and, in most cases, the formats and forms of registration are not always similar throughout the period of data collection (Appendix 3.1 and Appendix 3.2). Furthermore, data access was not straightforward; data was recorded during the colonial period (up to 1975), the post-colonial period and during the civil war (1975-2002) and the formats and forms of registration are not always the same. In addition, the data is in a manual form rather than digital or computerized. For this study all the original data were re-recorded in pre-prepared tables that give daily recording of minimum and maximum temperature, precipitation, and evaporation. The data were transposed into XL spreadsheets as a basis for the statistical analyses.

3.2.1 Climate Data Sets

The primary climatic data set is provided by the conventional meteorological station of the Institute of Agricultural Research of Angola (IIA), located in the city of Huambo, the village of Chianga, (latitude -12º74'349'', longitude 15º82'923'', 1690 meters above sea level). It is a daily historical data set and covers the period from the year 1960 to 2017. The station is the oldest in the region (Figure 3.3) and is the only one that contains well-preserved historical data over more than 60 years and with more than 95% of the data being archived.

Figure 3.3 - Chianga terrestrial conventional weather station in Huambo province, Angola thermometers to measure air humidity and Wind direction indicator

The Chianga data was cross-checked against the shorter and less complete data set from the nearby meteorological station located at Huambo airport (latitude -12º48'00'', longitude 15º45'00'', altitude 1700 meters asl) and at Kuito airport (latitude -12°24′15″, longitude 16°56′55″, altitude 1712 meters asl). Non-parametric statistical positive Pearson Correlation of rainfall, temperature, evaporation and rain day between Chianga and Huambo Airport 71.3%, (level of significance 0.01) and Kuito Airport 80.8%, (level of significance 0.01) and between the two airports with 63.3% (level of significance 0.01) were observed. With its near to complete data and statistically representative characteristics, the Chianga data set has been used in the subsequent analyses, The missing data was completed using the nearby weather station (Huambo airport and Kuito airport) determining the daily regional average obtained in the three meteorological stations.

Temperature:

The temperature values were obtained from the Chianga meteorological station, (Appendix 3.1 and Appendix 3.2) recorded manually. The data covers the period from the colonial and post-independence period (1960 -2017). For its evaluation, the mean monthly maximum and minimum temperatures were considered. Each year is compared with the temperature variability that occurred during the study period. All original data were recorded in pre-prepared Tables for daily recording of minimum and maximum temperature. Data were transferred to Excel spreadsheets for manipulation and analysis.

For temperature (°C) data the averages of the minimum and maximum monthly temperatures for 1960-2017 were calculated and annual mean temperatures were estimated using the formula to calculate the arithmetic mean:

$$\left(T_{mean} = \frac{Tmax + Tmin}{2}\right)$$

(Annual Mean temperature (T_{mean}); maximum temperature (T_{max}) and minimum temperature (T_{min}))

Evaporation:

Evaporation is difficult to measure. This is due to its considerable variability in time and space influencing the reliability of results. The effectiveness of collecting, recording and processing evaporation data depends on the skill, experience and efficiency of the monitoring team. In this research, to estimate the evaporation, the data records obtained are by circular pan evaporation mounted entirely above the ground (Figure 2.4). The daily evaporation was determined by the equation: $\mathbf{E_v = P \pm \Delta d}$, where ($E_v$) evaporation, (P) the amount of precipitation (mm) during the period between the two measurements, Δd is the depth of water added (+) to or removed (-) from the pan, (Figure 3.4).

Figure 3.4 - Circular Pan for measuring evaporation in soil surface in Chianga weather station.

Precipitation:

The total annual precipitation values were obtained for the sum of the total monthly rainfall and measured using rain gauges. For its evaluation, the total monthly values were considered (figure 3.5). The annual amount was determined by the sum of the total precipitation values of each month during the year (mm/year). Each year is compared as the rainfall variability occurring during the study period. All the original data were recorded in pre-prepared tables for daily recording of minimum and maximum temperature, precipitation, and evaporation. The data was transposed into Excel spreadsheets for manipulation and analysis.

Figure 3.5 - Rain gauges used in Huambo weather station, Chianga.

3.2.2 Statistical analyses of climate parameter relationships and predictions.

Assessment of climate change and forecasting models are potentially useful tools for risk management when considering climate instability. Researchers are constantly improving models with higher performance to predict climate conditions. Prediction as an affirmation of a probable state of climate in the future, depends on the evolution of a set of factors over time. Considering the characteristics of the long-term climate data set recorded and obtained from the region and establishing statistical relationships between these historical data allows assessment of change and how measured climatic factors influence each other.

Non-parametric correlation and regression statistical tools in SPSS were used to evaluate the trend of the time series and the relationship between climatic factors over a period of time (1960-2017). The annual temperature and precipitation data were normalized to calculate the Correlation Coefficient (CC) and to examine linear relationship between precipitation and temperature variability. The correlation coefficient (CC) was used to show the degree of dispersion between precipitation variability and temperature anomalies, which are statistically calculated at a significance level of 0.05 ($p<0.05$).

In this research, trend detection, climatic variability and temperature and precipitation projection were determined by the Statistical Reduction method using regression, correlation, and time-series analysis within SPSS tools. The statistical prediction method, integrated autoregression models and moving average (ARIMA) were also used. Typically, these models are appropriate in annual and short-term predictions through existing historical data, allowing the identification, modelling and extrapolation of patterns found in the data over time. This provided results that give a basis from which to plan contributions to reducing the impact of climate risks and in the adaptations to new and future climate scenarios.

To obtain reliable and robust results it was necessary to determine the models that best fit the data being analysed. Different models were tested taking into account the autocorrelation function (ACF) and the partial autocorrelation function (PACF) of the differentiated data. For both models, temperature and precipitation were considered with the strength of correlated values (p) and order of the moving average model (q) in the range of zero to two (0:2). As a result, the following models with 95% significance ($P<0.05$) were tested: (0,1,1), (1,1,0), (1,1,1), (1,2, 1), (1,2,1), (1,2,2), (2, 1, 0) and (2,1,1). The model with the lowest value of ACF and PACF that best fits the data was defined and selected for both temperature and precipitation.

3.3 Results and Discussion

Natural and anthropogenic processes produce gaseous compounds that alter the radiation balance of the earth's atmosphere and are drivers of global warming and climate change. Human activities especially have been demonstrated to have an impact on the variability of climatic factors by contributing to the emission of greenhouse gases, increasing in particular the amount of carbon dioxide (CO^2) and methane (CH_4) in the atmosphere. This has contributed to an increase in the temperature of the air and in the heating of the terrestrial surface (Ciais et al., 2013; Stone *et al.*, 2013). Changes in precipitation are also an indirect consequence of greenhouse gases driven climate change. In the results presented here, both temperature and precipitation parameters are used to identify climate change over time. Increasing temperatures and variability in the time series of precipitation is some of the main indicators of climate change evidenced in the weather data sets from Huambo Province, Angola.

3.3.1 Analysis of the temperature data from 1960 to 2017.

Data for this research were obtained from three meteorological stations within the study area. However, the data records of Huambo and Kuito airports are limited by having only 53 and 44 years respectively of valid data recorded. Therefore, Chianga station with complete data for over 58 years is used as the primary data set (figure 3.6). However, missing data was completed determining the monthly mean temperature (^{0}C) and total annual precipitation (mm) between the three stations were determined. The Chianga data is thus considered to be representative of climatic conditions in the region.

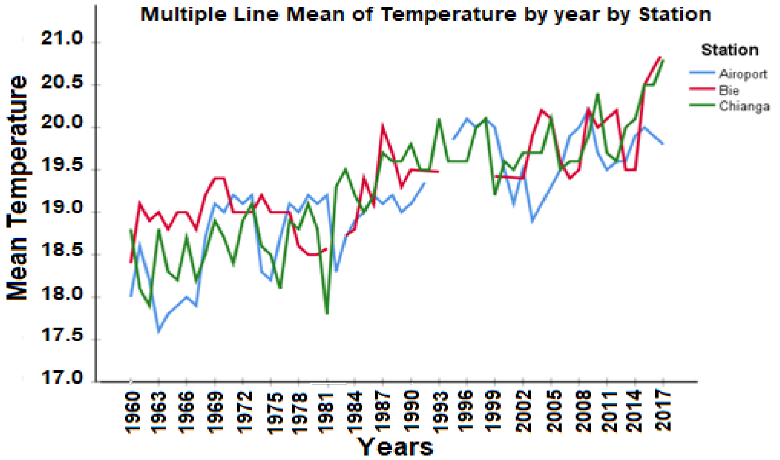

Figure 3.6 - Temperature variability over 58 years in Huambo province observed in three weather station

The results presented in figure 3.7 illustrates variability of annual maximum and minimum temperatures average during the period from 1960 to 2017. However, the year 2017 recorded the highest annual average of maximum temperature of 30.63°C with a deviation of + 3.64°C, above the average for the study period.

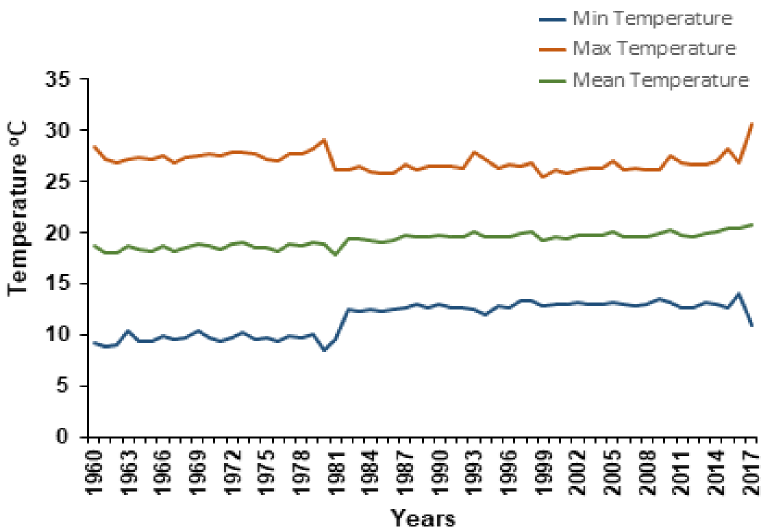

Figure 3.7 - Inter-annual variability of minimum and maximum temperature in Huambo province of Angola from 1960-2017.

In contrast, the lowest annual average of the minimum temperature of 8.54 ° C is evident in 1980 (figure 3.7). A sudden drop in the maximum average temperature in 1981 can also be observed followed by an increase of the minimum average in 1982. Those factors influencing the sudden fall occurring in this year could not be identified in this research. Nevertheless, the annual average temperature of both the maximum and the minimum continued to increase from 1992 with the winters became warmer each year; These forms of temperature variability are an indicator of the presence of climate warming and climate change in the province of Huambo. This is similar to that reported by Tyson (1991), who explained that temperature changes in southern African region will be most evident in winter with the winter and the mean winter temperature increasing faster than the annual temperature.

Average maximum temperature: Maximum average temperatures of 1960, 1979, 1980, 2015 and 2017 were above the general average of the period (Figure 3.7), with a positive standard deviation of + 1.36 ° C, + 1.22 ° C, + 2.14 ° C, + 1.29 ° C and + 3.64 ° C, respectively. These years are considered the hottest throughout this study period. These high temperatures may be associated with the inter-annual Southern Oscillation typical in tropical climates in Southern Africa and sub-Saharan region (El Niño ENSO; Neelin, 2000) occurring at these time and particularly in 2017. These warmer temperatures correspond to the global climate model predictions developed by the Canadian Climate Centre, (CCC); Laboratory of Geophysical Fluid Dynamics (GFDL); and the United Kingdom Meteorological Office (UKMO), in conjunction with the IPCC (2007) that suggest a 2 °C to 4 °C increase during the hot season across the subcontinent. The highest negative values of average deviation from the mean maximum temperatures occurred in 1984, 1985, 1986, 1999 and 2001, with negative standard deviation values of -1.04ºC, -1.14ºC -1,19ºC, -1.48ºC and -1.1 ºC, respectively. 1999 was the lowest mean values of the maximum temperature average 25.51°C, the coldest year in study period (Figure 3.7).

Average minimum temperature. Figure 3.7 shows that the highest values in relation to the mean for the minimum temperature of the period were recorded in 2016, 14.06ºC with a positive standard deviation of +2.46ºC. 1980 is the lowest annual average minimum temperature, 8.54ºC with negative standard deviation of -3.05ºC. Between the years 1960 and 1981 the mean annual minimum temperatures were lower than 11.59 °C, the minimum estimated average of the study period. From 1982 to 2016, the data presents a positive standard deviation, above the average estimated for the entire period, except 2017 which has a negative standard deviation of -0.63°C. These year on year changes indicate that the annual average minimum temperature increases in a similar manner reported by Hulme et al., (2001), IPCC, (2007) and Niang et al., (2014) for the region as a whole, indicating air surface temperature increases of 0.5 C in the last 50 years across most of Africa and supporting the argument that minimum (winter) temperatures are increasing faster than maximum (summer) temperatures (New *et al.*, 2006) and now evidenced in Huambo Province, Angola.

Annual average temperature. During the 1960 – 2017 period there has been persistent increase in average temperatures over time (Figure 3.8). From 1960 to 1986, the mean temperature records were below the general annual average temperature estimated for the period with the exception of 1981 and 1982. For the years 2010, 2015, 2016 and 2017 the annual average temperatures were above the 19.29ºC average for the period. These are the warmest years with standard deviations of +1.07ºC, +1.21ºC, +1.18ºC and +1.50ºC, respectively. 2017 was the year that recorded the highest average temperature in relation to other years with an average of 20.79ºC. The statistical results obtained in the study, as shown in Figure 3.8, confirm the relationship between temperature and time, with gradual increase in mean temperature and a positive significant difference ($p < 0.05$), (r^2 0.7535); 75% of the temperature variability is explained by the linear relationship with the time series. (Zhou et al., 2010; Kruger and Sekele, 2013) have identified similar relationships indicating that the Southern Africa region has experienced an increase in mean temperatures during the second half of the twentieth century with the most significant warming occurring in the last two decades. We suggest that this is already having a locally observable negative influence on crop production through enhanced evapotranspiration and reduced water storage in the rooting zone (Chapter 5, social survey data, Huambo province).

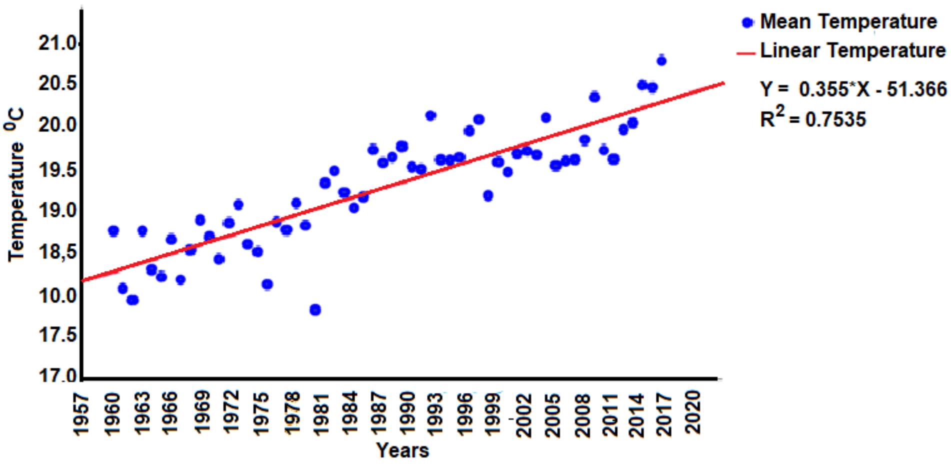

Figure 3.8 - Inter- annual mean temperature variability over time, Chianga – Huambo 1960-2017 climate data set, Huambo.

Year on year variability.

Temperature variability between years is represented in figure 3.9 showing fluctuations in the temperature behaviour that have occurred over time. In this data analyses, 1960 was considered the 'zero' year, after which the comparison between the years begins. Values with a negative sign indicate that in the previous year the average temperature was higher than that of the following year. Thus, the years 1981 and 1982 with the greatest difference in degrees over the study period with values of 1 ° C and 1.5 ° C, respectively. In general, the average temperature variability year by year is 0.33 ° C. The marked year on year fluctuations carries significant implications for the planning of agricultural activities even though there is no strong evidence to suggest such fluctuations are widening over the time period of this data set.

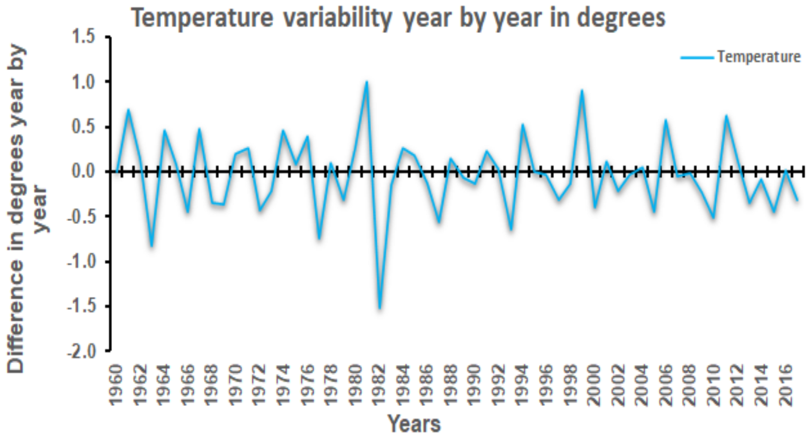

Figure 3.9 - Year on year temperature fluctuation over the studied period in Huambo province, Angola.

3.3.2 Analysis of Precipitation data for the period 1960 to 2017

Characterising temporal changes in precipitation is essential to plan future water resources for subsistence farming systems that are entirely based on rainwater (Yan and Bai, 2017). This is the vital climate element for subsistence farming in Huambo province. Assessment of precipitation data from the three weather stations indicates shortcomings in the data recorded at two of the stations, namely Huambo airport and Kuito airport, with 5 and 14 years respectively without data recorded (figure 3.10). For the rainfall data available was determined the mean average of the month of the three-weather station indicate that the Chianga station data set is an appropriate reference data set for the region.

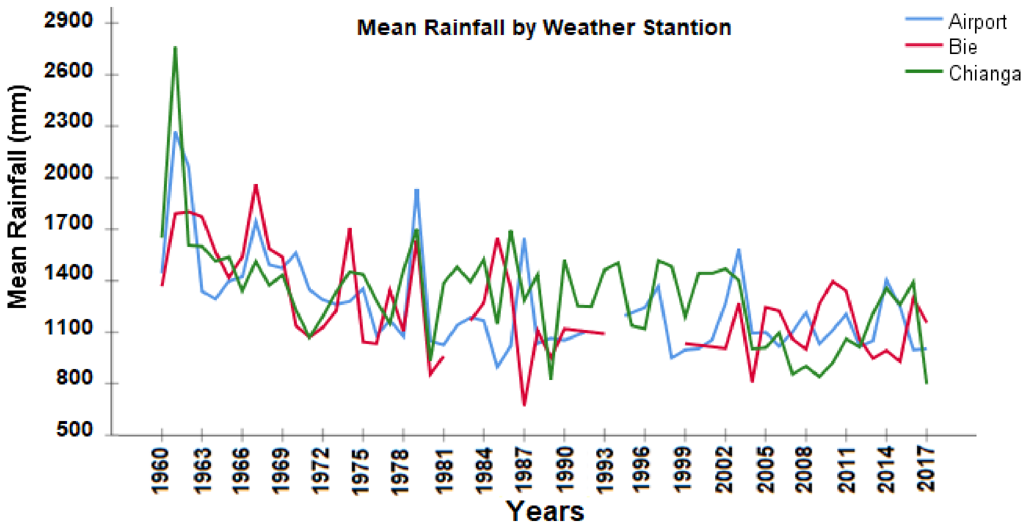

Figure 3.10 - *Rainfall variability over 58 in Huambo province in three weather station*

Figure 3.11 shows annual precipitation for the Chianga – Huambo province data set from 1960 to 2017. The wettest year of this period was 1961 with precipitation of 2813.13 mm/year and +1462.46 mm/year greater than the 1350.64 mm/year mean for the study period. This is however such a major outlier in the distribution that care is needed in its interpretation. The lowest annual precipitation is observed in the years 1998, 1989, 2007, 2008, 2010 and 2017, -523.44 mm/year, -482.14 mm/year, -424.54 mm/year, -502.44 mm/year, -413.64 mm/year and -534.34 mm/year, respectively lower than the mean for the period, and strongly indicating decreases in the annual values of precipitation over time. Statistical assessment (Figure 3.11) indicates a significance negative relationship between total annual precipitation over time with a coefficient of determination (R^2 = 0.2781) at $p < 0.05$, and 27.81% of the precipitation variability explained by the decrease of the linear relationship over time.

However, in statistically analysing variability of the number of rain days (days with rain occurrence; Figure 3.12), there is no significant change over time ($p<0.05$, R^2= 0.0371), and this climate indicator remain stable even although precipitation decreases. Although there is no difference in the total number of days considered as rainy days, there is however a significant reduction in precipitation. This is due to the increase in years with months with a total rainfall of less than 100 mm as can be seen in figures 3.13 and figure 3.14.

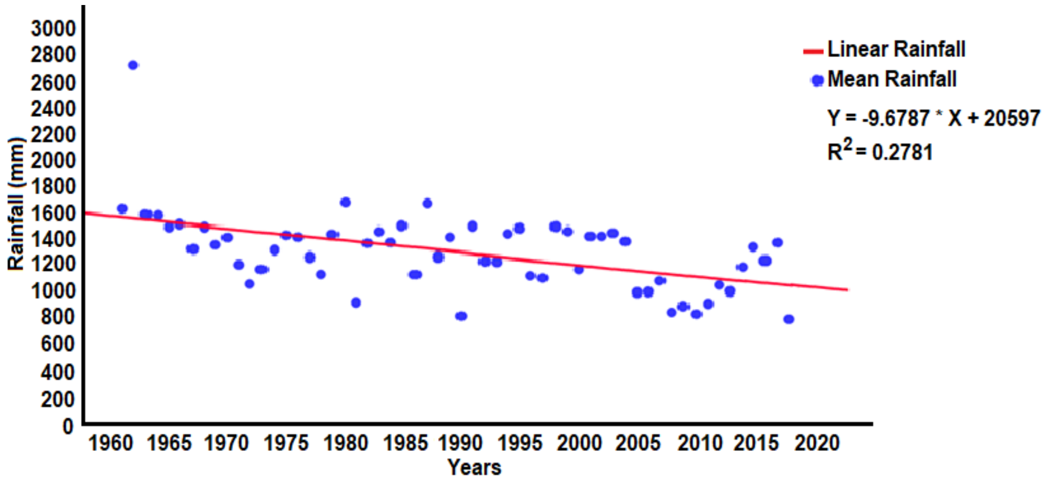

Figure 3.11 - Annual total rain variability over time, Chianga – Huambo 1960-2017 climate data set, Huambo.

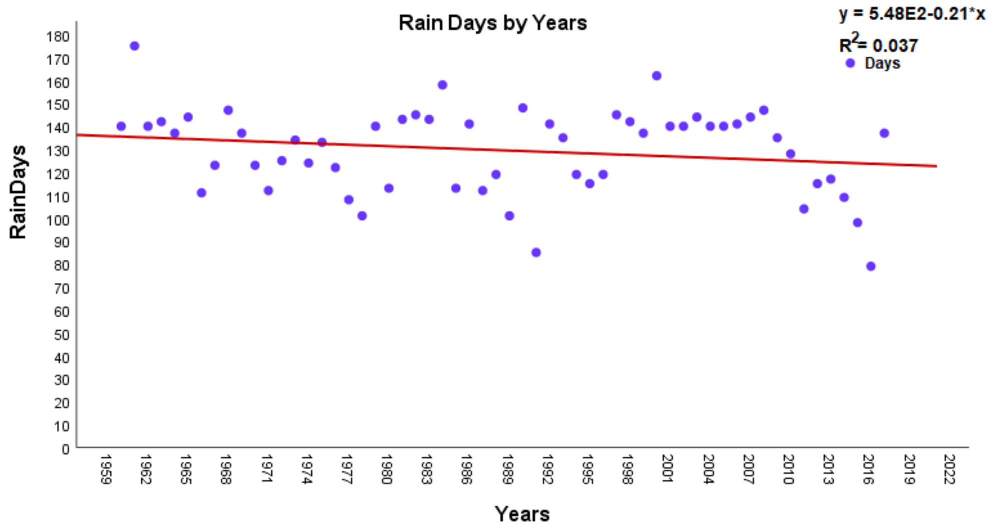

Figure 3.12: Total annual rain days variability, Chianga – Huambo 1960-2017 climate data set, Huambo.

These results show that rainfall intensity is generally declining year by year influencing soil moisture availabilities for subsistence agriculture. This temporal relationship shows that the decrease in precipitation over time is likely to have had a direct negative impact on the productive process of livelihoods agriculture that is totally dependent on rainwater. This may have caused a negative effect on subsistence agriculture practiced by the majority of the small farmers of the central plateau of the Huambo province. The results are similar to those obtained and predicted by Hulme et al., (2001) and Niang et al., (2014) confirming that Southern Africa is suffering the strongest decrease in precipitation with a decline in rainfall of about -0.6 mm/day for each considered rain day per month in study period, with simultaneous drought risks due to the effects of The ENSO phenomenon in some localities of the region. (Sivakumar, Das and Brunini, 2005 and Hellmuth, et al 2007) have argued that inter-annual variability in precipitation is extremely important for agricultural success and can be detected in some regions over a period as short as ten years.

Changes in the rainy and dry seasons. Climate change is directly contributing to changes in precipitation patterns and the observed temperature increases may have also had a great influence on the alteration of the rainy season and dry season occurrence. The duration of soil moisture – the subject of next chapter - is determined by the amount and frequency of rainfall and it is naturally related to the duration of dry periods. Soil moisture content is directly related to the amount of precipitation recorded, number of rainy days, their temporal and spatial distribution, and intensities. The balance between the wet and dry periods are factors that contribute to the construction of the intra-seasonal structure of the hydro- climate.

Figures 3.13 and 3.14 indicate changes to the rainy season over the data set period, evidencing later commencement, earlier ending and concomitant extension of the dry season. Typically, the rainy season has started during August or September in Huambo region but there has been a progressive increase in the number of months with less than 100 mm of rain by decade. In the first two decades, from 1960 to 1979, the months with precipitation below 100 mm was 3 months from June to August. In 1980-2009 there were 4 dry season months and from 2010 to the present, 5 months from May through to September. These observations give further indication of reduction of rainfall amount and distribution across the months even though the number of rainy days remains stable. In evidencing both the rainfall distribution over time and the changes in the rainfall regimes at the beginning and at the end of wet and dry season, these important findings are similar to observations made by (Bauer and Scholz, 2010) indicating that in the climatic conditions in the region of Southern Africa will become warmer and drier.

The late onset of rains can cause serious problems in the productive processes of subsistence family farming and in particular where there are delays at the beginning of the sowing period. A lack of soil moisture availability also exposes crops to various risks if forced to grow out of their best development period. This may contribute to a higher probability of pest and disease incidence resulting in further reduction in crop yields (Hulme et al., 2001, Sivakumar, Das and Brunini, 2005, Hellmuth, et al, 2007, Niang et al., 2014). New adaptations in subsistence agriculture practices (land ploughing, sowing time, improved cultivars, small irrigation systems water storage and improved crop seeds) are needed in response to the new reality of intra-annual variability in rainfall and to manage the year-on-year variabilities that make farming decision difficult and long-term sustainable farming hard to achieve.

Self-evidently, homogeneous distribution of moisture over time favours the obtaining of sufficient water by crops during the growing season, and from which adequate yields may be provided, in contrast to when precipitation is concentrated only at certain periods. The duration of soil moisture availability to crops is determined by the amount and frequency of rainfall and the related duration of the dry season. Soil moisture availability and rainfall are directly related to the amount of precipitation recorded, number of rainy days, their distribution, and intensities. The balance between the wet and dry periods are factors that contribute to the construction of the intra-seasonal structure of the hydro- climate. The results suggest that for subsistence agricultural production practiced by small farmers in the province of Huambo, which depends entirely on precipitation, there must be adaption in production practices (land ploughing, sowing time and improved cultivars) and a start to the agriculture season that recognises the new reality of variability in rainfall and changes in wet and dry seasonality.

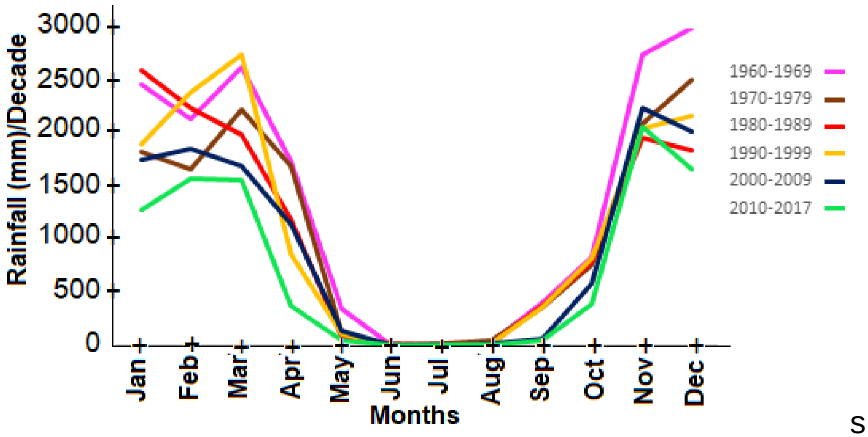

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Figure 3.13 – Analysis of dry season and the start of the rainy season over time in Huambo Province.

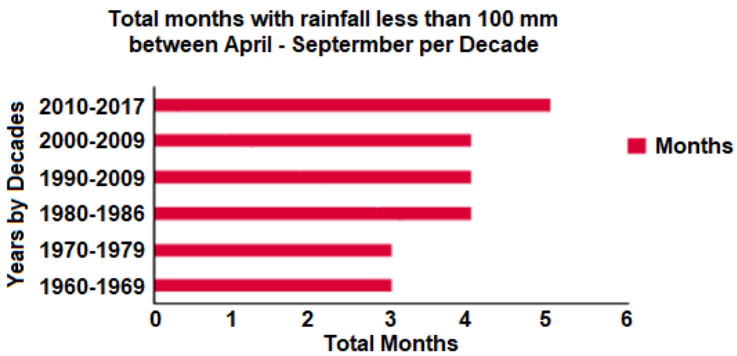

Figure 3.14: Inter annual relationship between the mean rainfall and annual average of temperature in Huambo according with the historical data in analysis.

Year on year rainfall variability

The fluctuations in precipitation that occur during the 1960 - 2017 period shows a large difference between the amount of rainfall that occurred in the years 1961 and 1962, with values of 1154.5 mm and 1110.1 mm, respectively. This difference can be caused by the occurrence of any abnormal change in precipitation due to a natural phenomenon that may have been cyclone or extreme rain invent happened in region in 1961. Likewise, years with fluctuations greater than 500 mm can also be observed from year to year, as in the 1980s. 1986s, 1989s, 1990s and 2017s with 766.2 mm, 542.8 mm, 611.5 mm and 699.6 mm and 594.2, respectively (Figure 3.15). Even more so than year on year temperature fluctuations, the lack of temporal consistency in precipitation patterns make planning the agricultural year ahead fraught with risk (Chapter 5: social survey data, Huambo province). Again, however there is no strong indication of to suggest such fluctuations are widening in the most recent decades although the future prospect of this is there given the fluctuations observed between 1978 and 1992.

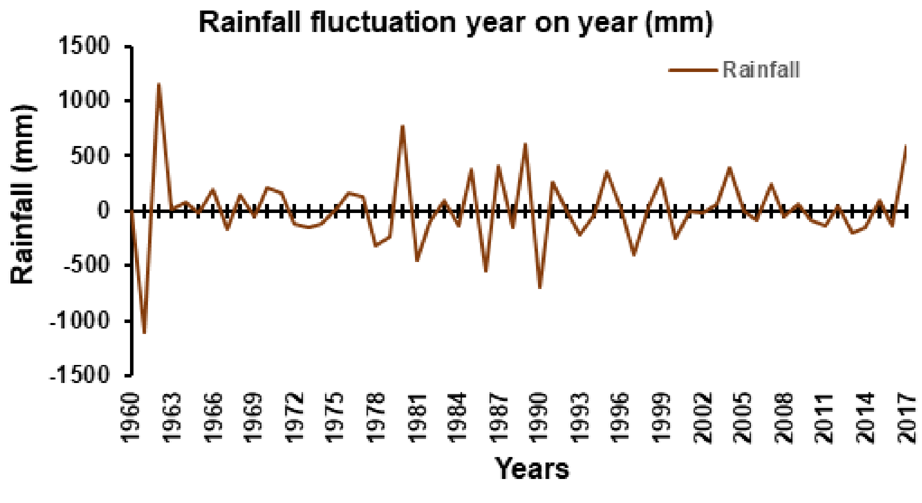

Figure 3.15 - Rainfall variability year on year in Huambo Province, Angola.

In combination, observations from the precipitation data suggest that rainfall intensity is, in general, declining year on year. This served to highlight and support earlier analyses anticipating that climatic conditions in the Southern Africa region will become warmer and drier and that Southern Africa is suffering substantial decreases in precipitation with the El Niño Southern Oscillation (ENSO) phenomenon contributing to a decline rainfall approximating 0.6 mm/day with simultaneous drought risks (Bauer and Scholz, 2010).

3.3.2. Relationship between Temperature and Precipitation (rainfall)

Results obtained from the historical data set of temperature and precipitation in the study location, indicate that the inter-annual average temperature from 1960 to 2017 has an increasing trend in each passing year. In 2017, the average annual temperature was 20.79ºC, almost +1.50ºC above the estimated annual average for 58 years. In parallel total inter-annual precipitation observed over the same period indicates a decreasing tendency. In 2017, the inter-annual rainfall was the lowest 816.30 mm that corresponds about 60.44% of the inter-annual average estimated at 1350.67 mm per year over 58 years.

Further analysis of the relationship between temperature variation and precipitation variation shows a high correlation coefficient with 18 % of variability in precipitation, explained by the linear relationship between the two climatic factors with R^2=0.1817 at $p<0,05$ level of significance (figure 3.16). The results show that there is a negative correlation between temperature and precipitation over the 58 years of data; as temperature increases, precipitation declines. These climate parameters can perhaps be best considered as inter-dependent (rather than independent and dependent variables) and so is not a statistically pure analysis. However, there is some evidence to suggest that this decline in precipitation evidence climate changes that may be linked to the El Niño phenomenon, influenced by increasing temperatures in the region, which have caused a gradual fall in rainfall and leading to temperature rises year after year (Hulme *et al.*, 2001, Bauer and Scholz, 2010). Another perspective may be the influence of the warmer winters having influencing precipitation decreases (Ziervogel *et al.*, 2014). While addressing the causal factors explaining the observed linked relationship between temperature and precipitation in the data sets is important, the analysis does show the linked nature of these two major climate parameters, both of which can fundamentally influence agricultural activity.

These results translate to agricultural livelihoods and the necessity to adapt production techniques used by smallholders' farmers to the new climate reality of the region. This might include small irrigation systems water storage and improved crop seeds so that subsistence householders farming does not depend only on rainfall. It is becoming imperative to introduce new and sustainable land management systems to improve crop productivity under current and future climatic conditions

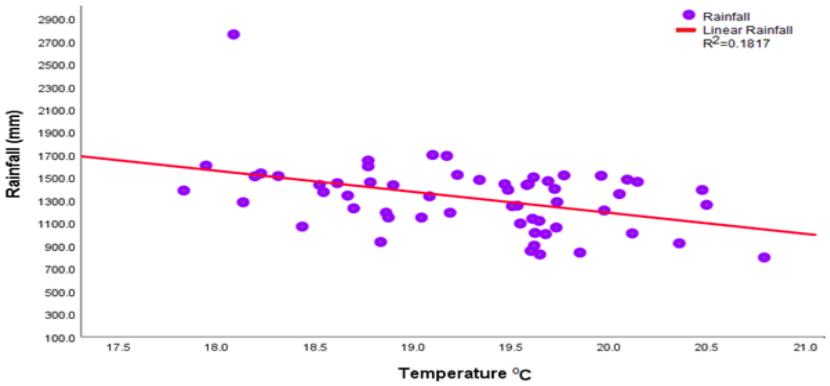

Figure 3.16 - Interannual relationship between the mean rainfall and annual average of temperature in Huambo according to the historical data in the analysis.

3.3.3 Evaporation

Rainfall is a key climate parameter; its annual and inter-annual variability is the major input to soil water and in so doing shapes the success or failure of subsistence agriculture. However, soil water depends on the balance between evapotranspiration and rainfall. Increased transpiration of crops and evaporation from bare soil surfaces implies a greater increase in the amount of water required to maintain the water balance needed by the crop for its physical activities and the amount of water lost.

Evaporation can therefore be considered as a factor that can contribute to reduction in crop yields.

Analysing the observation of evaporation over time (figure 3.17) shows that in the Huambo locality the long-term evaporation variability is stable although there are substantial annual fluctuations. The statistical analysis shows no relationship between evaporation and time over the study period, at the $p<0.05$ level of significance. These results may mean that regardless of the increase in temperature and the decrease in precipitation, evaporation continues at similar rates without significant differences and at similar amounts of water loss per year.

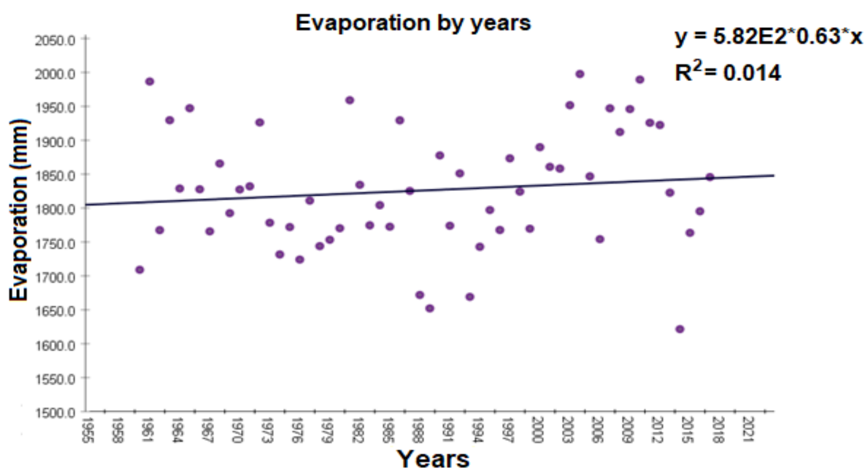

Figure 3.17 - Annual total evaporation in Huambo region

3.3.4 Projecting climate future for Huambo. Temperature and precipitation.

Analyses were carried out to project future temperature and precipitation changes over 83 years to 2100 is based on trend projections from the Chianga – Huambo 1960-2017 climate data set and developed as regression, correlation and autocorrelation analyses between climate parameters (temperature and precipitation) and time. The analyses indicate future trends in inter-annual temperature and precipitation change assuming consistent atmospheric dynamics over the period of analyses (figures 3.18.amd 3.19). These statistical analyses indicate that Huambo province will continue to warm year on year, with a projected increase of 0.04ºC per year (Figure 3.18), noting that the error becomes wider as the projection progresses in time. During the period considered, the amount of rainfall is projected to decrease by about 9.16 mm per year. During the period under review, the amount of rainfall will decrease by about 9.16 mm per year, which may reach values approaching a total of 531.23 mm by the end of the year 2075. These findings point to the prospect of prolonged droughts, impact on the agricultural production potential of subsistence agriculture in the locality and the consequence of greater food insecurity.

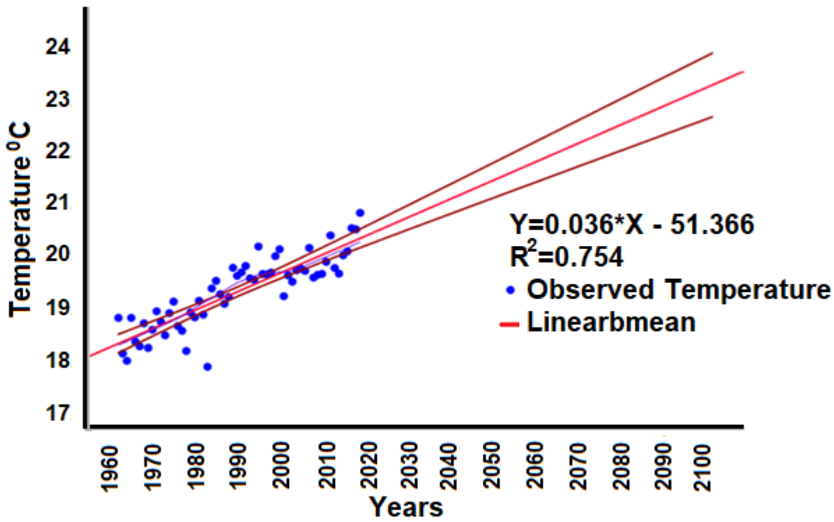

Figure 3.18 - Observed Temperature and mean projection for next 83 year in Huambo, Angola

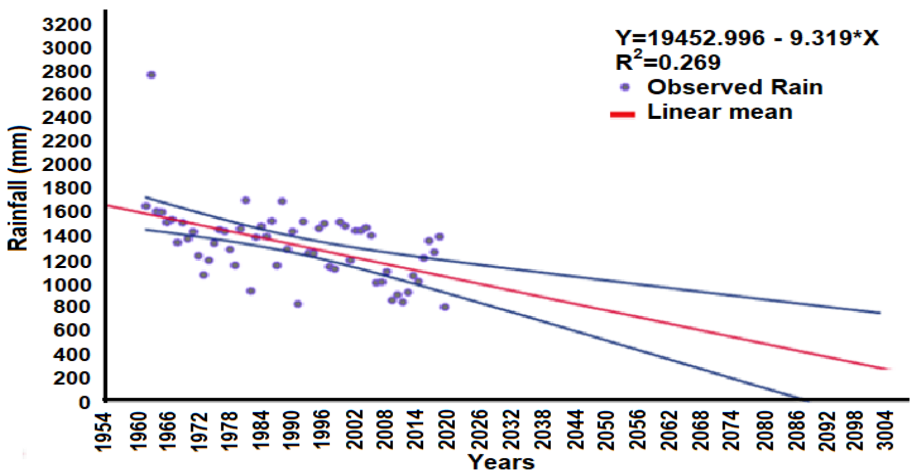

Figure 3.19: Prediction of average annual rainfall for the next 83 years. Based on projection from Chianga – Huambo 1960-2017 climate data set.

To verify the accuracy of the models, a comparison was made between the observed historical data series and the prediction series over time, through the generation of the Autoregression Moved Average model (ARIMA model). The analyses performed created prediction models that fit the existing data at the 95% confidence interval. The series of precipitation and temperature data observed, and the models predicted for data series are presented in (figure 3.20 and 3.21) respectively. The results show that the variabilities in the series of forecast data generated by the model do not differ significantly from the data set observed. The variability of the precipitation generated by the prediction model shows that over time the temperature gradually increased in the region while the expected precipitation follows the trend of constant fall.

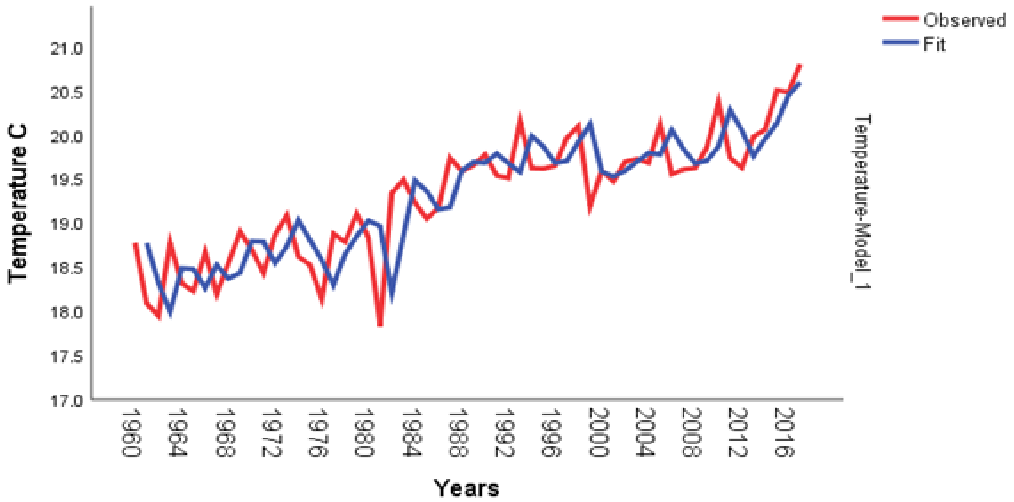

Figure 3.20: *Observed and statistically fitted series of mean temperature (ARIMA model, 1.1.0). Based on Chianga – Huambo 1960-2017 climate data set, Huambo.*

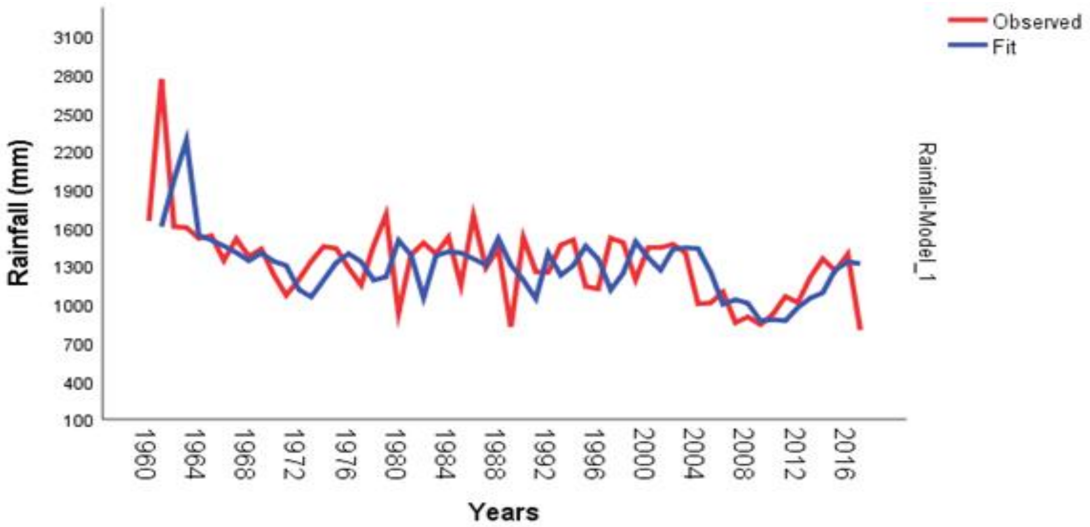

Figure 3.21: Observed and statically fitted series of mean rainfall for central plateau of Huambo (ARIMA model, 1.1.0).

In the future, it is the observed and predicted variability in temperature and precipitation values (figure 2.18 and figure 2.19) that may be considered just as important as the general precipitation decline, making year farming decision hard to make and long-term sustainable subsistence farming more difficult.

To verify the best fit and suitability of the model, (Figure 3.22 and Figure 3.23) it was necessary to examine the residual through the autocorrelation function (ACF) and the partial autocorrelation function (PACF), in which residues are observed within 95% of the confidence interval. No patterns were observed in the residues reinforcing the veracity of the models to represent the projected data and indicating a strong performance efficiency in the model. In addition to testing whether the estimated parameters are statistically significant, the analyses also ensured that the autocorrelation plot and partial autocorrelation of the obtained model residuals are useful for identifying specification errors as confirmed in figure 3.22 and figure 3.23

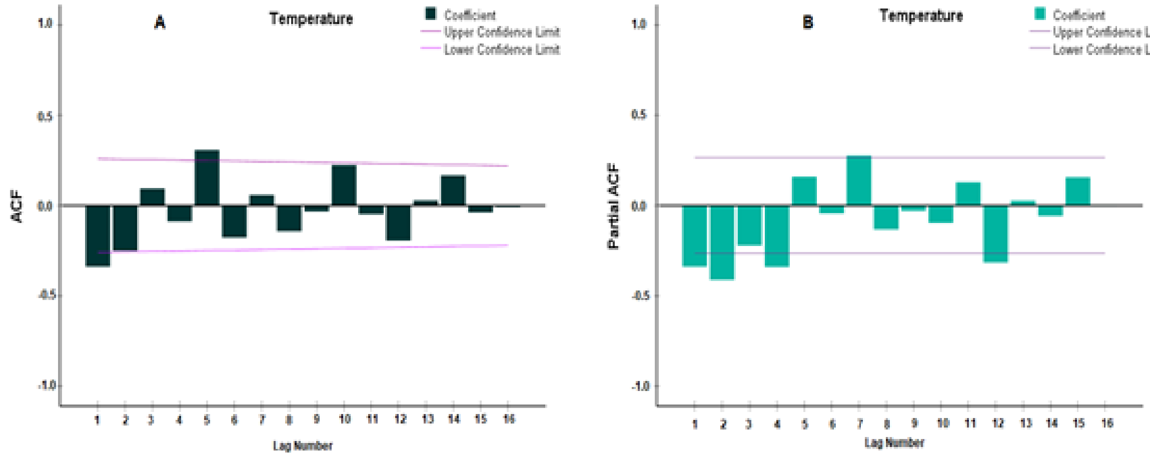

Figure 3.22: Residual plots of autocorrelation function (A) and partial autocorrelation function (B) of maximum temperature.

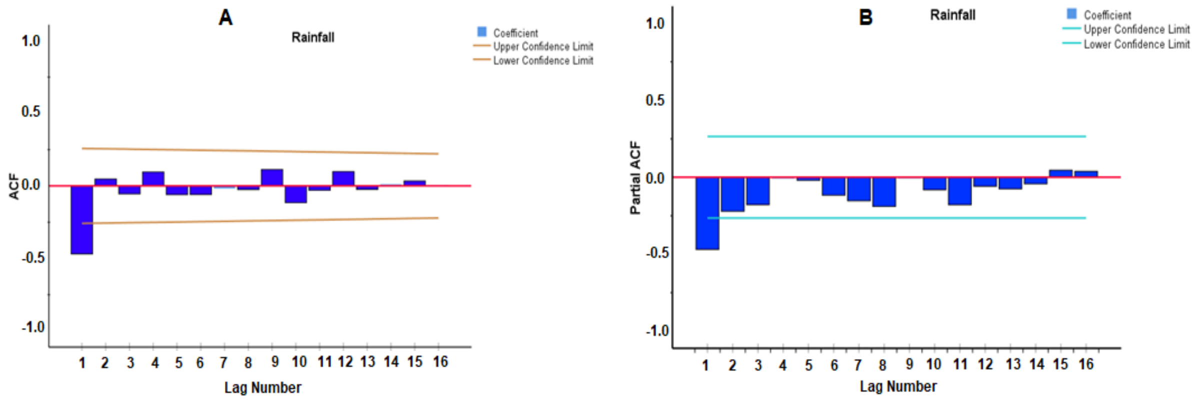

Figure 3.23: Residual plots of autocorrelation function (A) and partial autocorrelation function (B) of total rainfall.

3.4 Chapter Conclusion

Analyses of temperatures recorded in historical 20th and 21st Century climatic data sets from the central plateau region of Huambo Province indicate an average annual increase of 0.05°C per year between 1960 and 2017. This has increased the annual temperature by approximately 3°C during the last 58 years and is clear confirmation that climate warming is already a fact in Huambo. There is an associated, possibly linked, reduction in rainfall with year-on-year decreases in precipitation, estimated as 34.45 mm per annum. Critically, dry season months have increased from three to five, shortening the rainy season. Year to year variations in both temperature and precipitation will make planning increasingly difficult - whether to plan for a relatively dry year or a relatively wet year - and are almost certainly to have a several impact on the development of subsistence agricultural cropping in the locality. These trends are statistically projected to continue at least during the mid-21st century and possibly beyond. The analyses are clear confirmation that climate change and the warming of the environment are happening in Huambo Province during the period under review and projections anticipate a worsening of the climate conditions for subsistence farming.

To give further understanding to the data sets, the upward trend of average temperatures may be one of the reasons for the decrease in rainfall pattern in the region of the central plateau of Angola. However, a more comprehensive multivariate analysis is required, including data from various meteorological stations close to the region as well applying advanced technologies in the collection of meteorological data and their digitization, and which will allow a more comprehensive assessment and realistic view of the climate change situation and its impact directly influencing subsistence agriculture. Nevertheless, and despite these limitations in analyses, the analyses presented here offers a new way of assessing climate change at the local scale that can be adapted by others and is a first assessment of climate change within the agriculturally important Huambo province.

There is a broad and complex relationship between climate and subsistence agriculture. The agricultural practices used by small farmers are extremely dependent on atmospheric variations such as rainfall, temperature and other natural elements that interfere with crop production. It is undeniable that climate and agricultural activity are inseparable. As circumstances stand, the decrease in precipitation in the region will have a direct negative impact on the productive process of subsistence households farming, which is almost entirely dependent on rainwater. The rise in temperature observed each year will also directly affect crop yields by limiting crop growth physiologies. In addition, high temperatures accelerate evapotranspiration and increase the demand and need for water required by crops in this changing environment. Thus, the effect of climate change on family farming and subsistence farming practiced by most of the population of Huambo is likely to have a very significant impact, directly influencing crop productivity and the social sustainability of families in rural areas, since the sector is responsible for the livelihoods of a large number of citizens in the province.

Future temperature increases, precipitation declines and shifts on the onset and ending of the rainy season will inevitably require a reappraisal of land and natural resources management. This will require proactive management of agricultural resources to aid the anticipation and prevention of climate-related problems together with adaptation to the risks caused by climate change in subsistence agriculture. Anticipating and adapting depends on the availability of information on future climatic conditions, especially on the nature of climate risks and how they influence subsistence family farming. Current changes in climate conditions and the associate impacts on appropriate and effective farming techniques and systems suggest a broad and urgent need to adapt to emerging new climate scenarios. Future spatial planning and management of land for agriculture and the use of new agricultural practices must recognise the changing climate conditions identified in this research and new ways of mitigating climate impact on the subsistence production process found. Perhaps this may involve the introduction of improved technologies such as local irrigation systems to give the opportunity that crop productivity in subsistence agriculture can adapt to current and future climatic conditions in Huambo Province, Angola.

At the beginnings of this process of planning and innovation, the local nature of these data sets as a first assessment of climate change in the agriculturally important Huambo province has an immediacy and resonance with local government, agricultural extension workers and subsistence farming communities alike. The analyses can be a starting point for addressing the impact of future climate change on household agriculture. Work is now needed to link these climate analyses to practical guidelines for subsistence land management that are easily accessible to the subsistence family farm in Huambo Province.

Soil and Indicative Soil Water Holding Capacity in the Huambo Region.

4.1 Chapter Introduction: Soil Water Holding Capacity and Soil Moisture Content

Soil is the constituent of the environment (Lawal *et al.*, 2013) in which complex climate, lithosphere, hydrosphere, and biosphere factors interact, forming a soil ecosystem that moves towards equilibrium (Duarte *et al.*, 2014). Soil formation is a slow and gradual process that develops over time due to the influence of natural and environmental factors (Lawal *et al.*, 2014) that act to weather the rock from which the soil originates (Karmakar *et al.*, 2016). Rainfall and temperature are the climatic factors that have a pronounced effect on soil formation, properties, soil moisture content and soil water holding capacity (Osman, 2013).

Soil water holding capacity (SWHC) is the amount of water that a given soil can retain for the use of plants, the estimation of SWHC is of great value to practical agriculture, provides a means of determining the soil moisture contents required for plant growth (Olorunfemi, Fasinmirin and Ojo, 2016). It influences the growth of the crops, the rooting pattern, and the ability to supply water to the crops during the dry period. Soil water holding capacity is determined by its texture, structure, and organic matter content, soils with a high clay percentage and organic matter content tend to have a greater SWHC. It is also regulated by the number of pores and the pore size distribution (PSD) of the soil and the specific textural surface of the soil (Singh and Sainju, 1998). Soil available water content (AWC) is the amount of water stored in the soil that can be used by plants, being a dynamic property that depends on the physical and chemical characteristics of the soil, as well as the vegetation or crop to be cultivated. It is influenced by climatic factors, topography, soil properties, precipitation, infiltration, evaporation, transpiration, and the total amount of water the soil can store and release.

The shape and size of mineral particles of soil and the amount of organic matter accumulated in soil profile horizons influence its texture, structure (peds) and pore space characteristics (Rodriguez, Edeskär and Knutsson, 2013, Négrel *et al.*, 2015, Balasubramanian, 2017). These soil factors together with climatic factors (discussed in the previous chapters) determine soil moisture conditions and soil water holding capacity in natural soils (Figure 4.1).

Soil structure defines the arrangement of particles in aggregates, while soil porosity regulates several physical mechanisms such as water holding capacity, soil moisture content and the circulation of water and air. Organic matter plays an important role in the formation and subsequent strength of soil aggregates. During decomposition, humic acid, fulvic acid and humus interact with the mineral component to form aggregates. Understanding inter and intra-aggregate soil porosity is fundamental for the rational management of land resources for agricultural and environmental purposes since the retention and movement of water in the soil is closely related to soil porosity.

Understanding spatial variability of the biological and physical mechanisms governing soil functionality of the biosphere is essential to determining proper sustainable use and agricultural management practices, irrigation, drainage and conservation of soil moisture content systems (Reinert and Reichert, 2006). In addition, the changes in behaviour and variability of diverse climate parameters such as temperature and precipitation (Figure 4.1) influence water movement through the soil and changes in the dynamic of soil moisture content, soil water holding capacity and soil biodiversity.

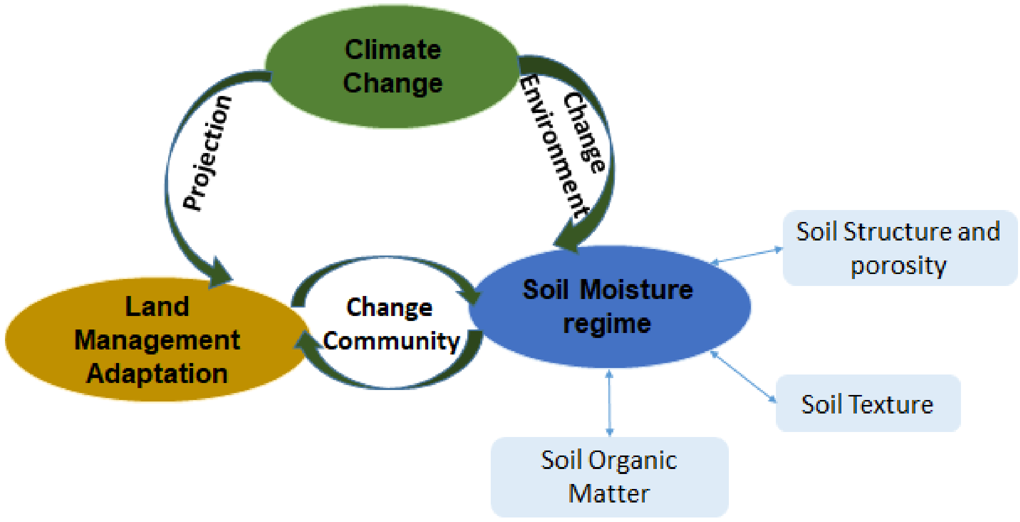

Figure 4.1. Interlinkages of climate change to factors contributing to soil water holding capacity and soil moisture content.

Subsistence agriculture depends entirely on the soil and the water contained in the soil (Rawls, Gish and Brakensiek, 1991). The quantity and the quality of soil moisture depend on its ability to store enough water to satisfy basic functions for sustainable crop development. (Eswaran *et al.*, 1996). Agriculture can provide a sustainable basis for the development of the world economy and throughout the world, there are signs of greater support for the sustainability of the subsistence family farmer to alleviate and eradicate the hunger that still exists in many parts of the world in general, and sub-Saharan Africa especially (FAO, 2014). Sub-Saharan Africa has the largest vulnerable both Environmental and social marginalized population in the world, family farming is critical to the sustainable development of subsistence farming, contributing to the stability of current and future food security (Eswaran *et al.*, 1996).

4.1.1 Central Plateau of Angola Soil Morphology Characteristics

Rain, drainage, evaporation and wind are climatic factors that contribute to Angola's complex soil morphology and genesis here the predominant soils are arenosol and ferrosol following the FAO WRB classification system, and entisols, ultisols and latosol in the USDA system (Huntley, 2019). The predominant soils in the central highlands of Angola according to Huntley (2019) correspond to red and yellow ferrosols (MPA, 1961), to the order of Oxisols (SSS, 2010) or the Main Group of Ferralsol (WRB, 2006) (Madeira, Ricardo and Neto, 2015). Morphological assessment of the ferralic soils group of the central plateau of Angola demonstrates that mostly soil they have an ABC horizon sequence well defined in their profile. Their B horizons generally present medium or fine textures and in most cases, with chromatic colours that vary from yellowish to reddish they are weakly structured with granular aggregates of very friable consistency. These soils have clay clusters dominated by low activity and high sesquioxides clays, they can be of great depth and are generally well drained. These regulating profile attributes result in low organic carbon, chemical fertility and water holding capacity. Their distinguishing chemical characteristics are the strong occurrence of iron and aluminium oxides originating from weathering of kaolinic minerals. In some cases, these soils may have lateritic concrete dispersed along the profile or concentrated in layers with varying depth (Osman, 2013).

4.1.2 Soil Texture, Structure, and Organic Matter

Soil texture

Soil texture depends on the proportions of silt, sand and clay contained in the soil (Karmakar *et al.*, 2016) This measure of particle size distribution is a fundamental characteristic for land classification and determines hydraulic behaviour and the ability of a soil to retain water in the soil (Bronick and Lal, 2005) and as such has a direct impact on climatic scenarios influencing soils response to climate change in an arid, semi-arid, sub-humid and humid environment (Patil, Phule and Vidyapeeth, 2018). To evaluate soil texture, soil science assesses the size of the various individual particles that comprise the soil (Towett *et al.*, 2015).

Soil structure

The spatial arrangement and aggregate stabilities of soil directly influence the flow and infiltration of water during rainfall (Várallyay, 2010). It controls soil porosity (inter and intra aggregate) and the spatial variability in the amount of water present in soil (Patil, Phule and Vidyapeeth, 2018). The structure of the soil is important for all aspects of soil land use and management (Indoria *et al.*, 2017). It demonstrates the arrangement and organization of various forms of the soil particles combined and their susceptibility to erosion (Rawlins *et al.*, 2009; Patil, Phule and Vidyapeeth, 2018) and is responsible for regulating the movement of gases, water infiltration, plant nutrients, soil fauna and crop emergence through the soil (Karmakar *et al.*, 2016). Aggregate formation and stabilization and sedimentation are influenced by physical, chemical and biological processes (Fayos, Cases and Imeson, 2001).

Soil organic matter (OM)

Organic matter is an important component of the soil, improves its quality and influences the functional structure of the soil (Karmakar *et al.*, 2016) and doing so promotes root proliferation (Singh and Sainju, 1998). The decomposition of the organic matter depends on the variability of the temperature and the humidity contained in the soil (Mihailovi *et al.*, 2016). The amount of organic matter has a direct influence on the constituent structure of the soil and the stability of soil aggregates. The decline in organic matter levels predisposes soil as susceptible to erosion and, to compaction, increases the likelihood of sudden flooding and decreases soil aggregate stability.

Organic matter plays a fundamental role in guaranteeing soil quality, soil water holding capacity, stability of soil aggregates, nutrients, and maintaining soil oxygen circulation capacity (Romaniuk, Giuffré and Romero, 2011, Karmakar *et al.*, 2016). Organic matter influences the physical conditions of the soil in several ways. Plant residues that cover the soil surface protect the soil from sealing and crusting by raindrop impact, thereby enhancing rainwater infiltration, and reducing runoff. Surface infiltration depends on several factors including aggregation and stability, pore continuity and stability, the existence of cracks, and the soil surface condition. Increased organic carbon contributes indirectly to soil porosity and increased soil faunal activity (Li *et al.*, 2007). Increased levels of organic matter and associated soil fauna lead to greater pore space with the immediate result that water infiltrates more readily and can be held in the soil. The improved pore space is a consequence of the bioturbating activities of micro-organisms and macro-organisms and channels left in the soil by decayed plant roots. However, in the case of the Huambo soil, nothing or almost nothing is known about the detailed composition of the organic matter in its soils, which constitutes a challenge for researchers.

4.1.3 Soil Water Holding Capacity and Available Soil Moisture Content

Soil water holding capacity is a natural and fundamental phenomenon for maintaining the balance of various ecosystems including agro-ecosystems. Mutual relations between soil and water are essential resources that influence quotidian anthropogenic activities closely linked to the soil's ability to retain water and maintain soil moisture content (Mudgal *et al.*, 2014). Naturally, the soil is a reservoir of water used by plants for the extraction of water resources and a continuous source of water for subsistence agriculture, optimum moisture support for the activities of soil microorganisms guarantees the availability of nutrients for plants and minimizes the impacts of water deficit during drought. Knowing and understanding these phenomena allows the perception of environmental conditions in the region and gives a more comprehensive approach to environmental impact. The water holding capacity in the soil depends on the adsorption force (adhesion and cohesion), the texture and the structure of the soil.

The available soil water content is the difference between the field capacity and the permanent wilting point and depends on the size and diameter of the soil pores. Generally, water found in macropores is readily available to plants, while water in micropores requires more energy for the plant to absorb. The availability of water in the soil is influenced by climatic factors, as the lack of rain or irrigation reduces the soil moisture content, which negatively influences the water flow inside the plants and increases the transpiration rates of crops.

In light of the significance of soil water holding capacity to agro-ecosystems and temporal and spatial variability of the soil factors regulating soil water holding capacity, the chapter objectives are to:

- Classify soils in Huambo Province according to their water holding capacity and the implications that this carries for sustainable subsistence agricultural productivity,
- Assess the water holding capacity in relation to the physical properties of the soil,
- Develop a practical method to assess soil water holding capacity that local communities can use for climate change resilience.

This chapter will assess the morphological and physical properties of the soil and soil water holding capacity and classify these soils in light of impacts predicted to arise from the new realities of climate change. The chapter will give a first assessment of soil physical properties from Huambo province on a transect basis and derive a first assessment of soil water holding capacities for these soils. The results obtained in this soils-based study will contribute to the development of regional land and water management strategies for adapting to climate change and assist in implementing agriculture land characterization and classification in the growth and management of subsistence crops in a climate changed future.

4.2 Material and Methods

Systematic survey and detailed visual field description of soil profiles together with laboratory-based physical assessments of particle size distribution and the integration of micromorphology offer a powerful tool for land assessment and classification. For soil water holding capacity and soil moisture content assessment in Huambo province three pedons upper slope, mid-slope and bottom slope positions were considered in four locations across Huambo province. These are remote locations, difficult to access although well populated in subsistence agriculture areas and are the first detailed assessment of soils within Huambo province.

Visual observations were made to describe the soil profile, together with observations of relief and the landscape of the study sites. The assessment considered the type of relief in its relationship with the drainage that directly influences the soil in its physical properties as factors that contribute to soil formation and soil evolution. Analysis was carried out, establishing how the soil relations to slope with morphology and vegetation as well soil water holding capacity and moisture content.

4.2.1 Field Survey and Sampling

Soil survey and sampling was performed on a catena-based research framework, reflecting the region's undulating topography, and allowed classification of soil types in the region (Figure 4.2). Soil sampling and assessment gives the basis for physical analysis to determine soil water holding capacity, bulk density, soil moisture content and agricultural capabilities. In the present study, four different representative localities of Huambo province (Mungo, Bailundo, Ngongoinga and Longonjo (Lepi)) (Appendix 4.1) were selected. The sampling profiles were distributed following the toposequence slope of the landscape and from each of the four catena's, three profiles were exposed (upper- mid-and lower- slope) giving 12, (1m x 1m x 0,90m) soil profiles in total (figure 4.2).

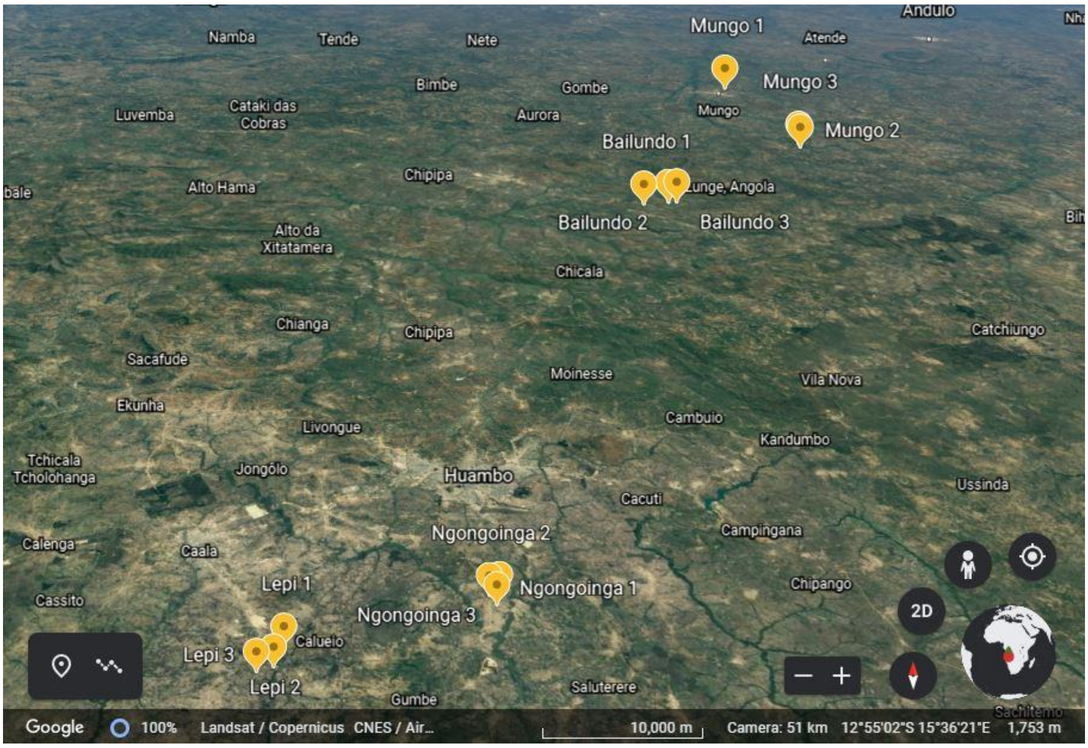

Figure 4.2. Sampling profiles positions in four locations using GPS co-ordinate from Google Hearth.

The visual morphological assessment was performed in the field analysing and describing the characteristics of the profile by field colour (Munsell), texture and structure; relief, type of vegetation cover information was also collected, and descriptions assisted by Monograph of the soil survey field handbook (Hodgson, 1976) at each sample location. All profiles were considered to be 90 cm deep, which approximates mean crop rooting depths. Soil samples were systematically collected at three depths (30 cm); (60 cm) and (90 cm) (Figure 4.3) as bulks samples. From each of the three profiles in the four catenas (Mungo, Bailundo, Longonjo and Ngongoinga) representative undisturbed samples were collected in Kubiena tins for thin section micromorphology microscopic porosity analyses.

Figure 4.3. Soil sampling performed on catena framework in Huambo province

4.2.2 Laboratory Analysis

Assessment of Soil Water Holding Capacity (SWHC)

For a better understanding of the soil's water-holding capacity, it is important to precisely determine the total amount of water needed to avoid irrigation. To assess the soil's water-holding capacity, the following materials and procedures are required to perform laboratory analysis using the percolation method. Soil samples were dried under natural environmental conditions and sieved through a 2 mm sieve. 250 ml graduated cylinders, 250 ml beakers, funnel, qualitative circular filter paper QL100, size 150 mm, analytical scale with a precision of at least one gram were used. 40 g of each soil sample were prepared and weighed and placed in pre-weighed and labelled crucibles. The samples were oven-dried overnight at a maximum temperature of 105 °C for measure SMC (soil moisture content). The temperature was maintained overnight to eliminate free forms of water. The filter paper was folded twice into a cone shape and inserted into the mouth of a funnel placed under the graduated cylinder. The pre-weighed soil samples are carefully poured, one by one, into the cones containing the filter papers. 100 ml of water was measured and carefully introduced into the funnel along with the pre-weighed soil sample. Eventually, water will begin to drain from the soil samples through the funnels and is collected in the graduated cylinders, once the entire water content of the beakers is poured into the funnel, the percolation settings are left intact for several minutes until the water stops flowing in the funnel and the soil sample is completely saturated with water, the volume of water collected in each of the cylinders is measured and the results obtained are calculated using the formula below which allows the total percentage of soil water holding capacity (SWHC) (figure 4.4).

$$(\%\ WHC) = \frac{\text{Volume of water retained by soil}}{\text{Weigh of sample}} \times 100 \longleftrightarrow (\%\ WHC) = \frac{(V_1 - V_2)}{W} \times 100$$

{*Where percent of soil water holding capacity* **(% WHC)**, *Weight of sample* **(W (g)),** *Volume of water poured through* **(V_1 ml),** *Volume of water collected in a cylinder* **(V_2 (ml)}**

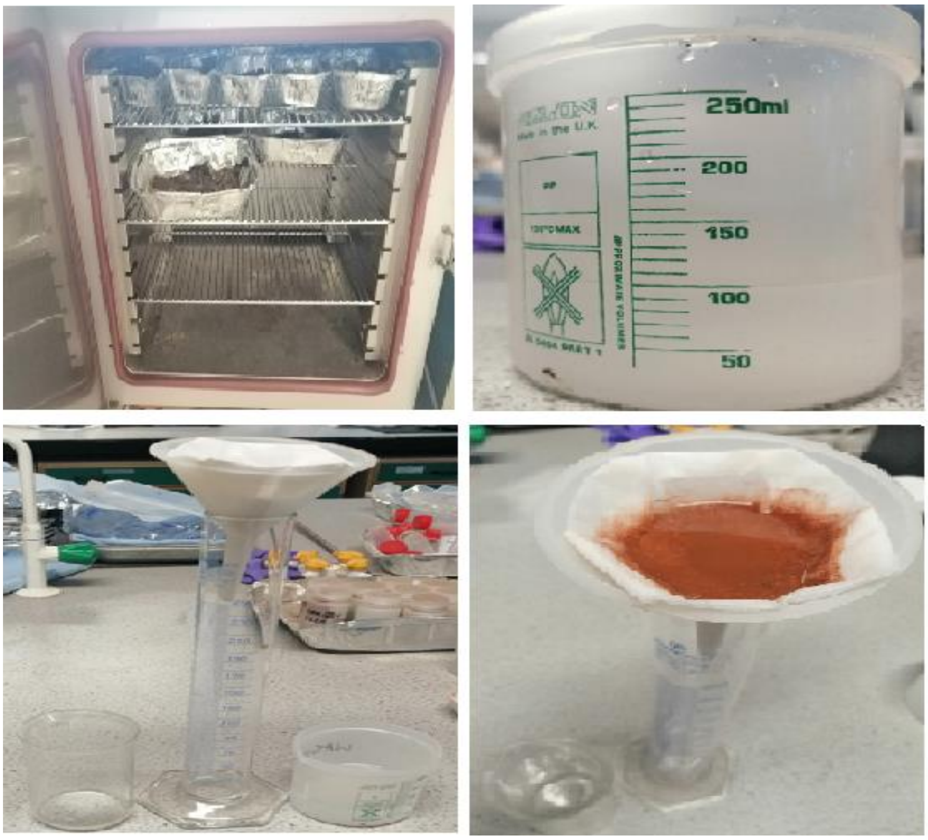

Figure 4.4. Soil water holding capacity determination using percolation method.

Assessment of soil organic matter (SOM)

Organic matter content in the soil was estimated by the method of Loss-on-ignition (LOI) procedure heated overnight at 550^{o} C, assuming the loss of mass as the loss of organic carbon matter contained in the soil (Figure 4.5). Soil samples were air-dried and sifted through a 2 mm sieve. The 10 g subsamples were then oven-dried at 105°C overnight, cooled in a desiccator before being weighed (Figure 4.5). The following process was subsequently followed: Weigh a clean, dry crucible for each sample each crucible was filled with the oven-dry sample and weighed again and combusted at 550°C overnight after combustion, samples were cooled in a desiccator and weighed again. An estimate of the organic matter content of the soil was calculated by the following equation:

$$\textbf{\textit{LOI of OM (\%)}} = \frac{(\boldsymbol{W2 - W3})}{(\boldsymbol{W2 - W1})} * \mathbf{100}$$

*(**%** of organic carbon Loss-on-Ignition* **(LOI**), *Weigh before of Dry (oven)* (W_1)*, Weigh of Crucible* (W_2), *Weigh before dry in crucibles* (W_3))

Figure 4.5 - Soil oven-dried for OM determination by Loss-on-Ignition.

Soil particle size analyses (SPS)

Soil particle size analysis quantifies the individual distribution of soil particle size volume giving a quantitative basis for soil texture assessments. The laser-based soil Coulter Counter Technique (CCT) was used for analyses. The soil was dried at air temperature and sieved using a 2 mm sieve. 10 g of sieved soil was placed filled in 50 ml plastic bottles and filled to 1.5 cm with distilled water 2 ml of sodium hexametaphosphate dispersant (Calgon) was added to aid deflocculation. Samples were then placed on the shaker table overnight. The sample is dispersed again using a magnetic stirrer for 15-20 minutes before being placed in the laser reader based on the Coulter Counter Technique. Particle size distribution curves based on size categories were the main output from the analyses.

Bulk density

Soil bulk density was obtained through the weight of the sample mass by its volume, obtained by collecting the sample with a coring ring sample of known volume. Thus, the sample mass was obtained by weighing the soil after drying in an oven at 105^{o}C for 24 hours, and the volume by measuring the internal volume of the cylinder used in the sample collection. Where (BD= Bulk density, m = mass, and V= volume).

$$\boldsymbol{BD = \frac{m}{V}}$$

Soil Micromorphology and porosity measurement.

For void observation, the undisturbed samples had water removed by were dried using acetone replacement vapour to minimize cracking in the sample. Then, the acetone replacement samples were impregnated with polyester resin under vacuum, sliced and bonded to glass slides before being lapped to a thickness of approximately 30 µm

(Figure 4.6). The analysis and observation of the images of the undisturbed samples were made with a binocular stereomicroscope and the polarizing microscope. All procedures followed, in this case, were supported by the book Handbook for Soil Thin Section Description (Bullock *et al*., 1985) where the concepts were used as a basic reference semi-quantitatively, the porosity was classified according to Stoops, 2021 (2nd edition) based on a visual estimate of percentage slide cover (Figure 4.6) with the following nomenclature was used considering the estimated percentage of voids being: *Very Dominant > 70%, Dominant 50% - 70%, Common 30% - 50%, Frequent 15% - 30%, Few 5% - 15% and Very few <5%.*

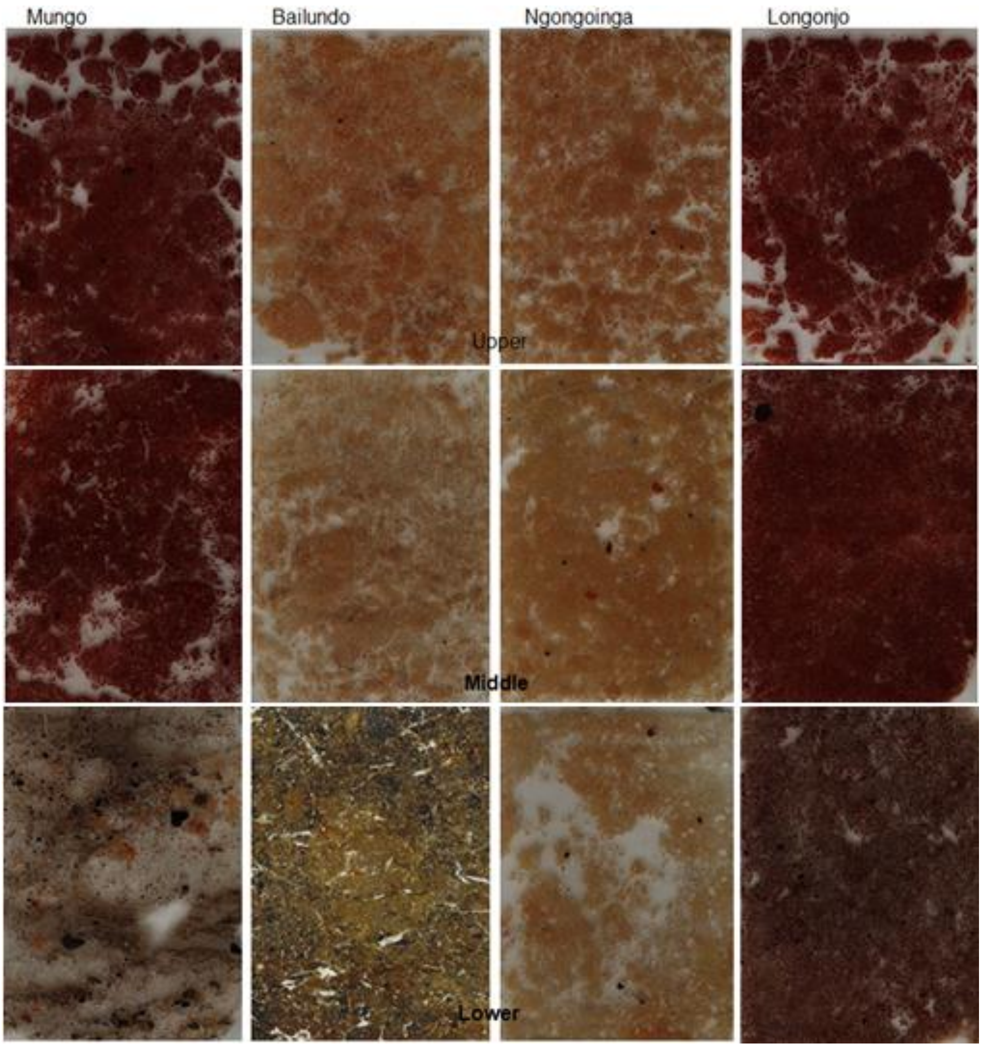

Figure 4.6 - Scanned thin section for micromorphology observation to characterize soil voids.

Quantitative image analyses pore space calculations and photographs were performed in AnalySIS v 3.0 software using an Olympus BX50 polarizing microscope equipped with a motorized stage and a CCD video camera. The primary metric used in measuring porosity was the proportion of the sampled area occupied by pore space. -Individually captured images were digitally merged to form mosaic images covering a larger and more representative portion of the thin section. Moreau *et al*. (1999) showed that this measure could be an effective surrogate for 3D porosity. It does rely on the effective exclusion of certain mineral grains, such as quartz or feldspar, which may appear transparent in plane-polarized light and could be mistaken for voids (Murphy *et al.*,1985). The approach used here distinguishes mineral extinction under differing angles of cross polarised light. An overlap of 65 pixels was specified with a correlation factor of more than (>85%) for features within the overlap. This allowed for the formation of 3x3 image mosaics covering an area of 6 cm^2 that exceeds the minimum representative elementary area proposed by VandenBygaart and Protz (1999).

Four images of each area of interest were captured under contrasting light conditions, one for plane-polarized light (PPL) and three polarized images (2,3,4) of the area of interest were captured in which the analyser and sub-stage polarizer was set at 60º to each other, with both polarizers being advanced by 30º between the two subsequent images (60º, 90º, 120º and 0º,30º, 60º). These images (2,3,4) were Combined, and the result inverted and added the PPL image to allow the colour threshold to differentiate between void and the minerals and soil mass. This allowed binary images of void space to be created so that voids appear bright and mineral grains dark.

4.3 Results and Discussion

4.3.1 Results

Morphological and physical properties of the Huambo soils: Field observations

The successive layers of profiles that form the soil are composed of horizons that differ in colour and composition. General results indicate that the drainage condition of the soils is moderate to well-drained, and the relief of the region vary. The vegetation across all study sites is predominantly savannah, characterised by open forests of herbaceous communities with grassy cover, shrub formations and undergrowth (Figure 4.7) with the dominant plant species including (B. madagascariensis, D. cymosum, G. coleosperma, E. arenaria, I. angolensis, D. chamaethamnus, G. senegalensis, C, angolense, B. populneu, C. fistula, S. nilótica, B. Africana, C. viminalis, E. africanum, D. condylocarpon and L. leococephal) (Figure 4.7).

Figure 4.7. Landscape and natural vegetation predominant in study site: Huambo.

In general, the soil profiles in the four catenas of the study areas have horizons defined by differences of the colour matrix, varying from dark brown and dark grey to red and yellow with a predominance of red and yellow colours. The upper part of the catena shows lighter Munsell colours, while the lower part (valleys) is darker.

Results on-field morphological and physical properties of the soils are shown in appendix 4.2. Considering identification of soil colours (Munsell), the various main sequences of the soil in the study area have different colour matrices, dominated by red and yellow ferralsols (FAO-WRB). The colours vary in hue, both in-depth (horizons) as well as following downslope along the profile toposequence of the catena landscape. The soil in this region is in general good drained. However, whilst in the upper profile horizons or top position of the hillslope of the catena it is generally easy to drain and this decreases downslope on the catena and lower down in the horizon profile, with the lower profile or the valley retains a greater amount of water than the upper profile slopes and which remains saturated for a longer period and evidencing the reduced drainage capacity.

Soil water holding capacity (SWHC) and soil moisture content (SMC).

The average soil water holding capacity obtained at each sampling point illustrates that the upper profile has recorded an average of 64.17% with a 10.18 standard deviation, in the middle profile 53.75% with 12.32 standard deviation and in the lower profile 57.73% with 10.75 standard deviation. Although minimal variability was observed along the slope positions of the landscape (Figure 4.8) there were not significant differences in the SWHC between the different positions along the slope toposequence (catena), $F_{(2,32)}$ =2.673, P<0.05 level of significance P=0.084.

Multiple comparison of catena-horizons on soil water holding capacity (Figure 4.9) also does not indicate significance difference, $F_{(2;23)}$=0.125; P=0.883, significance level P=0.05 (Appendix 4.3, Appendix 4.4, Appendix 4.5 and Appendix 4.6).

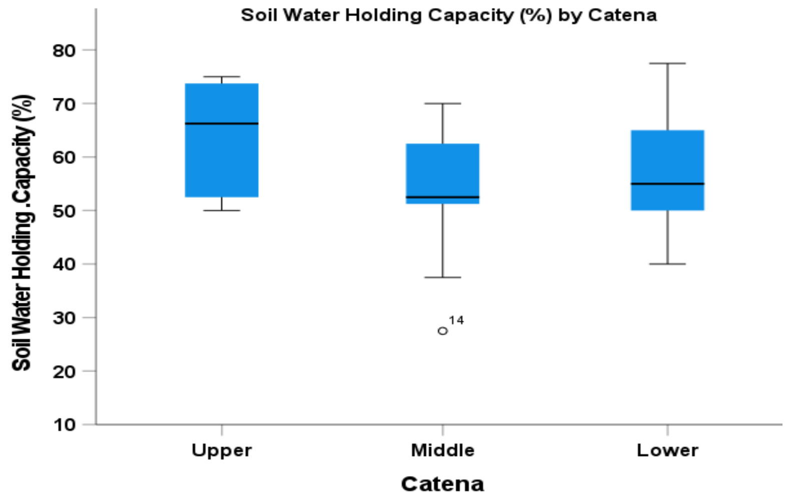

Figure 4.8: Mean of soil water holding capacity in different soil landscape toposequence in Huambo Province

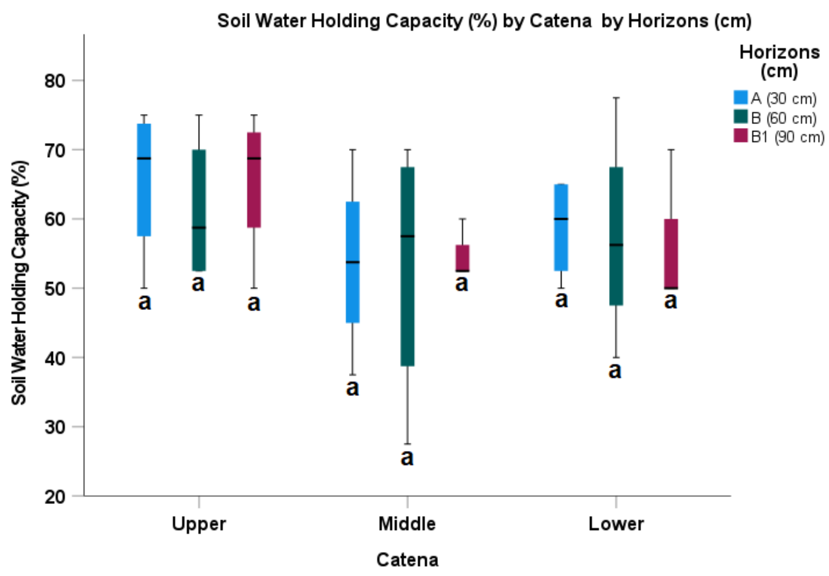

Figure 4.9: Multiple comparisons of soil water holding capacity by catena-horizons - Huambo province, Angola

Regarding to the effect of catena on SWHC and the interaction between catena-locality (Figure 4.10 and Figure 4.11) there are significate variations in SWHC, between Mungo and Bailundo with $F_{(3.31)}$=4.918 ; P=0.007 and Ngongoinga $F_{(2,23)}$=6,722; P=0.004 for the catena with a significance level of P<0.05. (Appendix 4.4, Appendix 4.7, and Appendix 4.8)

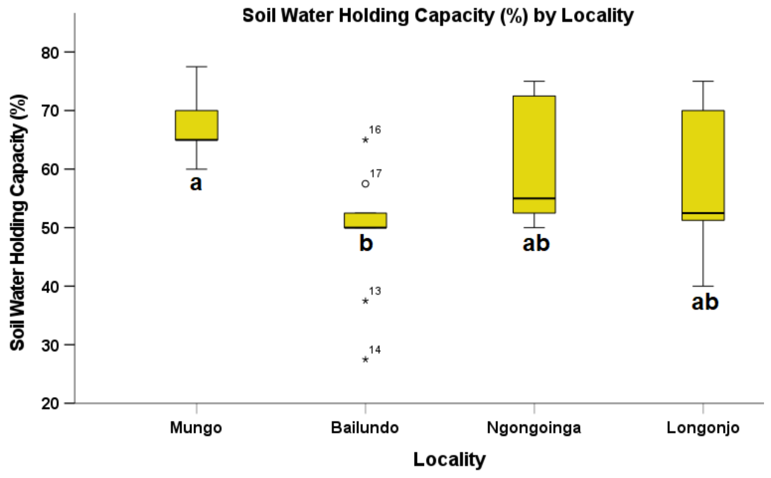

Figure 4.10. Variability of soil water holding capacity by localities in Huambo province.

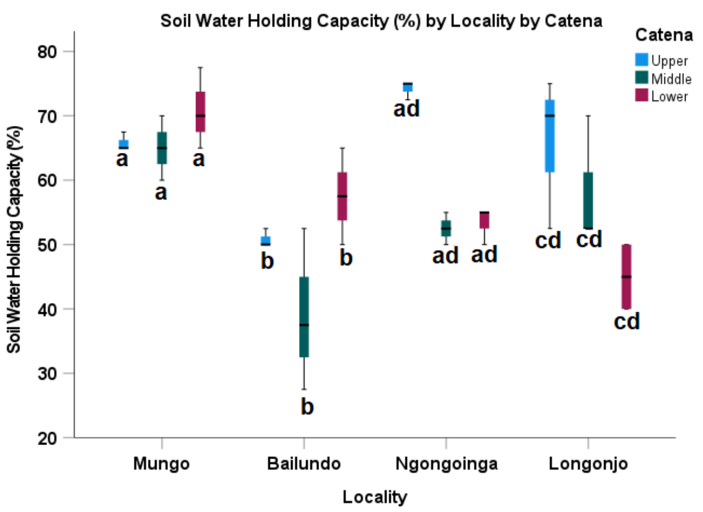

Figure 4.11: Estimated Marginal Means of Soil Water Holding Capacity (%) interaction between catena-locality.

Effect of catena and horizons on soil moisture content variability.

The top of the catena has a lower soil moisture content that increases towards the valley bottom (Figure 4.12, Appendix 4.3, Appendix 4.4 and Appendix 4.9). The average soil moisture content obtained at each sampling point illustrates that the upper profile registered 7.51% of soil moisture content 2.92 standard deviation, while the middle and lower profiles showed 7.06% and 7.65% and with a standard deviation of 4.07 and 4.79 respectively. This does not present significant differences between the different positions along the slope toposequence (Figure 4.12) with $F_{(2,32)}$ =0,068, P=0.934 with the level of significance P<0.05 (appendix 4.9)

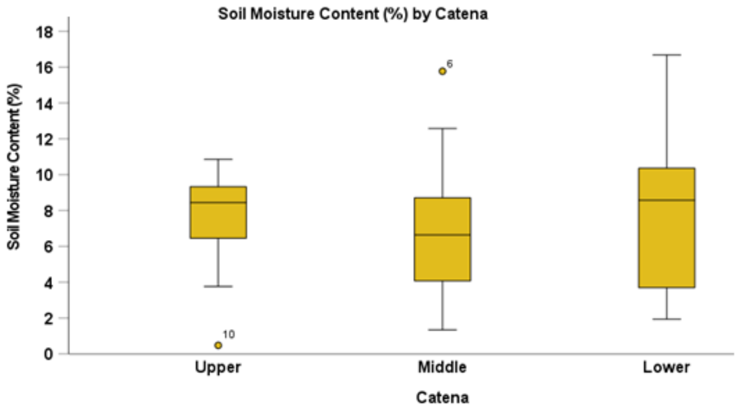

Figure 4. 12. Soil moisture content variability by catene on landscape slope toposeequence in Huambo province – Angola

In the case of horizons figure 4.13 show the results of the mean of soil moisture content by soil horizons which records horizon A as 5.67% with standard deviation 3.82, while horizon B and B1 are 8.22% and 8.39% with standard deviation 3.83 and 3.61 respectively. This minimal variability observed with depth in the profile does not give significant differences between horizons with $F_{(2,32)}$ =1.938, P=0.161 with the level of significance P<0.05.(Figure 4.13, Appendix 4.10).

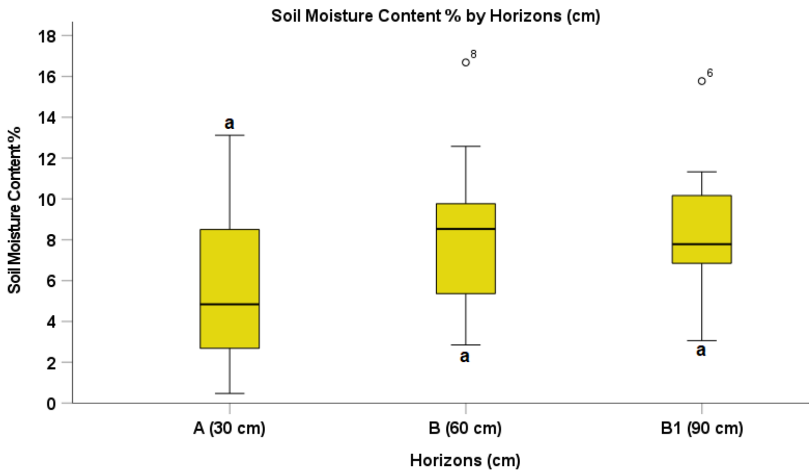

Figure 4.13. Soil moisture content variability on depth profile by horizons on landscape slope toposeequence in Huambo province - Angola

Analysing the multiple comparisons with the interaction between the landscape toposequence catena-locality (Figure 4.14, Appendix 4.11) and the different levels of soil depth horizon-locality (Figure 4.15, Appendix 4.12) and horizon-catena, their influence on soil moisture content shows variations, the Mungo locality differs significantly in relation to the other localities (Bailundo, Ngongoinga and Longonjo) both in depth and in landscape slope toposequence with F(3.31)= 9.576; P=0.001 and significance level P<0.05 of the interaction between locality-catena and with F(3.31)=9.927; P=0.001 in depth (locality-horizons). However, there is no significant difference between landscape slope toposequence (catena) and the depth profiles (horizons) at the same location. (Figure 4.16 and Appendix 4.13)

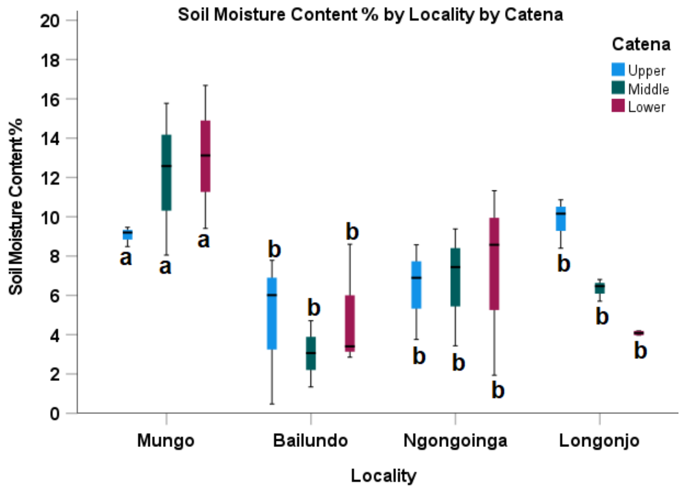

Figure 4. 14. Multiple comparation of the mean of soil moisture content (%) variability by locality by catena

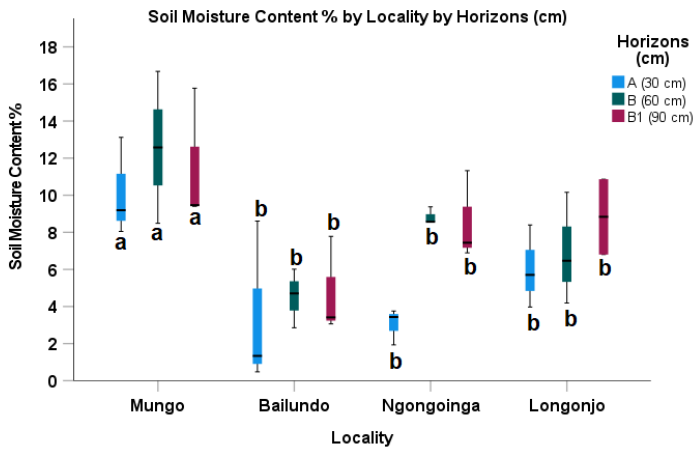

Figure 4.15. Estimated marginal Mean of soil moisture content (%) variability by locality by horizons.

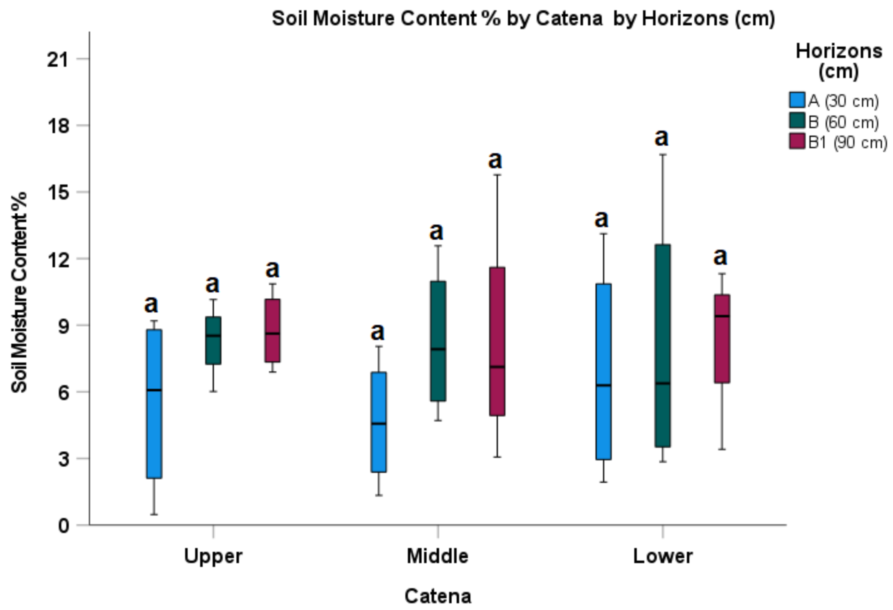

Figure 4.16. Multiple comparation of the mean average of soil moisture content interaction by horizons by catena

Soil physical properties texture and particle size distribution Huambo soils

Results presented in figure 4.17 reveal the proportional variability of the particle size of the mineral fraction in Huambo soils. Although there are variations along the catena and within the profiles of the horizons, the soils predominantly comprise particle sizes between 2µm to 60µm (silt fraction) and which vary between 42.09% to 74.14% of the sample in most locations. The exception is Bailundo, where the lowest proportions of silt are evident a maximum of 15.56% in upper and middle slopes and where higher sand fractions are evident. In all profiles, clay content increases with depth as observed in Appendix 4.13 Appendix 4.14 and Appendix 4.15, the distribution of soil texture is illustrated in a textural triangle in figure 4.17

For an enhanced understanding of soil texture classes that can provide a basis for the support of subsistence agriculture, it is necessary to have a more detailed soil classification of each specific location. The graphs in (Appendix 4.13 Figure 4.17) demonstrate the distribution of textural fractions according to the mean proportions obtained in each studied location (Mungo, Ngongoinga, Bailundo and Longonjo) illustrated as a USDA textural triangle.

Therefore, summarizing the panorama of the municipalities in the studied site, the representative sizes of the average soil particle size in Mungo are distributed as follows - The upper hill profile is predominated by 19.46%, 58.17% and 22.35% clay, silt and sand; - Mid-slop profile19.29%, 61.05% and 19.66% of clay, silt and sand; and - Lower profile 6.88 %, 55.46% and 37.70% of clay, silt and sandy respectively. In this case, there is no doubt that the predominant soil in this area can be classified as silt loam soil.

Bailundo soil texture on average is formed as follows. Upper profile the clay mean is 5.61% silt with an average of 23.66% and sand 70.70%. the mid-slope profile presents an average of 11.48% of clay, silt 41.90% and sand with 46.37%. Lower-slope profiles have an average of 12.95%, silt 65.92% and sand with 21.01%. Thus, it is evident that the predominant soil, in this case, can be classified as loam sand soil, but with an upper profile with loamy sand soil.

Ngongoinga is distributed as - The upper catena profile is dominated by silt 60.84%, clay 18.96% and the sand content is 20.21%: - Mid-slope profile with an average of silt fraction of 71.80%, clay 24.11% and 4.09% sand: Lower-slope profile is 72.43% silt with a 1.92 standard deviation and clay 23.79%. Therefore, the predominant soil, in this case, can be classified as silt loam soil.

Longonjo are as follows. – upper-slope in general, the average amount of clay is 27.30%, while silt has an average of 71.91%. The sand was only found in horizon A with a value of 24.60%; - Middle profile recorded an average of the clay content of 25.93%, silt average is 65.87% and the amount of sand average is 8.20%; - the lower profile has of clay average of 17.14%, the silt average is 61.60% and the sand average is 21.27%. Therefore, the prevailing soil in this case in Longonjo can be classified as silt loam soil.

The granulometric distribution results, as seen in (Figure 4.17 Appendix 4.13, Appendix 4.14 and Appendix 4.15) indicates that the soil of Huambo comprises a high content of silt along the catena and in almost all horizons, with horizon A presenting a silt content range of 4.09% to 74.90% by weight of the soil granulometry, except at Bailundo locality where the proportions of sand fractions are dominant in all horizons, reaching 63.46% in horizon A. The clay fractions vary between 5.22% to 29.47% and increase with depth in most of the catena except in Mungo locality, where in the upper profile of the catena (horizon A) with 26.24% is the highest value. The lowest clay content can be found in Bailundo, where the upper profile of the catena reaches a maximum value of 6.36% clay (Figure 4.17 Appendix 4.13).

The textural class is similar in the upper profile in all locations where horizon A is dominated by silt loam soil, except for Bailundo with sandy clay soil dominate. In the middle and lower profile on all slopes studied, horizon A is formed by the textural class of silt loam. However, the deep profile (horizon B_1) has the greatest variability with horizon B with texture class varying from silt loam, loam, sandy loam, loam sand and silt clay loam, and in the case of horizon B_1 with silt loam, loam, loam sand and silt clay loam respectively (WRB IUSS Working Group, 2015). With these results, there is no doubt that the Huambo soil is predominantly made up of the silt fraction or loamy silts although part of the Bailundo soil has high sand content. Silt has been the dominant fraction in almost all the remaining sites studied (Figure 4.17 Appendix 4.13)

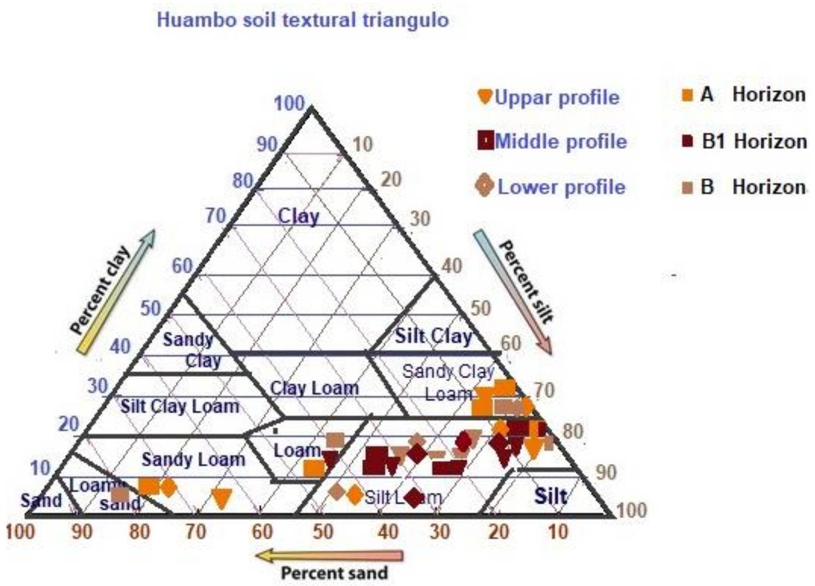

Figure 4.17. Distribution of the soil texture of the Huambo province database illustrated in a textural triangle of Huambo soils.

Soil Bulk Density

The soil bulk density of Huambo province, generally, does not show variability in the same locality, both in landscape toposequence (catena figure 4.18, Appendix 4.17) $F_{(2.32)}$=1.428; P=0.255 with a significance level of P<0.05 and in-depth $F_{(2.32)}$=;0.611 P=0.549 with a significance level of P<0.05 (soil horizons figure 4.19, Appendix4.18).

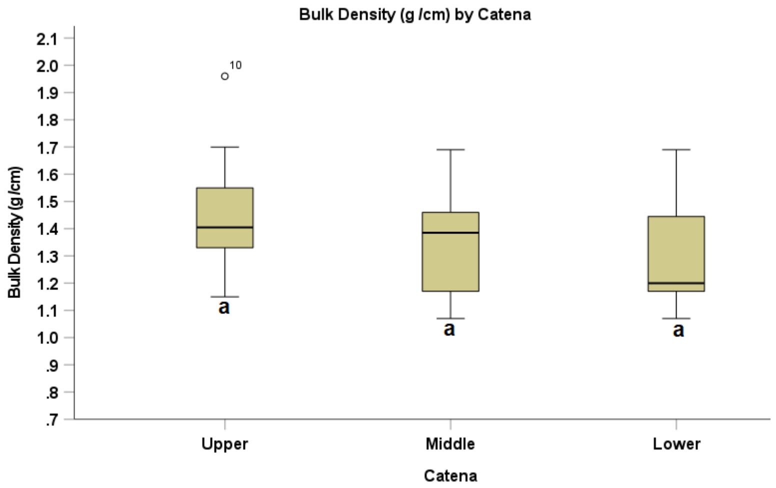

Figure 4.18. Soil bulk density variability in catene on landscape toposeequence *on a cultivated slope*, Huambo Province – Angola

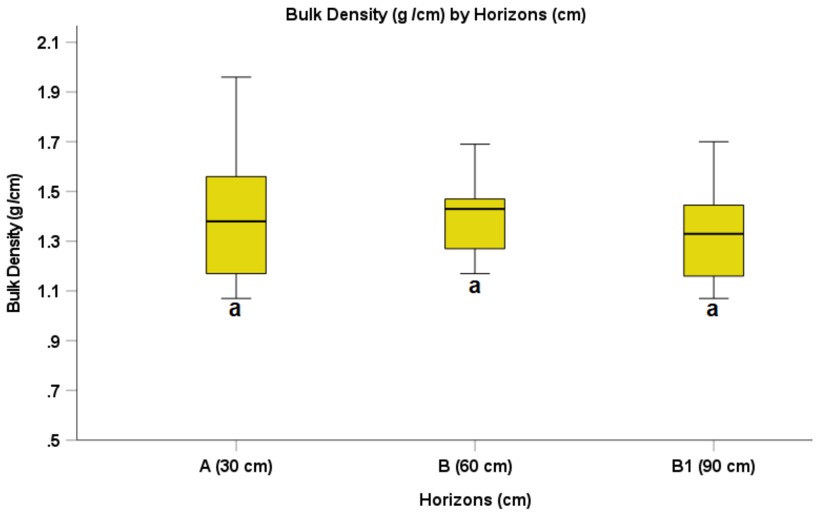

Figure 4.19. Soil bulk density variability on depth profile by horizons on landscape toposeequence *on a cultivated slope*, Huambo Province – Angola

The effect of catena on soil BD shows variability in the interaction of catena-locality. There is a significant difference between Longonjo and Mungo and Ngongoinga localities with $F_{(2;23)}$=7.542; P=0.003, but does not differ from Bailundo (Figure 4.19, Appendix 4.16). For the interaction between locality-horizon there is no statistically significant difference found between the sites along the horizons transect with $F_{(6.23)}$=0.015, P<0.05 and significant difference level P=1.00 (Figure 4.21, Appendix 4.20)

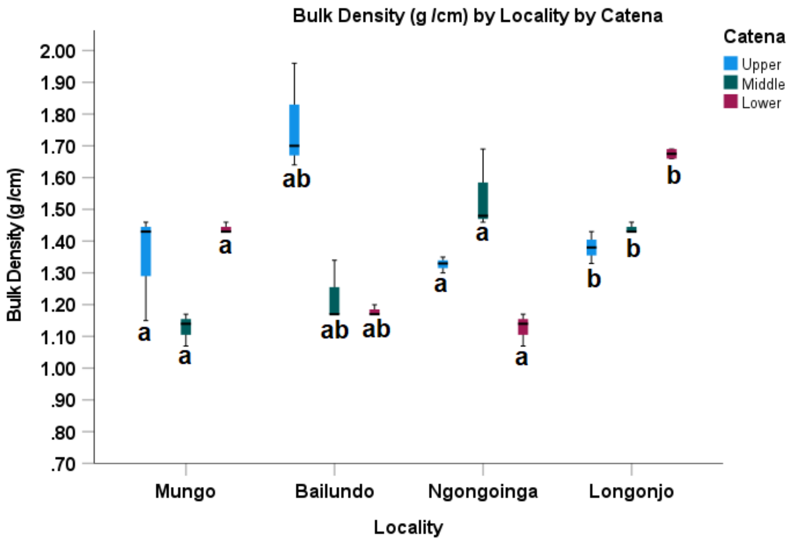

Figure 4.20. Multiple comparisons of the average of soil bulk density by locality by catena in Huambo Province.

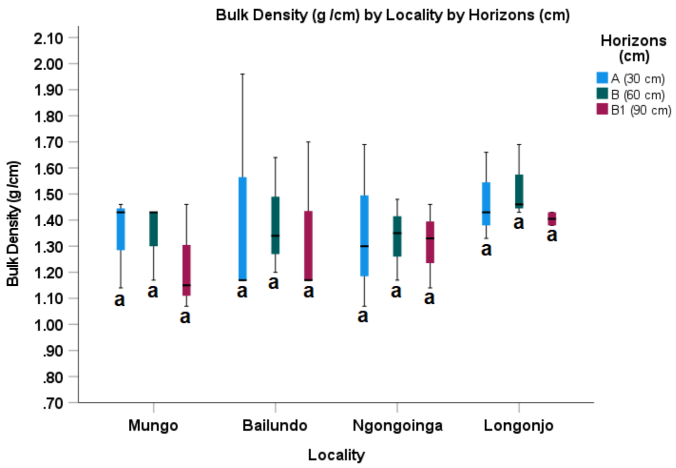

Figure 4.21. Multiple comparation of the average of soil bulk density by locality by horizons.

Soil organic matter content in Huambo soils.

The soils of Huambo show a slight variability in the organic matter content between the different catena profiles and horizons. The amount of mean organic matter found in the study area is shown in Appendix 4.3 and Appendix 4.4 In general, the soils of the region have moderate organic matter contents that varies from 1.8% to 2.3%. these are low percentages considering the scale (0 to 5%) being 5% the maximum percentage required in a fertile soil. In all profiles, there is an equilibrium in the content of organic matter with slight variability in catena landscape toposequence and in depth (horizons).

Effect of catena and horizons on the distribution of organic matter in the soil.

The results demonstrate that the distribution of organic matter along the toposequence-catena of the cultivated slope landscape generally does not present a statistically significant difference (Figure 4.22, Appendix 4.21) with $F_{(2,32)}=0.408$, $P=0.668$ with a significance level of $P<0.05$. Depth profiles (horizons) also do not show statistically significant differences. (Figure 4.23, Appendix 22) with $F_{(2,32)}=0.70$, $P=0.932$ with a significance level of $P<0.05$

Analyses of multiple comparisons between locality-catena and locality-horizons show that the Mungo locality presents a significant difference from the other localities (Figure 4.24, Figure 4.25, Appendix 4.23 Appendix 4.24), $F_{(2,32)}=35.172$, $P=0.001$ with a significance level $P<0.05$ and in depth between the horizons $F_{(2,32)}=10.06$, $P=0.001$ with a significance level $P<0.05$.

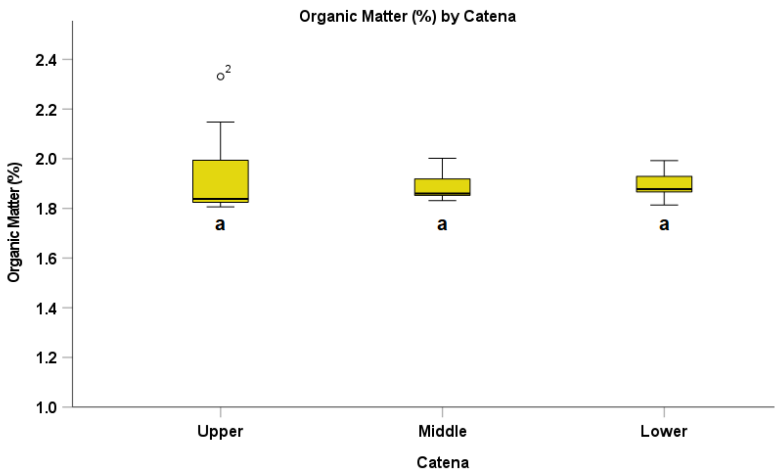

Figure 4.22. Mean soil organic matter distribution along the catena toposequence on a cultivated slope in Huambo province - Angola

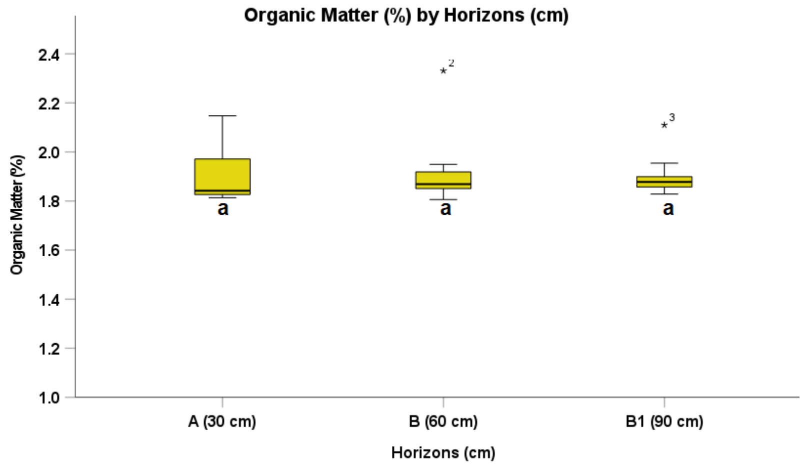

Figure 4.23. Distribution of Soil organic matter by horizons along de catena toposequence on a cultivated slope in Huambo province – Angola.

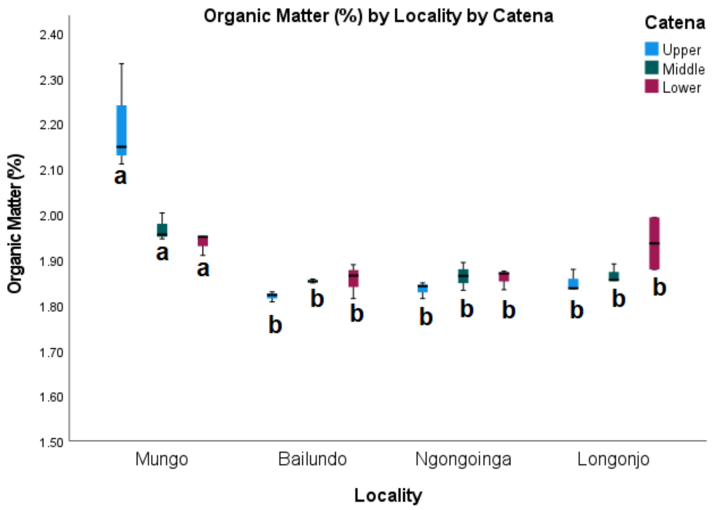

Figure 4.24. Multiple comparation of the mean of organic matter by locality by catena

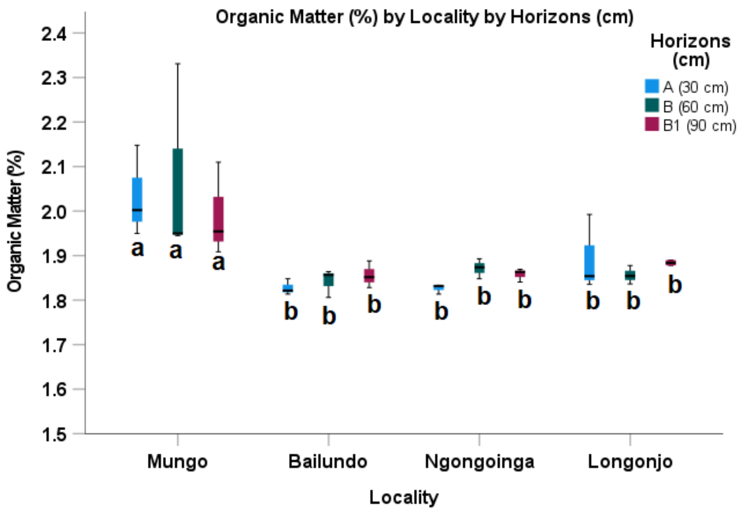

Figure 4.25. Multiple comparation of the mean of organic matter by locality by horizon in Huambo province – Angola.

Soil water holding capacity and soil moisture content are directly correlated where an increase in soil water holding capacity increases soil moisture content by 48.60%, with significance at levels of $P<0.01$. The result also confirms that the amount of organic matter in the soil is a major contributor to the increase in soil moisture content and soil water holding capacity. In addition to increasing the duration of soil moisture, it increases soil moisture content by 32.30% and soil water holding capacity by 23.20%. However, in relation to the soil bulk density, this negatively affects the water holding capacity of the soil and the moisture content of the soil, with increasing bulk density contributing a reduction of the capacity of the soil to retain more water and reducing the amount of SWHC by 18.30% and SMC by 22%, (Appendix 4.25).

Soil microstructure and void space characterisation

Thin section micromorphology of undisturbed soil samples from the study area demonstrates that most of the soil profiles have a high percentage of porosity, with predominantly granular and crumb microstructures and subsidiary void defined chambers and channel microstructures (Table 4.1). The mean total proportion of void space varies between few to dominant (7.72 %-64.92% slide area) with channel and compound packing voids the dominant forms (Table 4.6). Due to the high overall proportion of pore spaces present in the soil, they can be considered to have good drainage soil and higher water holding capacity in the rain season. The results indicate that the lower part of the catena have a lower quantity of soil pores being Mungo with 7.72% the lowest proportion, Bailundo with 11.17% and Ngongoinga 33.25%. A higher proportion amount was found in Ngongoinga in the upper part of the catena archiving the proportion of 64.78%.

Table 4.1. Microstructure and void characteristics, Angolan Ferrisols, Huambo province

Catena site	Observed area µm²	Total pore proportion (%)			Soil void macrostructure
		Micropores	Macropores	Total	
Mungo					
Upper	472529907.4	18.65	12.22	**30.87**	Granular with compound packing, channel
Middle	472529907.4	6.41	10.90	**17.31**	Granular with crumb, chamber, channel
Lower	472529907.4	2.78	4.94	**7.72**	Granular with crumb and chamber
Bailundo					
Upper	478281356.8	7.16	29.09	**35.34**	Granular with chamber channel
Middle	478281356.8	21.02	15.46	**36.48**	Granular with crumb and channel
Lower	478281356.8	4.26	6.58	**11.17**	Granular with chamber and crumb channel
Ngongoinga					
Upper	479252887.0	35.24	29.68	**64.78**	Granular with compound packing, channel
Middle	479252887.0	24.15	15.10	**39.12**	Granular with crumb, chamber, channel
Lower	479252887.0	17.10	16.22	**33.25**	Granular with crumb and chamber
Longonjo					
Upper	378356827.5	8.56	27.65	**36.21**	Granular with compound packing, channel
Middle	378356827.5	10.14	16.77	**26.91**	Granular with crumb, chamber, channel
Lower	378356827.5	12.81	13.48	**26.29**	Granular with crumb and chamber

Notes. Horizon samples (middle of the horizon). Magnification: Objective X1.25; eyepiece X10. Light source: Oblique incident light and cross polarising light. Microstructure. Dominant microstructure notation: Granular with crumb. Subordinate microstructure notation: Channel

The abundance of pore space in the soil and the proportion of macropores and micropores (Table 4.1) illustrates that in the case of Mungo, the upper and middle catena the total pore Cam be classified as common with 30.87% and 17.31%, 35.34% and 16.48% and the lower part of catena with a lower porosity proportion of 11.17% be classified as a few. It is evident that the lower part is susceptible to flood and will retain more water in soil with 4.29% corresponding to micropores and 6.86% with macropores. Bailundo with 35.34 and 36.48 for the upper and middle part of the catena of the hillslope and 11.17% in the lower part of the valley. Ngongoinga presents a higher proportion of void space, being the upper part classified as dominant void with 64.78% while middle and lower part as common of 39.12% and 33.25% respectively. In Longonjo the upper part is dominated by common voids of 36.21% while the middle and lower part with frequent voids of 26.91% and 26.26% of the slide area respectively.

The irregularities of the pore geometry in each type of soil in the study region refer not only to the total porosity of the soil but also to the shape and continuity of the pores (Figure 4.26), that contribute to improving the flow of water in the profiles of the subsoil layers.

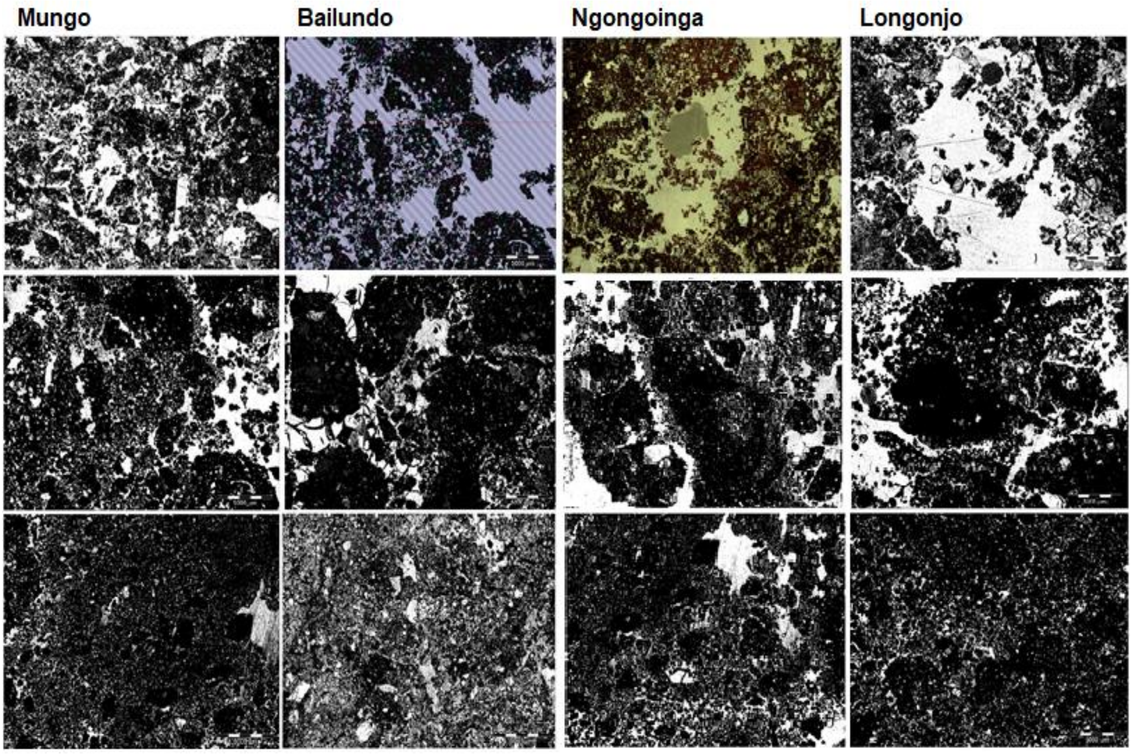

Figure 4.26. Microscopic soil voids geometric configuration observation (Few, common and Dominant). Scale bar 5000 µm.

The microscopic observations made (Figure 4.26) illustrate the variability of the geometric configuration of the pore spaces present in the soils of the Huambo region, where there is a high prevalence of micropores and macropores with connections between them. This indicates that the soil has good through profile water circulation, as well as subsoil water holding capacity and aeration. The total amount of pores presents in the Huambo soil vary in size and are distributed in different geometric configurations, being small and very small (less than 60 µm) which has the important role of storing water in the soil and large (more than 60 µm), governing the important processes of air and water movement.

4.3.2 Discussion

Morphological and physical properties: Field observations

Visual observations carried out in the landscape of the relief of the region, the soil profile varies according to the different effects resulting from the different factors of soil formation, such as parent material, type of vegetation and climatic factors. These factors also contribute to soil colour and soil water holding capacity and moisture content. The variability of the colour tone in the catena from top to bottom and within the depth horizons profile (from dark to light) verified in all the studied sites, can be attributed to factors of the source material, and the high proportion of pore areas, that contribute to the flow of water inside the soil and the amount of water that accumulates at the bottom of the catena, due to the moderate and precarious state of the internal drainage, as well as perhaps the movement of mineral solute or the influences of human agricultural activities that incorporate plant residues in the subsoil causing changes in the structure and texture of the soil. This contributes directly or indirectly to improving the water holding capacity and moisture content of the soil.

This variability of colour tones observed in the profiles of soil depth and toposequence of the landscape, in which horizon A is darker in all profiles in relation to B and B_1 and the valleys also present darker tones in relation to the upper profile of the catena, may be due to the fact that the upper part of the catena is well-drained along the horizons, has a greater flow of water and makes it more susceptible to surface erosion and greater drainage capacity, decreasing as it approaches the valley where there is accumulation long-term moisture. This is similar to what was confirmed by (Lawal *et al*., 2013, Adegbite *et al*., 2019) who argued that the increase in dark colour in soil profiles is indicative of insufficient drainage attributed to the presence of sesquioxides in the hydrated form and the accumulation water over long periods.

Topographic and landscape features have also influenced the soil colour patterns in the Huambo region through their effect on runoff rates, erosion and deposition processes. In addition, the difference in the ability to filter water from the interior of the soil to the subsoil is associated with the characteristics and composition of the minerals that dominate in the parent material and physiographic conditions, climatic factors (precipitation, humidity, and temperature), and the toposequence of catena, perhaps may have been contributed significantly to the variability of the soil colour matrix in each horizon and topographic unit. As agreed by (Eze, 2015, Jimoh *et al*., 2020) the upper crest drains well, while the valley is imperfectly drained.

Therefore, the shape of the slope can also be influential in soil colour variation. As can be seen in the variability of soil tone colour across the catena landscape toposequence, with concave sites (valleys) tending to receive more water and erosion products than flats or convex gradients. These small differences in these landforms can give considerable variation in land textural characteristics, particularly when soil organic matter is redistributed in various parts of the hilly topography and can contribute to different shades of soil colour.

The visually observed water in subsurface horizons (horizon B_1) specifically in Bailundo and Longonjo is indicative of the presence of imperfect and poor drainage conditions at depth in soil profile within the valleys. The reduced drainage capacity on the subsurface horizon restricts the vertical flow of water and causes an increase in height of the water table towards horizon B_1, which contributes to the increase in water holding capacity and humidity in the valley and induces flooding and horizontal flow of groundwater. This can also be attributed to the toposequence of the landscape that keeps the valley saturated during the drought period due to the accumulation of water from the surrounding hillsides, As argued by Lawal *et al.*, (2013) valley profiles are imperfectly or poorly drained.

Soil water holding capacity and moisture content

The results obtained in the studied region show that the SWHC variability is not affected by the landscape slope toposequence, there is in generally no significant difference between the different parts of the catena in the same locality (upper, middle, and lower) (Figure 4.8). However, differences are observed when performing multiple comparisons between the locality-catena interaction (Figure 4.9). where Mungo differs from other localities. Analysing soil moisture content, which is highly dependent on depth and increases after rainfall events, finds that in general, the deeper horizons (horizons B and B1) give greater soil moisture potential than the shallower horizon (horizon A). Table 4.2 and Table 4.3 show the percentage variability of soil moisture content and water holding capacity across soil profiles at each of the sites at different landscape positions in a cultivated land slope.

The increase in soil moisture is a determining factor in subsistence agriculture that is totally dependent on rainwater and is considered a relevant factor in the growth and development of crops and in crop productivity. For both the mean of soil water holding capacity and soil moisture content a minimal variability was observed across the slope positions of the landscape toposequence although the lower part of the catenas have a greater water retention capacity and higher moisture content. This may be attributed to the fact that during the rainy season the concave landscape profiles (valleys) accumulate larger volumes of water which are retained for longer or perhaps it can also be attributed to the deposition of erosion products of fine particles transported by surface flow from the plans or convex gradients profile (upper parts) of the catena and deposited in the lower profiles of the catena.

Another contributory factor may be lower soil bulk density values attributed to the modification of soil structural properties caused by the intensive use of the soil for subsistence agricultural practices, the geometric characteristics of the pore space dominated by micropores and the faster soil water saturation leading to compaction and acceleration of leaching and erosion processes. Another explanation may be the mean content of organic matter in this pedon. The moderate content of soil organic matter in the region plays an important role in maintaining higher moisture content in the lower profile of the landscape position as well as increasing soil hydraulic saturation conditions. Furthermore, the soil can hold more moisture for longer, providing water for crop growth; as argued by (Nnaji, Asadu and Mbagwu, 2002)), higher organic matter improves soil water holding capacity.

Another contributory factor is the textural composition of the soil, with the lower horizons predominantly silt or silt loam soils and the upper horizons loamy sand soil in some localities such as Bailundo. This has the effect of maintaining soil moisture content longer in upper and middle catena profiles. FAO (2005), (Olorunfemi, Fasinmirin and Ojo, 2016) reported that soils with a high proportion of sand are associated with low SWHC. Another view that can also be considered is based on the amount of moisture that occurs due to the rainy season or agricultural practices used by subsistence farmers, which may have contributed to changes in the structural properties of soil aggregates, improving the soil to maintain moderate organic matter. This, in turn, may have been influenced by the higher proportion of porous spaces in the soils and the percent soil bulk density associated with moderate values of organic matter content, which may have improved the soil moisture content and water holding capacity and the soil texture. (Olorunfemi, Fasinmirin and Ojo, 2016), argued that if the clay and organic matter contents increase, the water holding capacity of the soil also increases and maintains soil moisture for a longer time.

At Ngongoinga, the soil water holding capacity, despite not having a statistically significant difference, presents a greater variability between the upper part and the middle and lower parts. This may be due to the difference observed in the proportion of soil porosity, or perhaps due to the erosive process that contributed to the deposition of fine particles in lower profiles. Concerning soil moisture content, it varies slightly along the catena, likely due to the high pore space observed on these soils allowing good circulation of water between the horizons and along the catena toposequence of the landscape and may have contributed to the movement of mineral particles and organic matter deposited by erosion, perhaps it has varied the soil structure at the bottom of the catena. (Sujatha *et al.*, 2016) argued that organic matter serves as a reservoir of nutrients and water in the soil and increases water infiltration into the soil.

The observed soil moisture variability content can also be speculated as reflecting the source material and the degree of weathering of the soils and, consequently, the physical and mineralogical properties that form the soil aggregate structure and the soil texture associated with moderate organic matter content may have a greater influence on soil water holding capacity and moisture content retention.

Soil physical properties and particle size distribution in soils

The textural composition of the soil forms the basis for their classification in relation to formation factors as well as inherent their functional properties. Mineral particles in the soil differ widely in size and can be classified according to the proportion of clay, silt and sand present in the soil (Towett *et al.*, 2015). In all Huambo, soil profiles studied the clay content increases with depth, and this may be an indication of down-profile movement of the fine mineral fraction by percolating water and water erosion in surface exposing agricultural soils of low organic matter content and fertility. The inherent physical properties in soil formation and the variability in the composition of these properties and their spatial distribution mediated by relief toposequence and diagnostic criteria are relevant to give a basis for their classification (WRB IUSS Working Group, 2015). To better understand and support subsistence agriculture it was necessary to have a more detailed classification of each specific location the type of soil, characterizing the capacity to retain water and the predisposition to subsistence agricultural practice.

The increase in the clay content verified in the subsurface profiles can be attributed as an indicator of the occurrence of erosive phenomena that may be caused by gravitational water flow, associated with the high permeability and drainage as well as water percolation translocating the fine particles of the soil to the layers of the subsoil as indicated by Towett *et al.*, (2015). The review by Osujieke, Ezomon and Aririguzo, (2018) suggests that the increase in clay content of the soil with the depth can be a consequence of processes of eluviation. It may also be due to the agricultural practices used by householder family farmers contributed to the movement of vegetation residues to lower horizons through tillage and spatial distribution of the soils that are influenced by the landscape toposequence and maybe by the faunal activity, eluviation and illuviation.

The proportion of sand particles generally increases with depth, although this does not follow a particular pattern, it highlights oscillations within and between profiles. In the case of Bailundo, where the medium and lower profiles have higher proportions of sand fraction in the B horizon, these high values may be attributed to weathering processes on parent material contributing to the process of soil formation within a humid climate, soil management practices and the type of vegetation covering the soil may have to contributed (Chikezie *et al.*, 2009). While Ngongoinga has the highest values of sand in horizon A in the upper and middle profile, perhaps this can also be attributed to erosive processes that cause deposition of these coarse particles on the surface or by the effects of soil management practices, type of vegetation and pedogenesis, since the deeper horizons have low fraction percentage value of below 2%. In the case of Longonjo the proportion of sand fluctuates it is almost non-existent in the upper part of the catena, however, the middle profile has a high value in horizon A while in the lower profile there are high values in horizon B. This oscillation and the values of the sand found can also be attributed to deposition and the reduced amount of organic matter in the soil can also be a potential contributor to the erosion process caused by rainwater.

The observed variability of textural class in subsurface horizons has grading textural classes from silt loam to silt clay loam and can be attributed to the movement of water by filtration causing the finer particles to wash through the soil and accumulate in the subsoil. However, depositional processes by water flow may have been perhaps responsible for the variability of textural classes in the subsoil. Therefore, it is obvious to say that the movement of water is primarily responsible for the observed variability of textural classes in the subsoil and the development of the soil in Huambo province. On the other hand, this also confirms that soils in the region at all studied sites are highly susceptible to water erosion that contribute to the reduction of soil crop productivity for subsistence householder farming.

The physical properties that characterized the soil of Huambo given good conditions for contributing to the development of plants and their roots with adequate soil water holding capacity, aeration, water filtration and availability of Acceptable humidity during the rainy season. These structural and textural conditions associated with the moderate organic matter content found in these soils influence positively the amount of soil water available into the dry period. The physical constitution of aggregates, the abundance of micropores and macropores, which retain and allow water to circulate horizontally and vertically in the soil profile contributes to prolonged retention and better soil aeration. The quantity of OM even in moderate amounts plays a key role in soil water holding capacity and maintaining soil moisture for longer

Analyzing soil bulk density and influence on soil water holding capacity and moisture content

In general, the bulk density of the Huambo soil varies according to the composition of the aggregates that compose the soil and is directly affected by the mineralogical, organic matter composition and porosity. The average values of soil bulk density in all the studied sites can be considered moderate to low and vary according to the textural class of the soil, average values range from 1.13 g/cm^3 to 1.77 g/cm^3. Low bulk density may serve as an indicator of the dominance of large porous spaces, macropores and micropores in the soil, a view similar to that reported by (Esu *et al.*, 2014) indicating low bulk density soils have high macroporosity and are well aerated.

The increase in bulk density with depth and along the slope of the catenas may be due to changes in the content of the aggregate proportion of clay, silt and sand, characteristics and size of porous space and the runoff erosive effects that occurred along the toposequence of the relief with the influence of depositional flow across the toposequence that are responsible for the differences observed in the textural classes

The subsurface of the upper profile in some localities (Bailundo) is made up of sandy loam textural classes with the subsequent horizons of loamy sand indicating the increase in aggregate of sand particles. This is an indicator of soil with good aeration and drainage stimulating the movement of water in the subsoil. However, in the middle profile of the catena, the horizon A textural class is composed of silt loam and the subsequent horizon by loamy sand and the lower profile of the catena or in the valley is entirely formed by silt loam in all horizons. This variability along the toposequence of the landscape, reveals the occurrence of processes of leaching and eluviation-illuviation stimulated by the movement of runoff water that can contribute to the decreases of bulk density value within toposequence, as similar to that confirmed by (Osujieke, Ezomon and Aririguzo, 2017) who stated that high sand content gives high infiltration and low bulk density which encourages down profile water flow.

Analyzing the relationship between silt and clay particles, it is observed that in all profiles studied, the highest silt/clay ratios were observed in the A horizon of the soil and decreased with the depth. This can be attributed to the greater weathering of the subsoil layers or the consequence of immigration and the existence of local conditions favorable to the migration and accumulation of materials such as inorganic colloids, mainly clay minerals, organic colloids, organo-mineral colloids, and carbonates, associated with the eluviation-illuviation process caused by the action of rainwater erosion. This surface erosion and depositional processes influenced by the topography may have been responsible for the slight differences observed in the content of organic matter, soil water holding capacity and soil moisture content in the three slope positions studied

The greatest amount of organic matter was found in the upper profile horizon A. This may be due to the agricultural practices used by farmers, with deposition of vegetable residues in the soil, which due to their decomposition contribute to the increase of organic matter in this layer. That argument is similar to those given by Bianchi *et al.*, (2008) who argued that the highest soil organic matter content in the upper layers of the soil results from plant residues deposited in the soil.

The results show that the soils of the Huambo region have low and moderate organic matter content. The low values of organic matter can perhaps be attributed to several environmental factors, such as the increase in average temperatures and the high relative humidity of the air that influences the rapid decomposition and mineralization of organic matter in the soil. These climatic factors are considered fundamental in accelerating the mineralization of organic matter as well as influencing soil water holding capacity and soil moisture content, the activities of microorganisms in the soil, both beneficial and harmful to agricultural production. (Sujatha *et al.*, 2016) argued that a low amount of organic matter negatively influences the ability to retain soil moisture the availability and adherence of nutrients in the soil for absorption by the plant and in minimizing soil erosion. Organic matter behaves somewhat like a sponge, with the ability to absorb and hold up to 90 percent of its weight in water.

Organic matter has a greater influence on the formation of stable soil aggregates and soil structure and therefore, on the infiltration of water that influences soil moisture content, and soil water holding capacity. However, Scholes *et al*. (1994) cited by

Craswell and Lefroy, (2001) evidence that the organic matter in the warmer weather was more oxidized than colder weather.

These results corroborate that the soils of Huambo have mostly low organic matter content, and therefore, has negatively influenced subsistence agriculture in upper and middle profiles in dry seasons and where there is no irrigation. This is because the dry season soil retains little water, and the soil moisture is very low and not available for the plant to absorb for its physiological needs. However, valleys generally have more water holding capacity and maintain soil moisture content longer in the dry season because of accumulated water during the rainy season. Therefore, it is essential to adopt effective soil management that improves the organic matter content of the soil through the incorporation of cultural residues and the application of organic fertilizers or manure. This incorporation of organic matter in the soil can contribute to the revitalization of the soil, increasing fauna and the activities of soil microorganisms, the availability of soil nutrients, increasing soil water holding capacity, maintaining soil moisture content for longer and contributing to its availability available in the soil for use by the plants

Void pore space influence on the water holding capacity of the soil

The pore size distribution of different parts of the soil is the fundamental basis for the concept of aggregates. Pore size can allow essential distinctions between micropores responsible for water retention in the soil and macropores for water circulation during the rainy season and decreasing as the dry season approaches. The soil of Huambo present variable pore size geometry and they are, therefore, less prone to flooding in the rainy season, especially in upper and mid-catena slope areas. The lower profile of the catenas can be affected when the rains are very intense with risks of floods caused by excessive accumulation of rainwater. The abundance of pore spaces contributes to the increase in edaphic fauna activity and the development of the growth of plant roots vital to agroecological activities.

4.4 Chapter Conclusion

It is obvious that the information collected for each soil requires proper organization and management for agriculture production as well it is essential for the allocation of soil in various classes to simplify information and communication among the subsistence family farmers, other users, and decision-makers. The results suggest that the variability of the distribution of morphological and physical properties of the Huambo soil is influenced by the topography of the landscape and this influences soil water holding capacity and soil moisture content. Red and yellow ferralsolic soils with a granular structure predominate, characterized by a compound packing and channel voids that provide the soil to be well-drained and the plant roots development and that have influence on soil water holding capacity and moisture content. The tonality of the profile varies from top to bottom, being generally lighter at the top and darker in the valleys, which is due to the accumulation of water and moisture content for longer both in the depth of the horizons and in the toposequence of the landscape.

The soils of Huambo, during the rainy season, have a high soil water content of accumulated which increases slightly as the lower slope approaches and makes the valleys more likely to keep the soils moist for longer, allowing the cultivation of Short-term vegetables, as winter intensifies, the likelihood of soil water availability tends to become scarce, causing crops to dry up. In general, soils tend to have enough water for subsistence agricultural practice only in the rainy season, as long as rainfall is well distributed throughout the crop season. Another aspect to consider from the analyses is soil organic matter which plays a key role in improving soil water holding capacity, soil moisture duration, and soil aggregate improvement in turn contributing to increased soil moisture and the availability of water for the use of plants. Regardless of the minimal differences in soil water holding capacity between different landscape toposequence profiles in the transect basis of agricultural practice, the valley continues to have greater moisture durability due to the accumulation of water experienced during the rainy season. and allows the production of some short vegetable cycles without the need for watering. However, during the dry season (winter) it becomes impossible to carry out subsistence agriculture without the use of irrigation systems, as the availability of water in the soil is practically impossible to be absorbed by the plant, especially in the upper and medium profile, of the same way in the valleys, although in this case, it depends on the amount of water accumulated in the rainy season and on the weather conditions. Therefore, in the dry season (winter) agriculture is only possible when supported by water supply to the crop by using irrigation systems which can minimize crop drying due to lack of the availability of rainwater for crops.

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the valleys, although in this case, it depends on the amount of water accumulated in the rainy season and on the weather conditions.

In terms of thin section micromorphology, the Huambo soils are dominated by silt to a greater extent. therefore, they are soils that can be classified as clayey loam and clayey sand, mainly soils prone to good aeration and with potential for the development of plant roots and agricultural practices, but which require irrigation to keep the soil moist in the absence of rain.

5 Householder Land Management and Social Adaptation for Soil Water Retention

5.1 Chapter Introduction: Land Management for Agriculture and Adaptability to Climate Change

Global climate change is causing extreme impacts on the environment and agricultural production systems (Onyeneke *et al.*, 2019). Agriculture integrating livestock and arable production is the most important economic sector in Southern Africa supporting large numbers of subsistence families as well as large urban conurbations (Branca, *et al*, 2011). Generally, rural farmer's families, including landlords and tenants, combine the characteristics of both producers and consumers. Sustainable land management not only provides sustainable food products for their families but is also responsible for providing food for landless families in rural and urban areas (Khalid and Schilizzi, 2013).

Humanitarian crises are often associated with environmental conditions in the region, including severe and prolonged droughts and flooding as well as socio-economic tensions. (Montle and Teweldemedhin, 2014, Smit, 2016).These crises are now being accentuated by the occurrence of extreme weather events that have necessitated changes and adaptation of production systems to new environmental conditions (IPCC, 2013). The impact of extreme events is evident in all areas of society but particularly impacts the well-being of rural communities. (Bellprat *et al.*, 2015).

The changes that have happened, and are happening, in environmental systems will continue to impact especially vulnerable and marginalized subsistence agriculture (Petzold *et al*., 2020). Climate shocks severely affect communities that survive on subsistence agriculture, whose vulnerability is affected in part by poverty and weak institutional support, and which can have devastating consequences for food security and livelihoods (Smit, 2016).

The vulnerability of human systems to climate change broadly recognises the expected impacts of climate change on a national and regional scale and the broad types and strategies of adaptation that can be employed to mitigate its effects (Westerhoff and Smit, 2009). Adaptive capacity to climate change concerns the conditions that allow individuals or communities to anticipate and respond to changes, capable of minimizing the consequences and recovering and taking advantage of new opportunities (Grothmann, 2005, Bohensky et al., 2010) in the context of the interaction of non-climatic changes factors (Moser and Ekstrom, 2010, Cinner *et al.*, 2018).

In the context of Angola and Huambo in particular, the impacts of climate change are already evident and affect the rural communities and natural resources and ecosystems on which subsistence agriculture depends. With the urgency to increase the adaptability of rural communities, multisectoral action is needed covering local and national governments, universities and research institutes, and development agencies committed to developing the adaptive capacity to climate change. In the Angolan reality, there is still little guidance on how these capacities can be developed within communities, in a chain that inter-links traditional authorities, subsistence agriculture and other authorities, both governmental and scientific research linked to the climate change social adaptation (Cinner *et al.*, 2018). Neither has there been any consideration of or data gathering of existing local community knowledge on the limits that climate poses for subsistence agriculture, or of land management adaptation to climate conditions. Subsistence farmers from different regions of Angola have different perceptions and adaptation strategies to adjust to the impact of climate change and devastation. However, this adaptability governs several underlying aspects such as financial, social and human availability. Evidencing current local community land management adaptations to climate is the purpose of this chapter.

Adaptation by communities occurs through activities of participation involving community members through collective and individual limitation actions shared in the socioeconomic and productive process. (Adger, Neil and Kelly, 1999 and Cinner *et al.*, 2018). Mitigation and adaptation strategies to climate change are two of the main needs to reduce the impacts of global warming to improve soil water holding capacity, contributing to eradicating hunger and poverty. Therefore, changes in subsistence agriculture that increase crop yields and can contribute to the increase in commercial crops from farmers' agriculture and so reduce agricultural system vulnerability are needed (Nnaji, Asadu and Mbagwu, 2002).

Vulnerability can however act as a driver for adaptive resources management and appropriate soil and water management (Adger, Huq and Hulme, 2003). Adaptation can be seen as a continuous process of learning and reflection to climate change (Kuruppu and Liverman, 2011) in rural communities and its effectiveness depends on the speed with which changes occur. Climate change can manifest itself slowly with interannual and seasonal variability, at medium time scales, with a high frequency of extreme events, and more rapidly with immediate and devastating effects on ecosystems (Tompkins and Adger, 2004). Social adaptation to this range of climate change rates can be thought of as social learning and includes both the individual and the collective adaptation of the community. Any research on the implications of climate change for subsistence agriculture that guarantee food security and the means of subsistence family farmers production would benefit from specific information about the complexity of how people respond to the multiple climate variation and the tensions they experience at a more local scale.

Reducing the impacts of climate change requires a sustainable climate approach to agriculture practices systems applied. The adaptability of subsistence agriculture is based on the sustainable improvement of soil water holding capacity, maintaining soil moisture content, food production, adaptation to new climate scenarios and the increase of resilience. Adaptation plays a significant role in assessing vulnerability to climate change and is an adjustment to reduce vulnerability or increase resilience in response to expected changes in climate and associated extreme weather events. Adapting to changes in the environment is necessary for a greater understanding of, and determination of, an adaptive capacity that recognises and values the complex dynamics of the region (Bohensky *et al*., 2010). This will enable subsistence agriculture to develop new approaches to climate change to enable sustainable soil water holding capacity and food production to ensure food security for vulnerable subsistence farmer family communities while ensuring environmental quality (Singh and Singh, 2017).

With the geographical focus of the thesis on Huambo Province, an area vital to subsistence agricultural production in Angola and typical of the wider Southern African region (see chapter 1), chapters 2 and 3 set out the emerging physical constraints on agricultural activity. Chapter 2 highlights an increase in temperature and reductions in precipitation, with a shortening of the rainy season. Given the particular significance of changing rainfall amounts, frequencies and changing periodicity to subsistence agriculture, chapter 3 focussed on the inherent water holding capacity of agricultural soils in Huambo province. The chapter concluded that, although there are some variances depending on the location on the catena, the soils are generally of low water holding capacity because of their coarse texture, lack of organic matter and typically open structure. It is clear from these analyses that changes to precipitation patterns will create greater limitations than already exist to subsistence agriculture in Huambo Province.

This chapter aims to assess the subsistence agriculture community and practices that can be assessed against the 'climate emergency' that appears to be emerging in Huambo Province. It works towards this aim through a series of objectives that first of all characterising the nature and production of subsistence agriculture as currently practised in Huambo province. It then goes on to identify the prevalence of local knowledge of climate change, establish what local adaptations there have been, and perhaps in the future, to changing precipitation patterns including use of water, and to identify what agricultural extension organisation support needs are required as communities move into a climate changed future. Fundamental, the chapter seeks to answer the question: How well prepared are subsistence farmers in Huambo Province for a climate changed future? In addressing this question, the chapter is the third major theme of the thesis (Figure 5.1) and identifies agricultural practices which are the foundation for Chapter 6.

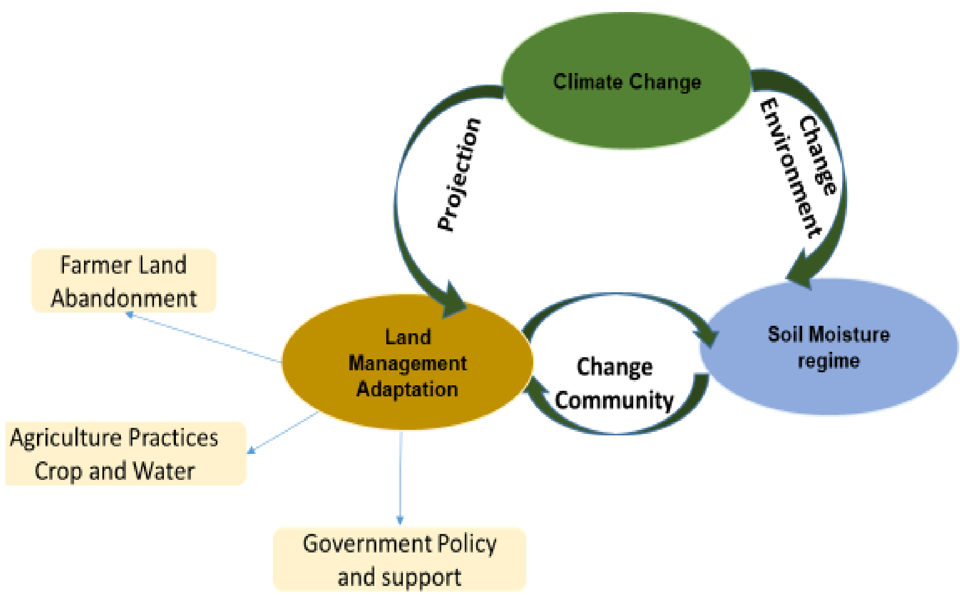

Figure 5.1- Interlink Climate Change and land management adaptation regime for soil water holding.

5.2 Material and Methods

The vulnerability of rural communities is driven by dimensions of exposure and adaptive capacity that can be measured quantitatively or characterized qualitatively. Subsistence farmers from 4 municipalities in the Huambo region were involved in the research program, contributing quantitative and qualitative information related to soil management techniques and agricultural technologies used by farmers for food production, water availability, and management of water for irrigation, and the impact of climate change on crop productivity. A full ethical assessment of this social survey programme was undertaken prior to fieldwork as; extension workers and traditional leaders of the communities under study were surveyed.

Target group of research

For the collected information to be considered valid, the target group was defined with the following characteristics. The respondent must be a farmer over 18 years old, living in the community for more than 3 years and practising subsistence farming no less than 3 years. Agriculture is the main activity and source of income for the family.

The questionnaire was developed in five parts, the first being related to personal data of age, sex, number, and structure of family members living together in the same house, level of education (knowing how to read and write). The second part contains questions that facilitate the collection of information about farmer's agriculture techniques used for land management and included land ownership, main crops cultivated, size of the arable area and techniques used for ploughing the land. The third part refers to water management availability for irrigation, and the fourth part sought to identify farmer perception of climate variability. The final section of the questionnaire sought to identify information about crop productivity and food availability and trends in these indicators. The questionnaire was tested with a pilot group and its final version used is given as Appendix 5.1.

Justification for this structure for the questionnaire reflects the agricultural for subsistence activity in Huambo Province takes account of the two main agricultural seasons, with different characteristics, the rainy (summer) and the dry (winter) It also reflects issues such as the start of sowing or planting crops, cultivation techniques used in crop production, use of intercropping two or more crops in the same field or single production can provide valuable information about the shift in the agricultural calendar due to climate change in the region. General questions related to the knowledge of family farmers in soil treatment and soil health, and whether they use limestone, chemical or organic fertilizers (manure) as chemical fertilisers.

Farmer agriculture techniques and technologies for land ploughing

During the research, issues related to the cultivation techniques used by family farmers to mitigate the negative impacts of climate change on soil moisture conservation and crop productivity over time were addressed by considering the type of equipment used for land ploughing, the beginning of sowing seasons and main cultivars produced. The use of manual equipment such as a hoe, shovel and machete, animal traction and tractors by a labour force in ploughing the soil and maintenance of crops in removing weeds and other work was also identified.

Water availability and soil moisture content management for subsistence agriculture

Subsistence agriculture is majorly dependent on rainfall. During the research period, information about the beginning of the rainy season, the existence of prolonged drought, floods and crops that have dried up due to lack of rain are the main indicators from which to better understand to mitigate the impact of climate change on the variability, distribution and intensity of rainfall in the region. It is also extremely important to obtain information about water planning for irrigation purposes and the irrigation systems and methods used by subsistence farmers and to understand what mechanisms are used to conserve and control erosion and maintain soil moisture content.

The impact of climate change on subsistence crop productivity

Climate is the determining factor in the development and growth of crops, and climate change influences crop productivity. Questions related to the perception of subsistence farmers about the impact of climate change on crop productivity, changes in climate between the past and the present, and new crop varieties incorporated into the production process were part of the quantitative and qualitative analysis of subsistence family farming.

Data Analyses

Questionnaires were completed in the four study locations and took place between June and July 2018. The information was collected by extension workers after initial guidance. Village elders were approached, and the interview process was discussed with them to ensure legitimacy within the community. Questionnaires were completed by interview taking approximately 30 minutes per interviewed farmer each. The total number of farmers interviewed was 417, with a locational split of (Mungo 94, Bailundo 100, Ngongoinga 113 and Longonjo 110).

The questionnaire had a total of 53 questions; the information collected and validated were subjected to nonparametric statistical analysis using the SPSS tool and the data processed, the results were presented in the form of tabulation and graphing.

5.3 Result and Discussion

The chapter 1 review has indicated that rising global temperatures are destabilizing the dynamics of environmental systems, natural resources, ecosystems and agricultural production processes and that the southern African region is experiencing greater climate variability (O'Brien *et al.*, 2000). Increasing evidence of climate variability shows a trend towards extremes in storms and gradual changes in mean annual precipitation. These changes have impacts and implications for the natural resources directly linked to subsistence agriculture productive process. Analysing the subsistence agricultural production sectors in Angola and the Huambo region in particular, which depends on the totality of rainfall, it is evident that the region is directly affected both in the distribution of rainfall and in productivity of its crops.

The constant alternations between prolonged droughts, delays in the start of the rainy season and short rainy periods show a negative impact on the agricultural production of family farming. In part because of this, smallholder farming in Angola has low agricultural productivity growth rates. However, the sector is still responsible for more than 60% of food production in rural areas and continues to be considered the most important sector for reducing food insecurity. Climate change poses significant threats to this crucial, but perhaps underperforming, sector of the economy, and is playing a detrimental role in domestic food production.

This chapter now explores smallholder farmers' knowledge and perceptions of climate change's impact on subsistence agriculture and the mitigation measures they have already put in place.

5.3.1 Characteristics of the Research Target Group

It is important to know the characteristics of the demographic composition of subsistence farmers, those who constitute the target group of this research (Figure 5.2 and Appendix 5.2) presents the results obtained from the demographic constitution of the respondent family farmers that make up the researched areas. The age group with the highest percentage of interviewees is between 26 to 50 years old, while those under 25 years old present a lower proportion in all studied locations. Likewise, in the proportion by gender has more females with an average of 56.1% than males that represent 43.9% of the survey cohort.

Figure 5.2 - Subsistence family farming farmer with all family members (Cornfield)

In subsistence agriculture, the workforce is generally composed of family members, and in the study area, the average number of members per household is between 4 to 10 members. When analysing the characteristics and composition of the members that make up the family, it is noted that most family members are under 15 years of age, with an average of 3 to 7 children per household (Figure 5.2). This may indicate that in many families at least two people will work in the field.

Farmer landownership and main crops produced.

Production systems consist of the set of strategies put into practice by farmers to develop their agricultural system and in Angola family farming predominates in the agricultural production process. Most small subsistence farmers plant on an average area of between 1 ha to 2 ha per family 61.6% (table 5.1). These lands are often not a single continuous plot but are divided into small plots often in different agro-ecological areas. The different land uses are then influenced by the dry and wet seasons, influencing when the land is left fallow as well as the type of crop to be cultivated. Agricultural production is in general based on a single rainy season, being the only resource to give soil water.

The use of agricultural mechanization techniques or animal power for land ploughing is almost negligible and uses relatively low levels of improved inputs such as seeds or fertilizers. In detail, 6.5% of farmers use mechanized techniques for land ploughing, 30.0% animal power and 63.5% manually using rudimentary equipment. The data also evidences differences between different age groups in use of mechanized, animal power and manually cultivation. with 0.7% for age group between 18-25 years, 2.6% for age group 26-50 years and 3.1% for the age group more than 50 years old. Therefore, it is evident that the majority of subsistence farmers use rudimentary techniques for land ploughing aged between 26-50 years representing 34.1% of the total of farmers using rudimentary techniques. However, there is no statistically significant difference between different age demographic groups with regard to the use of rudimentary and mechanized equipment for land ploughing ($\chi^2_{(4,417)}$= 6.559, P<0.161, with level of significance P=0.05) (Table 5.1, Figure 5.3, and appendix 5.4).

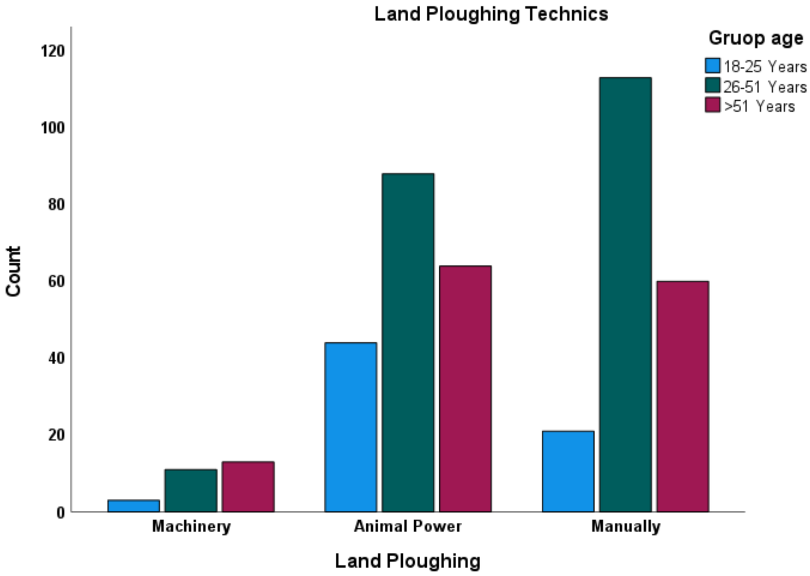

Figure 5.3 – Overall householder soil ploughing techniques used by different demographic age groups

Table 5.1 - Householder land ploughing techniques used in relation to demographic difference by age groups

			Group age			Total
			18-25 years	26-50 Years	>50 Years	
Land Plowghing	Machinery	count	3	11	13	27
		% Within land ploughing	11.1%	40.7%	48.1%	100%
		% Within Age	4.4%	5.2%	9.5%	6.5%
		% of total	0.7%	2.6%	3.1%	6.5%
	Animal Power	count	27	59	39	125
		% Within land ploughing	21.6%	47.2%	32.7%	100%
		% Within Age	39.7%	27.8%	28.5%	30.0%
		% of total	6.5%	14.1%	9.4%	30.0%
	Manually	count	38	142	85	265
		% Within land ploughing	14.3%	53.6%	32.1%	100%
		% Within Age	55;9%	67.0%	62.0%	63.5%
		% of total	9.1%	34.1%	20.4%	63.5%
Total		count	68	212	137	417
		% Within land ploughing	16.3%	50.8%	32.9%	100%
		% Within Age	100%	100%	100%	100%
		% of total	16.3%	50.8%	32.9%	100%

In Angola, all land belongs to the state and the state itself aims to respect the land rights of its rural communities. However, household ownership of land for subsistence agriculture demonstrates that customary access is the main way to obtain land and its resources. The land is often acquired through its passing from generation to generation with traditional village authorities and through local government mediating this transaction. For subsistence farmers, secure access to land is the fundamental basis for decent living conditions and is considered the main wealth of the family.

Based on the questionnaire results presented in Figure 5.4, the farmers in the four municipalities who claim ownership of the land where they work is 84% of family farmers, 9% of respondents confirmed that the land was owned as a co-operative and 7% confirmed land as leased for subsistence farming.

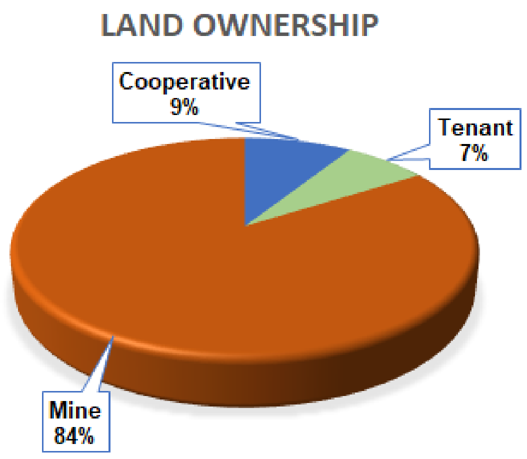

Figure 5.4 – Subsistence family farmers land ownership proportion.

Availability of land area for subsistence family farming.

The availability of land is a decisive factor for family farmers to be able to produce enough food for their families. Overall, the results indicate that 63.5% have an available area of less than 2 ha. This is the group of families that uses the most basic agricultural production system, represented mainly by subsistence agriculture and these families can be characterized as the most vulnerable to social and environmental change. The workforce in this vulnerable part of subsistence farming is mostly made up of family members, with an agricultural calendar of activities taking place mainly during the rainy season. However, in the dry season or when the rainy season is limited some family members provide external services to other properties or carry out other non-agricultural activities that contribute to the overall household income. Some farmers also undertake additional parallel work on other parcels of land in exchange for cash or household consumption of goods during the non-rainy season (winter). Sometimes, these farmers end up working in exchange for basic food and seeds to ensure future cultivation in the rainy season. Another phenomenon that is also identified by subsistence farmers and directly affects farmers in this category is the migration of young people to urban centres in search of temporary jobs as labour during the non-rainy period (winter).

A second production system is formed by small family farmers with several family properties. 31.9% of the questioned farmers have areas ranging between 3 and 6 hectares (Table 5.2). These farm holdings can be considered as the most stable agricultural families due to their autonomy in guaranteeing seeds and family labour for the agricultural harvest and allowing a little more productivity and better product performance that ensures food for the family during most of the year. Generally, there are a greater number of active family members working in the field, thus enabling pluri-activity of labour on the family's property.

Family farmers in this productive system also practice agriculture in the non-rainy season with small plots of vegetables, allowing them to maintain productive stability of food for the family through diversifying their crops and agricultural practices. With the aid of at least one ox for animal traction to plough the land, these small plots cultivated in the non-wet season (winter) for horticulture are often manually irrigated with buckets. and farmers who have their land located on sloping areas often use gravitational irrigation through channels that are built by family members as a collective with families in neighbouring user members.

The remaining 4.6% of farmers questioned represent landowners with areas larger than 7 hectares (Table 5.2). This productive householder group make full use of family labour and some permanent employees who are hired by the land manager, usually the head of the family. In relation to cropping systems, these larger farmed areas also practice irrigated horticulture cropping systems in dry or non-rainy periods, which allow them to increase their productivity, giving a vegetable crop surplus for markets that provides income to keep the family financially stable. Some of these holdings have the possibility of using animal manure to improve soil fertility and cultivate the land with their plough equipment using animal strength as well as having the possibility to rent a tractor to plough the land. Many of them are also part of cooperatives and associations of producers in the region, which allows them to obtain some benefits in terms of seeds and some agricultural equipment.

Table 5.2– Subsistence family farmers available land for agriculture practice in Huambo Province – Angola

			Available Land			Total
			< 2 ha	2– 6 ha	>7 ha	
Land Ownership	Mine	ount	130	106	16	352
		% Within land Ownership	65.3%	30.1%	4.5%	100%
		% Within Available Land	86.8%	79.7%	84.2%	84.4%
		% of total	55.2%	25,4%	3.8%	84.4%
	Co-operative	count	24	9	3	36
		% Within land Ownership	66.7%	25.0%	8.3%	100%
		% Within Available Land	9.1%	6.8%	15.8%	8.6%
		% of total	5.8%	2,2%	0.7%	8.6%
	Tenant	count	11	18	0	29
		% Within land Ownership	37.9%	62.1%	0.0%	100%
		% Within Available Land	4,2%	13.5%	0.0%	0.0%
		% of total	2.6%	4.3%	0.0%	7.0%
Total		count	265	133	19	417
		% Within land Ownership	63.5%	31.9%	4.6%	100%
		% Within Available Land	100%	100%	100%	100%
		% of total	63.5%	31.9%	4.6%	100%

These results demonstrate that most subsistence family farmers are only able to work a maximum of 2 ha (table 5.2), which may be related to the family workforce, or the number of family members able to work on the property. Another important factor that can also be considered is the general absence of mechanized or animal-traction equipment, (Table 5.2) which would facilitate the execution of agricultural work and contribute to managing an increase in the cultivation area. The use of rudimentary work equipment drastically limits the cultivated area that can be managed by farmers. As can be seen in the results, most rural producers use rustic manual equipment such as a hoe, shovel, machete, pickaxe, and axe (see below).

Family-Farming land management and ploughing techniques used.

Family farmers in the central highlands of Angola are part of a people that traditionally have strong agricultural practices that are handed down from generation to generation. The use of various equipment and techniques for ploughing the soil developed over generations are part of everyday life and traditional soil preparation is one of the conditions and techniques used for better crop development. Table 5.2 and Figure 5.5 reflects the methods of soil preparation used by subsistence agriculture producers in the region. 63.5% of the farmers questioned use traditional and rudimentary soil preparation methods that are manual and, a hoe is the most used tool, although this method is very laborious and tiring and can only cultivate a limited area that usually never exceeds 2 ha. Nevertheless, it does have advantages, depending on the crop to be planted. The hoe rarely disturbs the land being largely limited to weeding and immediately afterwards the land is planted with no further tillage, saving time, reducing soil erosion to some extent, keeping the organic matter in the root zone and increasing water infiltration into the ground.

Another technique also widely used by subsistence family farmers to plough the soil is with animal traction. This represents an average of 30.0% of the total number of survey respondents. The use of animal traction helps family farmers to increase their working area and a large proportion of this group of producers usually has a larger cultivated area compared to those who use the manual method with a hoe. Animal traction allows the soil to be disturbed and thus helps to incorporate plant debris and crop residues into the soil, thus improving structure and texture. It also contributes to the increase of soil porosity, thus improving the soil water holding capacity water and air circulation in the subsoil.

Only 6.2% of family farms plough the land with the use of mechanical and semi-mechanical equipment and tractors; this is rarely used by subsistence family farmers. Those who use this technique are usually members of a co-operative (Table 5.3) or are associated with similar organizations that have facilitated the use of conventional modern equipment for soil management or have been supported by government institutions linked to agriculture or non-governmental organizations for a particular agricultural crop that requires and benefits from mechanized land preparation. In table 5.3 it is shown that of the total number of subsistence farmers associated with the cooperative, around 16.7% use mechanical land preparation, 52.8% use animal traction and only 30.6% manually ploughing the land. In general, tenants and cooperative members have more opportunities to use animal traction and machinery on land farming with a value of (62.1% and 52.8%) for animal traction and (6.9% and 16.7%) in machinery respectively.

It is observed that mechanized techniques and traction animals for preparing land are less used among subsistence farmers, who have their own land and are not associated with any cooperative or tenant. Here it is observed that 93.1% (268) are landowners and most work the land manually. This is statistically significant when compared to those who are associated with a cooperative or tenant with $X^2_{(4,417)}$ =56.296 P=0.001 and a significance level of $P<0.05$ (Appendix 5.5). However, from the chi-square analysis, the dependence of each variable can be seen; this may be related to the fact that subsistence farmers who own the land do not have enough resources to facilitate the rental of modern equipment or animal traction, and are limited to the use of rudimentary equipment

Given the above, it is important to consider quantifying and directly qualifying how rural communities can benefit from new and modern technologies (Figure 5.6), transforming and replacing rudimentary techniques and animal-drawn equipment. This could help subsistence farmers to increase their cultivated areas, productive efficiency and productivity.

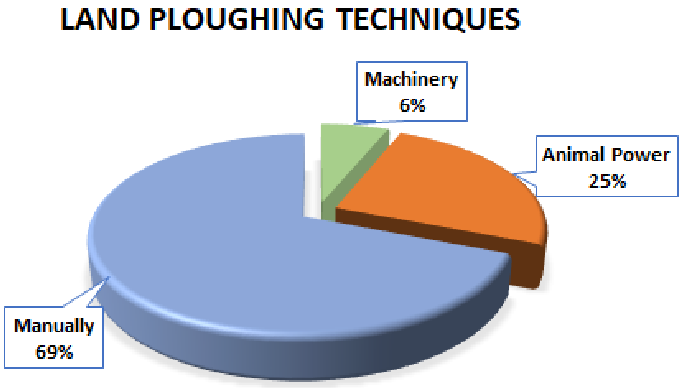

Figure 5.5 – Proportion of land ploughing techniques used by the subsistence agricultural system in Huambo

Table 5.3 - Proportion of land ownership and land ploughing techniques used by subsistence farmers

			Land Ploughing			
			Machinery	**Animal Pawer**	**Manually**	**Total**
Land Ownership	**Mine**	**Count**	18	66	268	352
		% Within land ownership	5.1%	18.8%	76.1%	100%
		% Within land Ploughing	69.2%	64.1%	93.1%	84.4%
		% of total	4.3%	15.8%	64.3%	84.4%
	Co-operative	**Count**	6	19	11	36
		% Within land ownership	16.7%	52.8%	30.6%	100%
		% Within land Ploughing	23.1%	18.4%	3.8%	8.6%
		% of total	1.4%	4.6%	2.6%	8.6%
	Tenant	**Count**	2	18	9	29
		% Within land ownership	6.9%	62.1%	31.0%	100%
		% Within land Ploughing	7.7%	17.5%	3.1%	7.0%
		% of total	0.5%	4.3%	2.2%	7.0%
Total		**Count**	26	103	288	417
		% Within land ownership	6.2%	24.7%	69.1%	100%
		% Within land Ploughing	100%	100%	100%	100%
		% of total	6,2%	24.7%	69.1	100%

Figure 5.6 - Householder farming using manually and animal attraction techniques for land ploughing and particular crop benefits from mechanized land plough.

Crop sowing season of Subsistence householder farming.

The sowing season is determined by the start of the rainy season. The results in Figure 5.7 show that 68% of the subsistence family farms sow in the rain seasons of the year, while 32% sow in both seasons. The rainy season is critical for sowing and is when most crops are planted; most farms do not have irrigation systems to facilitate crop production in the absence of rain. In the study region, the individual results are detailed by municipalities in Appendix 5.6.

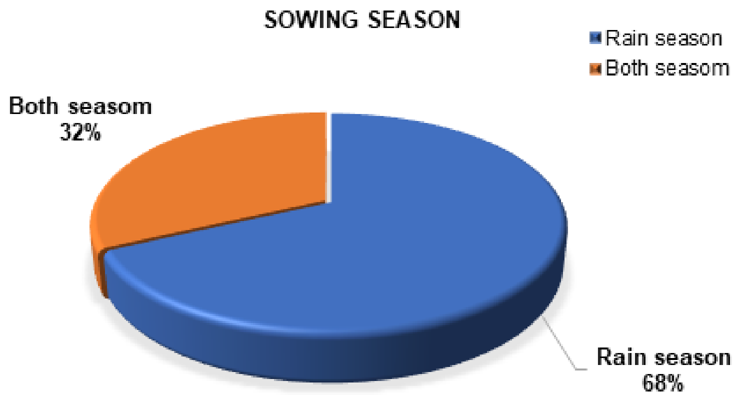

Figure 5.7 - The different sowing times related to the rainy season, Huambo province, Angola

5.3.2 Family-Farming Principal Crop Producing Systems.

Hunger, severe malnutrition, and extreme poverty are the ills faced by much of the family farming sector in rural areas of Angola. Therefore, agriculture has a fundamental role in increasing the accessibility and consumption of food, ensuring adequate nutrition and environmental sustainability. The aim of agricultural development and production in the face of climate change is to reduce community vulnerability and promote sustainable development. The agricultural sector, and in particular family subsistence agriculture in Angola, is recognised as a fundamental pillar of food security for rural communities, sustainable development, and the national economy and provide a level of adequate food production which is seen as a vital contributor to poverty reduction in rural communities.

However, subsistence farmer farming in Huambo faces several constraints to its sustainable development. Most farms continue to use obsolete technologies and production systems and a set of strategies are required to develop agricultural production systems where mixed crops grow together on a given plot of land. Despite the various initiatives undertaken by family farmers, the sector remains a significant challenge to be self-sustainable, especially for the marginalized and poor rural population who use rudimentary food production techniques and are dependent on rainfall. In the context of climate change, this situation is anticipated to worsen and to which local communities must adapt to mitigate the risks caused by climate change. Figure 5.8 shows the clusters of various crops produced by subsistence family farmers in the Angola province of Huambo.

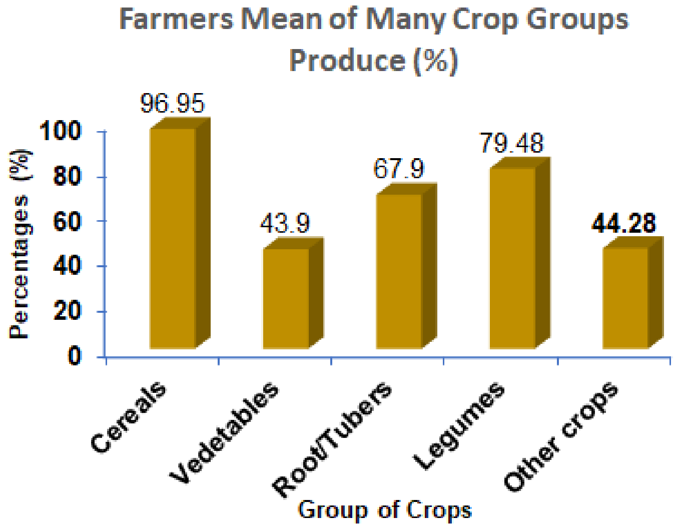

Figure 5.8 - Main different groups of crops grown by subsistence agriculture

The results show that cereals – corn (*Zea mays)* are the crop most cultivated by subsistence family farmers in the central highlands of Angola, which corresponds to an average of 98.4% of the respondents (Figure 5.9). This high participation in corn production is because the Ovimbundu ethnic group is dependent on corn consumption and is part of their daily life as the main food for the family. The second group of crops also with great relevance in terms of production and consumption of family farmers are legumes. This group of crops is part of a quotidian consumption by the rural population, specifically beans (*Phaseolus vulgaris*) which is the legume most produced by subsistence family farmers in the region. The results obtained indicate that in general, an average of 76.48% of farms produce legumes (Figure 5.9 and appendix 5.7). This varies slightly between the municipalities with the Mungo locality reporting the largest number of legume producers at 85.1%; the other locations of Bailundo, Ngongoinga and Longonjo have 76%, 76.1% and 69.4% of farms producing legumes respectively.

Roots and tubers are also of considerable importance and cultivated on 59% of all farms. The production of Potatoes (Solanum tuberosum), Sweet Potatoes (Ipomoea batata) and Cassava (Manihot esculenta) are of particular importance. However, cassava is the new crop being introduced in the region (Figure 5.9).

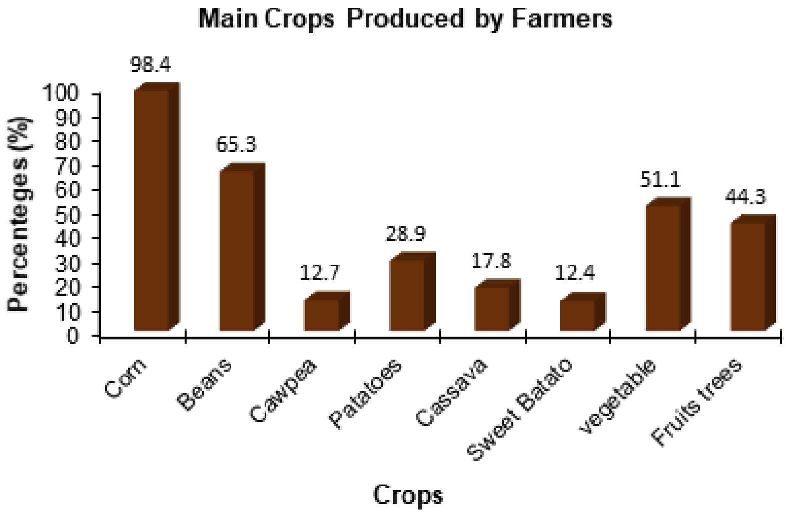

Figure 5.9 - Percentages of the overall average of the main crops grown by subsistence family farmers in Huambo.

The production of vegetables by small family farmers is also undertaken in the region, on 51.1% of the farms. Lack of irrigation systems contributes to a more limited cultivated area of vegetables and the participation of fewer members of the subsistence family community. Vegetable cultivars are very demanding in their water requirement, and this has been the biggest limiting factor in the production and participation of farmers in vegetable production. In the case of subsistence family farmers, most of the production of vegetables is carried out in the lower valleys of the landscape, taking advantage of the soil moisture after the end of the rainy season, and producing a range of vegetable varieties in small plots. Vegetables also play an important role in rural families, being the main crop used for commercialization and the family's profit (Figure 5.9 and Figure 5.10).

Figure 5.10 - Rural open market for subsistence farming farmers crop trading

Another group of crops also of great importance for rural communities in subsistence agriculture are fruit trees such as avocado, mango, guava and citrus with 44.5% of farmers cultivating fruit trees (Figure 5.10). In reality, this crop group does not have a specific crop plot but grows in very small areas that can be less than five trees at a farm. In addition to the product being for family consumption, a large part of the production is commercialized and serves as a source of family income.

5.3.3 Subsistence Family Farming Productivity of the Main Crop Produced.

Subsistence family farming is a productive system that forms the basis of food production in rural communities and is the key to ensuring food security for the most disadvantaged communities. It is much less productive and profitable due to a lack of access to inputs.

The low level of agricultural productivity achieved by subsistence family farmers where poverty, vulnerability and food insecurity are high, and the direct impacts of climate change are particularly severe. The introduction of innovative technologies that make it possible to increase the productivity of crops and the effectiveness of researchers from universities and research institutions and efficient rural extension service can play a key role in improving the varieties and species cultivated by subsistence farmers as the main basis for their food. The improvement of existing technologies and adaptation to current climatic conditions in a differentiated way, collaborating researchers, extensionists with subsistence farmers to identify the best solutions to mitigate climate impact and increase crop productivity would reduce environmental risks.

Table 5.5 shows the proportion of subsistence farmers' harvest in the production of major crops. To analyse productivity, the Table was divided into three groups: the first group composed of those who produce less than (500 kg) in each crop or group of crops, the second by those who produce between (500 kg and 900 kg) and the third by those who produce more than (900 kg). Corn is the main source of food for the Ovimbundu people. It is always present in many dishes that are usually eaten with beans, meat, fish, and other vegetables. The low productivity of Corn does however imply serious food problems for rural communities and beyond, as well as many of the urban and peri-urban areas of the region with the greater impact on rural subsistence communities that are dependent on what they produce.

The second most important crop is legumes, mainly beans, which are also the main component of the diet of rural communities, which is consumed simultaneously with any cereal and tuber produced in the region.

Table 5.1 - Proportion of many crops harvested by subsistence family farmers

	Less Than		Between		More Than	
	N	(<400 kg)	N	(500 kg-700 kg)	N	(>900 kg)
Cereals	152	36.45	158	37.89	107	25.66
Legumes	157	37.65	124	29.74	136	32.61
Vegetables	181	43.41	116	27.82	120	28.78
Roots/tubers	159	38.13	107	25.66	151	36.21
Other crops	146	35.01	137	32.85	134	32.13

5.3.4 Changes in Beginning of the Rainy Season and Availability of Water for Subsistence Family Farming.

The start of the rainy season is a very important seasonal change for subsistence agriculture as it determines the beginning of a new agricultural year season. Any variability or delay in the onset of rains imply changes in the agricultural calendar and this has many implications for both the development of a crop and the production of sufficient food. If crops grow and develop late and outside the proper time, there is a reduced growing season and various pests and the development of the most critical diseases become more prevalent. Figure 5.11 illustrates the views of farmers on the start of the rainy season in the region, with October being considered by most subsistence producers as the beginning of the rains at present (60.9% of respondents), with 38.4% highlighting the month of September and 2.7% viewing the month of August as the start of the rainy season. Many respondents claimed that it rained more in the past than currently, with previously September being considered the start of the rainy season, and a recognition that changes are taking place with the rains of September no longer reliable. Consequently, planting is now normally delayed until October

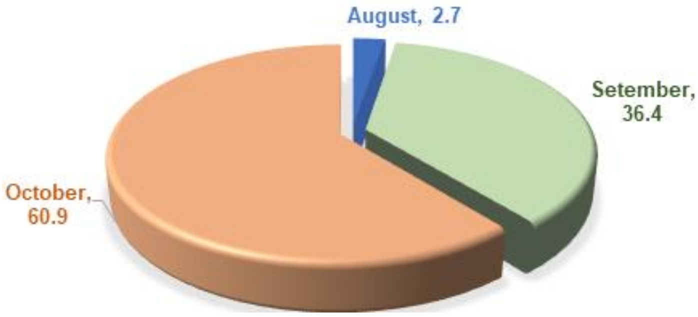

Figure 5.11 - Perception of householder farmers about changes in the onset of the rainy season

5.3.5 Farmer Perception and use of Irrigation Water Availability for Subsistence Agriculture

Water is an indispensable natural resource for the productivity and development of agriculture as well as supporting faunal, and floral ecosystem services related to agriculture in the area. The limits of subsistence agriculture are dependent on rainwater availability and spatial distribution influencing the crop sowing season as its distribution does not always meet the water needs of crops at the exact moment required. Irrigation is ideally required at these key moments, but the questionnaire results reveal that irrigated water for crop production is limited in its availability within the study region as observed in (table 5.4), recording an overall mean of 33.8% watering of crops using irrigation.

Table 5.4 - Subsistence water availability and proportion of use irrigation practices

			Uso of Irrigation		
			Yes Use	Do not Use	Total
Available Water	Yes Available	Count	141	78	219
		% Within Available water	64.4%	35.6%	100%
		% Within Use of Irrigation	100%	28.3%	52.5%
		% of total	33.8%	18.7%	52.5%
	Not Available	count	0	198	198
		% Within Available water	0.0%	100%	100%
		% Within Use of Irrigation	0.0%	71.7%	47.5%
		% of total	0.0%	47.5%	47.5%
Total		count	141	276	417
		% Within Available water	33.8%	66.2%	100%
		% Within Use of Irrigation	100%	100%	100%
		% of total	33.8%	66.2%	100%

Although most subsistence farmers have available water for irrigation (52.5%) only a minority use irrigation system and always in a rudimentary way, corresponding to an average proportion of (33.8%) of the overall respondents. Of these, 12.0% use manual irrigation through buckets and 18.2% use surface irrigation through channels and flood the soil surface with the water captured from intermittent rivers and small reservoirs made in a rudimentary way to accumulate water (Table 5.4 Figure 5.12 and Figure13 and Appendix 5.8). Generally, in the region under study, a total of 66.2% of family farmers are unable to apply irrigation

Figure 5.12 - A small spring and water reservoir where subsistence farmers draw water for irrigation and sometimes also for drinking and other domestic activities

Figure 5.13 - Household farm production of vegetables using manual and surface flooding irrigation systems method.

The high dependence of subsistence agriculture on seasonal rainfall makes it susceptible to environmental changes. Climatic change - as evidenced in Chapter 3 - is contributing to the reduction and poor distribution of rainfall, making it more unreliable for subsistence farming communities and more insecure for the practice of sustainable agriculture. Reduced capacity and lack of sustainable technologies in subsistence agriculture result in a dramatic challenge to produce enough food, where more sensitive crops end up drying out (Figure 5.14).

Figure 5.14 - Dry corn crop in subsistence agriculture system due to lack of rain and irrigation systems. Huambo province, Angola

Furthermore, it is becoming even more difficult for subsistence agriculture to practice irrigation agriculture due to its lack of technology, labour issues and lack of institutional capacity to mitigate adaptation to drought. Figure 5.15 shows the proportion of how often subsistence family farmers wet their crops. The questionnaire evidence that 24.9% irrigate once a week, while 7.0% irrigate more than once a week, 10.6% irrigate only once a month. However, 57.6% do not irrigate their crops at all and are entirely dependent on rainwater.

Although an average of 52.5% of subsistence farmers in the region expressed the view that there was enough water for irrigation, most indicated that water availability is being compromised by climate change, mainly due to reduced rainfall and increased water scarcity and, in some years, long periods of drought. Climatic changes are considered to be influencing the rainfall regime of the region and the irregular seasonal distribution, both of which impact the availability of water for irrigation.

Subsistence farmers have reported that in some areas their natural water sources have completely dried up and others contain little water and are steadily declining. Reduction in the amount of water in natural springs is contributing drastically to the reduction of vegetable range and production in winter, the main sowing and growing season for most varieties.

Table 5.5 - Crop watering frequency by subsistence family farming and water availability

			Availabe Water		
			Yes Available	Not Available	Total
Often Watering Crop	Two More/week	Count	24	5	29
		% within oftem watering	82.8%	17.2%	100%
		Within Available water	11.0%	2.5%	7,0%
		% of total	5.8%	1.2%	7.0%
	Once a week	Count	92	12	104
		% within oftem watering	88,5%	11.5%	100%
		Within Available water	42.0%	6.1%	24.9%
		% of total	22.1%	2.9%	24.9%
	Once month	Count	40	4	44
		% within oftem watering	90,9%	9.1%	100%
		Within Available water	18.3%	2.0%	10.6%
		% of total	9.6%	1.0%	10.6%
	Never watering	Count	63	177	240
		% within oftem watering	26.3%	73.8%	100
		Within Available water	28.8%	89.4%	57.6%
		% of total	15.1%	42.4%	57.6%
	Total	Count	219	198	417
		% within oftem watering	52.5%	47.5%	100%
		Within Available water	100%	100%	100%
		% of total	52.5%	47.5%	100%

For many subsistence family farm irrigation or manual bucket, watering is now impossible. This water deficit does not only affect the agricultural production process, but also the social life of rural communities contributing to increased food insecurity and reduced family income. Appendix 5.9 shows the proportion by location of how often subsistence farmers irrigate their crops, per week and month and show broadly consistent patterns.

Changes in rainfall patterns pose considerable challenges for subsistence family farmers in the central highlands of Angola, especially as an average of 57.6% (Table 5.5) of subsistence agriculture depends entirely on rainwater to moisten their land and grow their crops. As indicated in Chapter 3, the total amount of rainfall throughout the year has been changing and decreasing year by year. However, it rains in more concentrated and intense periods, sometimes with long intervals between one rain event and another. This intensification contributes to accelerating soil erosion and flooding in the valleys and has the consequence of reducing the permeability of groundwater filtration. Furthermore, increased rainfall variability and intensity leave farmers unable to make reliable planting and harvesting decisions at the right time, causing vulnerabilities in subsistence production systems that reduce productivity and contributes to increased hunger, poverty, malnutrition, food insecurity and rural livelihood fragility that affect the health and well-being of rural communities.

5.3.6 Smallholder Farming Knowledge and Perceptions of Climate Change and Climate Variability.

The sustainable development of subsistence family farming and rural communities' understanding of climate change, environmental variability factors and climate perceptions are of particular importance as they will influence and affect planning to support subsistence agricultural and food production in a climate changed future.

Better knowledge and management, at all levels of society, of the risks associated with climate variability can help build climate change adaptation capacities that sustain subsistence householder farming. Facing the challenges of adapting to climate change and the resulting impacts that occur in the local environment allows for a greater understanding of how these changes will affect agricultural production. Crop diversification can help insure against the effects of rainfall variability, as different crops are affected differently by climatic events and planting of drought-resistant crops is another common adaptation strategy.

The questionnaire-based study shows that householder farmers in subsistence farming recognise and understand climate change indicators. This is evidenced through the use of sensitive and nuanced language within the community using (translated) terms such as more or less heat, cold, rain, constant and strong wind and the appearance of frequent droughts, decreased water, an increase of insects in the fields, and season or month of beginning of planting. The recognition and interpretation of climate change indicators by subsistence family farmers varies from location to location and so these responses are presented and discussed regionally below, with the top three response score rankings highlighted. The region records a total of 91.3% of subsistence farmers reporting that the weather is getting warmer than now compared to the past, 5% stated that the weather remains the same and 4% did not know.

Another important parameter observed by the rural community is temperatures are increasingly higher than in the past where 89.3% say that temperatures are increasing now compared to the past, 7% saying temperatures remain the same and 4% did not know. Changes observed at the beginning of the rainy season are also observed by farmers across the region as important. 88.4% recognised change in the beginning of rains, 7% indicated that no changes are happening and 4% did not know. This last group of farmers indicated they are not aware of these changes; for them, it makes no difference whether or not the region is affected by the impact of climate change in the region. This is perhaps because of the lack of information on the impact of changes caused by climate change (Figure 5.15).

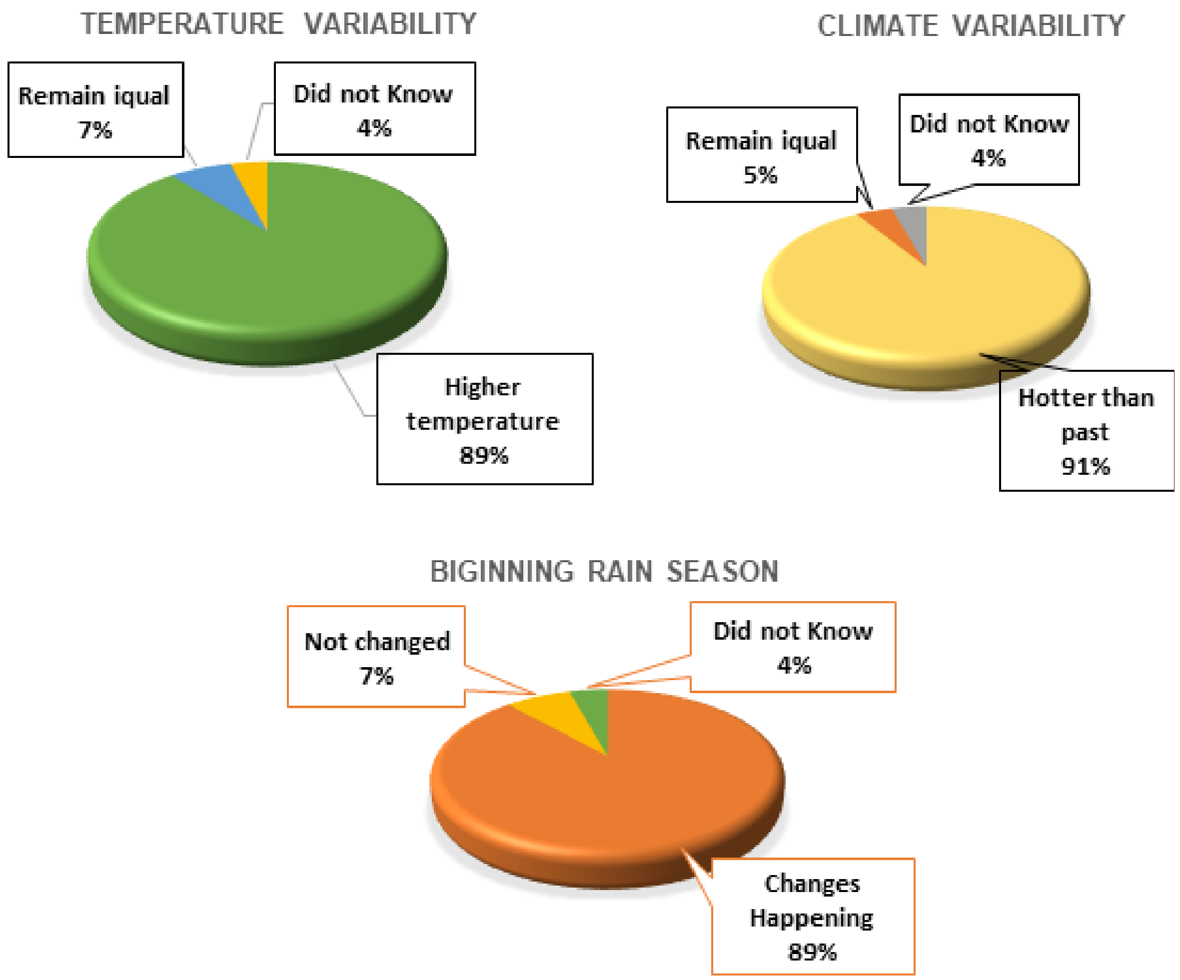

Figure 5.15 - Householder farmer's perception of the pattern of climate change comparing past and present on climate warming and temperature variability.

These three aspects of change were those identified by farmers as the most important factors (based on score ranking, Table 5.6). Other important change factors were also observed by farmers including reductions in crop productivity (80.8%), decreases in rainfall amount (78.4%) and rainfall seems to be more variable (70.6%). These results strongly indicate that in this region there is widely recognisable and consistent evidence of occurrences of climate change directly impacting the livelihoods of subsistence farming communities and wellbeing.

Table 5.6 - Perceptions of householder farmers on climate change over the years in the region.

Statement	Not Know	Remain	Agree	Score Ranking
	%	%	%	
The weather seems to be hotter now than in past	3.5	5.2	91.4	1
Average temperature seems to be higher than in the past	4.0	5.4	89.6	2
Changes observed at the beginning of the rainy season	6.2	5.5	88.3	3
Decreases in crop productivity	10.2	9.0	80.8	4
Decline in rain fall amounts	9.0	12.6	78.4	5
Rainfall seems to be more variable than in the past	15.6	13.9	70.6	6
Crop dryness seems to be more frequent than in past	17.6	13.0	69.5	7
Growing season seems to be shorter than in past	17.1	16.0	67.1	8
Prolonged drought increasing now than in pat	18.2	15.2	66.6	9
The rain are more intense than in the past	20.7	21.6	57.8	10
Increase crop productivity	30.6	15.2	54.2	11
Increase rainfall frequency than in past	26.5	20.1	53.4	12
Flood seems to be more frequent than in past	21.7	29.8	48.5	13
The weather seems to be colder now than in past	42.4	19.1	38.5	14
Average temperature seems to be the same	45.5	19.0	35.0	15

The results demonstrate that there is a strong and growing recognition among subsistence family farmers of climate change. Respondents integrated their observations with knowledge acquired from their earlier generations to perceive the environmental indicators of climate change evident in the region. The climate seems to be hotter now than in the past, which was the first ranked indicator in this regional survey.

Other indicators are also consistent across the Huambo province study area; these include the following: Changes observed at the beginning of the rainy season, decrease in the amount of rain, decrease in crop productivity, prolonged drought increasing now compared to the past and rains seeming more variable than in the past. All these indicators are highly significant to the success or failure of subsistence farming families. Subsistence farmers are aware of the climate changes that are taking place in their localities and recognise their effects on their agricultural endeavours.

5.3.7 Agricultural Methods and Practices used by Subsistence Farming to Mitigate Climate Impact.

Mitigation of climate change is an anthropogenic action that gives adaptability to the climate system, mediated in Huambo province by subsistence agriculture systems, to maintain crop productivity. Subsistence farmers can be considered as excellent empirical observers of climate and climate change through knowledge transmitted from generation to generation and by observing environmental changes through the behaviour of natural phenomena such as cloud colours, thunderstorms, wind direction, the flowering time of a particular species of plant, the emergence of a particular species of bird or animal that help in weather forecasting the weather and to create adaptive and mitigation strategies to maintain sustainable agricultural production. Among the agricultural methods and practices used by subsistence farmers, the manual agricultural practice with a hand hoe was the most popular - evidenced in the questionnaire - being practised by all participants in their agricultural operations from ploughing, sowing, planting and weeding. The hoe is even used in combination with semi-mechanical agriculture practices.

However, to mitigate climate change, subsistence farmers implement cultivation techniques that allow them to maintain a minimally acceptable agricultural productivity. These techniques enable protection for crops against pests and insects, maintenance of soil moisture for longer and give sustainable control of soil erosion, in addition to improving the activity of microorganisms in the soil. Figure 5.16 shows the general cultivation techniques most used in the region under study, with intercropping the technique used by most subsistence producers, 98.5% of respondents, conservation agriculture 63.% while cover crops represent 40.9%, crop diversification 46.5% of respondents, crops combined with animals 5.07% of respondents and crop rotation with 15% of respondents.

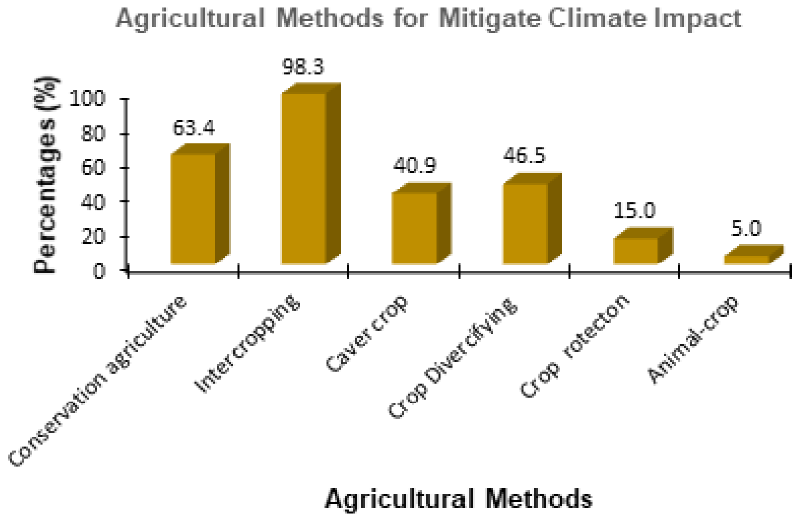

Figure 5.16 - Subsistence farming agricultural methods and practices to mitigate climate impact on crop production.

Method of intercropping farming.

Despite the use of rudimentary technologies and equipment in the agricultural production process, for subsistence householder farming one of the most used agricultural practices to mitigate the impact of climate change and to minimize the crop failure risk is the use of intercropping farming methods. This is a major adaptation strategy used by most subsistence family farmers to mitigate the effects of change and to sustain food production. It consists of cultivating more than one crop on the same plot of land where the crops grow together for mutual benefit. This agricultural production practice, often used in subsistence agriculture, allows greater efficiency in terms of land use, minimizing crop disease infestation and pest attack and control, maintaining soil moisture conservation and more crop water use available for much longer and increasing crop yield per area therefore, Intercropping allows for greater conservation of soil moisture and soil water retention largely due to the high rate of greater leaf area that leads to the creation of a cooler microclimate than the surrounding environment.

Farmers choose crops in intercropping systems according to the demands of family consumption customs, availability of inputs such as seeds, market trends, cultivation practices of agronomic traditions, as well as land use and current climatic conditions relating to the sowing season. This method is practised by most family farmers in Huambo province - some 97.8% of practitioners in the study site (Figure 5.17).

In this productive method, farmers can cultivate or combine annual with semi-annual crops, or annual with semi-annual and permanent crops, the combinations are dependent on the will of each producer and regional environmental conditions. As reported by Waha *et al.*, (2013) multiple cropping systems allow for intensification by growing two or more crops on the same field either at the same time or after each other in a sequence. Furthermore, this method serves to obtain several crops harvested simultaneously or at a different time in the same space (Figure 5.17 and Figure 5.18). In terms of agronomic benefits, it also conserves more soil moisture content and weed control into the crop field.

The use of intercropped systems by subsistence family farmers generally has many advantages (figure 5.17) greater use of natural resources, increased biodiversity and ecosystem, less damage and reduced insect and pathogen attack on crops, in addition to being much more profitable in terms of productivity and efficient use of land and water.

The use of intercropping by subsistence farmers makes it possible to reduce labour in maintaining crop weed control and reduces the most competitive effects from weeds, both in time and space. It also helps control soil erosion by protecting the soil from raindrop impact that tends seal the surface pores, thus preventing increases in surface erosion.

Figure 5.17 - Intercropping corn growing together with Beans, Potatoes and Leaf cabbage (Kale)

Subsistence farmers understand the use of simultaneous cultivation of more than one crop species in the same field (Figure 5.17) as a practical application of basic ecological principles that ensure diversity, competition, and facilitation of productivity. It is a highly productive agricultural systems and reduces crop losses caused by climate, as the crop variety has different climate adaptability; one crop may survive even if another is lost. It also allows farmers to harvest crops at different times (Figure 5.18).

Figure 5.18 - Subsistence farming harvesting crops at different times in the same field using intercropping methods.

Using method of cover crop.

Another method used by subsistence farmers to mitigate the impacts of climate change is the use of cover crops, which consist of full coverage of the soil surface. This method contributes to the sustainability of soils against erosion, maintains and improves water storage, increases the SOM content and contributes to weed control. Usually for the subsistence farmers in Huambo the use of the cover crop method is carried out when dealing with monoculture or in cases that are associated with a specific crop. In this case, some of the main crops used can be mentioned as potatoes, beans and sweet potatoes (Figure 5.19). As commented by Osipitan *et al.*, (2018), cover crops have been documented to improve soil quality and minimize environmental degradation while providing a level of weed suppression in crops.

Figure 5.19 - Subsistence family farmers field using cover crops (sweet potato, potatoes and maize mixed crop with beans).

- *Using method of integration animal crop and manure application.*

In subsistence agriculture, the use of an integrated animal farming and manure application method is a traditional practice used in subsistence agriculture over time. It is a sustainable method that contributes to increasing the fertility of the soil. In the study localities 21.6% of respondents have crop - animal manure integration and 35.4% applied manure at the field (Figure 5.20). Family farmers do not generally have enough resources to acquire small ruminants or large animals such as cows, goats and sheep. However, the few that have been mostly cattle owners used for field work in the preparation of the soil through animal traction and usually never exceed four animals. Most subsistence farmers only have free-range chickens (Figure 5.21) that feed on field insects and other seeds. The lack of large animals directly contributes to the low use of organic material even though integrating the animal component into the crop is favourable to biodiversity, allowing for greater biological control of pests and elimination of insects such as animal feed and contributes to the distribution of organic matter throughout the field

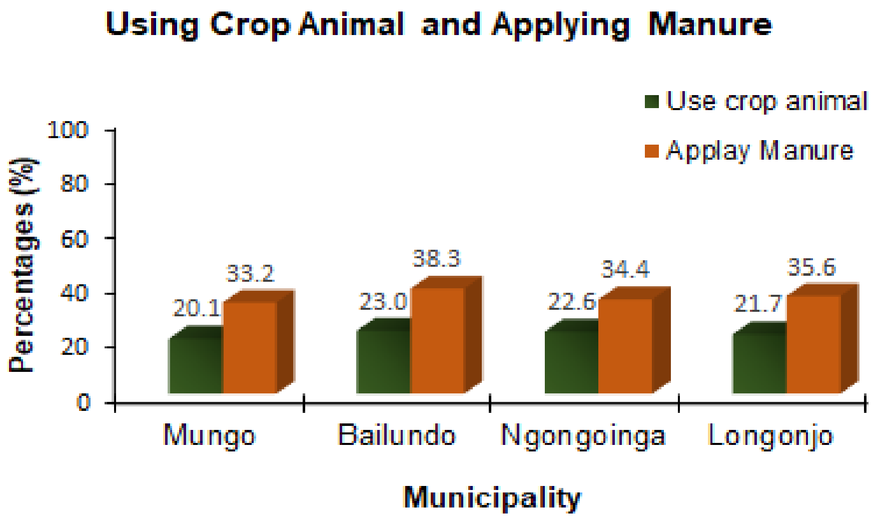

Figure 5.20 - Comparing integrated field crop animal using with applying field organic matter by subsistence farming productive system.

Figure 5. 21 - Subsistence farming using oxen after harvesting and free-range chicken in-farm with crops

- *Using method of crop rotation.*

Crop rotation is a method used in modern agriculture; in the case of subsistence agriculture this method is applicable in a natural way and depends on the availability of seed varieties and the sowing time of the year (winter or summer). In all the study locations, crop rotation is not carried out in a planned way, as subsistence farmers do not have good understanding of the significance of crop rotation; this only happens in the absence of seeds that are normally used locally. These observations indicate the fragility of support systems for family farming, such as rural extension services and other institutions dedicated to providing services for the sustainability of family farming development and resilience to the impact of climate change and adaptability.

5.3.8 *Changes in Subsistence Farming Practices and Adaptability Strategies to Mitigate Climate Change*

Subsistence farmers facing increasing environmental change can use crop diversification measures such as mixed cropping or intercropping practices to diversify farm-related risks. Adaptability to climate change is a process that is gradually acquired throughout human co-existence with the environment. As they adapt to new climatic realities, subsistence farmers make changes in certain agricultural activities that allow them to adapt to the new conditions imposed by the changes on climate.

The results from the questionnaire demonstrate that in adapting to climate change subsistence farmers introduce agricultural practices that vary according to their individual and collective perceptions. However, there is a set of agricultural practices that are most used by subsistence farmers in response to achieve crop resilience including resilience in the face of climate change (Figure 5.22). Good general farming practice can go a long way to indirectly mitigate the effects of climate change on subsistence agricultural systems.

Figure 5. 22 - Subsistence farming changes in farming practices and strategies to adapt and mitigate climate change.

- *Sowing more diverse types of crops now than in past*

The sowing of different types of crops allows for greater resilience and adaptability to climatic conditions. According to the results, family subsistence farmers are using the technique of diversification of agricultural production to mitigate the impacts of climate change and reduce the degree of risk of losing crops. In the study region, compared to what was sown in the past, 46.5% confirm that they have diversified their crops by incorporating new crop varieties and spaces, for instance cassava "(*Manihot esculenta*)" (Figure 5.9, Figure 5.16 and Figure 5.22).

Crop diversification allows for greater security in terms of crop productivity because each crop respond in a different manner to the impacts to environmental change. This practice has a greater safety in ensuring the probability of harvesting for at least one or more crop. The introduction of new varieties and new species of cultivars more tolerant to different climatic conditions is an important approach to reducing food insecurity and mitigating climate change in rural communities. The results in figure

5.22 show that an average of 30.9% have recently introduced at least one new type of crop that they had never produced before (Appendix 5.10).

- *Maintaining crop weed control and conserving crop residues in soil.*

Subsistence farmers' knowledge of precise weed control reflected in the results in figure 5.22 makes them an important activity to maintain high productivity from their crops. Subsistence family farmers know that weeds constantly compete with cultivated plants, causing a considerable loss in productivity, depriving cultivated plants of available nutrients, limited space, light and soil moisture content (Zoschke and Quadranti, 2002, Kumar *et al.*, 2012). In Huambo region, 72.7% of subsistence farmers always keep their crops weed-free throughout the growing process (Figure 5.22).

In subsistence agriculture the use of chemical fertilizers is almost negligible. Decreased soil fertility is a major constraint on productivity in subsistence agricultural farming systems and so investing in practices that lead to increased soil fertility is likely to generate large returns. Sustainable management of crop residues is an important source of organic matter that can be returned to the soil for crop nutrients. (Sarkar *et al.*, 2020) reported that the influence of crop resides on yield is related with overall fertility dimensions, such as soil physical, chemical, and biological properties.

Considering what is seen by some subsistence farmers as a lack of alternative solutions to burning agricultural residues in the open field, many still maintain the practice of burning plant residues. Although this number is still very high in Huambo province region, some sustainability practices and the incorporation of plant residues into the soil has been carried out by a considerable number of subsistence farmers in the region. Even so, these farmers recognise the complications in the management of agricultural residues for the sustainability of the soils and their protection against erosion together with the increase of the loss of soil mineral nutrients and fertility

There is a lack of clear knowledge and adequate information about the burning of plant residues by subsistence family farmers and its consequences for the soil, human and animal health . However, it is known that the burning of plant residues leads to the loss of soil nutrients, deteriorates the quality of the ambient air, causes the loss of nutrients from inherent soil organic carbon, generates several environmental problems in the emission of greenhouse gases, gives loss of diversity of agricultural soils leading to the deterioration of soil fertility (Sarkar *et al.*, 2020).

Alternatives approaches need to be promoted to encourage organic recycling practices to reduce air pollution and increase soil organic matter and soil water holding capacities and agricultural and plant residues management choices should be measured based on productivity, yield and environmental impact. (Erenstein, 2003) argued that complementary practices depend on the actual production technology and may include adaptations to residue management, sowing and nutrient management.

These criteria overlap with an ecological intensification approach to agricultural production systems for subsistence family farming. Here the purpose is to meet the need to implement good agricultural practices that enable the conservation of quality of the soil life, maintaining a higher soil moisture content, soil fertility and greater activity of soil microorganisms. In doing so it takes account of the growing demand for food from families, rural communities and the population in general while respecting acceptable standards of environmental quality. Although there may be different alternatives for burning plant residues, there are currently only two options for subsistence farmers to consider: integrate all plant residues in-situ and incorporate them into the soil or burn them in the field. Although subsistence farmers have claimed that in situ incorporation is very good, many woody plant debris takes a long time to decompose in the soil and as the crop is harvested and residues burned later, only those residues that decompose quickly are incorporated into the soil. Incorporation of crop and plant residues into the soil is seen as the best practice in the subsistence agricultural system for dealing with residues. Effective management of crop residues in the field conserves the soil and its resources with minimal adverse effects on the environment and contribute adaptability in the face of diverse climate change impacts.

In subsistence agriculture family farmers, crop residue management is a well-known and widely accepted practice to control various physical, chemical and biological functions of the soil. However, there are still farmers who barely use and manage plant residues. Crop residues incorporate many nutrients into the soil for crop production and affect positively soil water movement, soil water holding capacity and maintain soil moisture content, runoff and infiltration. Soil management with crop residues covers a wide range of aspects, such as residue decomposition, soil erosion control, recycling, and nutrient availability for plants, weed control and various conservation practices related to soil preparation and maximizing crop productivity (Singh and Rengel, 2007). Naramabuye, Haynes and Modi, (2008) argued that organic residues could be incorporated into soil in the plant row and that this would cause a substantial fertilising effect adding significant amounts of micronutrients to the soil. In subsistence agriculture, the incorporation of nutrients through plant residues is essential in the plant-soil and ecosystem relationship to maintain sustainable soil and adaptability to climate change in a productive agricultural system dependent on natural resources. The conservation and incorporation of crop residues into the soil facilitates better nutrient mobility, maintains soil moisture content and improves the water holding capacity of the soil.

Furthermore, the incorporation of crop residues into the soil constitutes a source of carbon as the main food source for soil microorganisms that are part of the biological cycle of nutrients for crops and can contribute to the adaptability of crops to environmental changes. Sarkar *et al.*, (2020) reported that soil microbial decomposition of crop residues releases unique chemicals that utilized by plants and soil organisms.

- *Changed in sowing and planting crop period.*

For subsistence family farmers, the change in the beginning of the crop sowing season is dynamically related due to interannual variability of the climatic conditions influencing the start of the rainy season. This implies that subsistence farmers adapt, to some extent, their traditional agricultural system to the changes imposed by climate change. However, the definition of the sowing season constitutes fundamental options in the management of agricultural activities for crop productivity and adapting them to different growing seasons, heat tolerance or resistance to drought and diseases. In addition, farmers can be forced to postpone planting because the soils cannot be prepared for being too dry. Figure 5.23 shows the questionnaire results obtained on the start of the sowing period. 39.4% have completely changed the start date of their sowing regardless of the time of the first rains. This group of family farmers are totally dependent on the beginning of the rain, sowing as soon as the rains start no matter what the period, they follow the fall of the first rain.

As can be seen (Figure 5.23), 39.4% of subsistence farmers in the study region of Huambo province have changed their sowing period. This is a relatively low percentage, but it is a valid indicator demonstrating that farmers are aware of climate changes that affect their communities, even without having timely weather forecast information. In this context O'Brien *et al.*, (2000) has argued that, many farmers feel that by the time that they had received the forecasts, it was too late to respond. For the other group of 23.1% group who did not change the sowing time, it is likely that many of them use irrigation systems to allow watering of the crop in the absence of rain; it may also simply be that they do not know literally how to answer. Another group of subsistence agriculture farmers in the study region (37.5%), are a group of family producers who follow the seasonal variability of the rains because they only sow as soon as the first rains fall; they are totally dependent on the seasonal variations of the rains. As argued by Waha *et al.*, 2013), the sowing season constitutes fundamental options in the management of agricultural activities and farmers are adapting their traditional farming system to some extent to a changing climate.

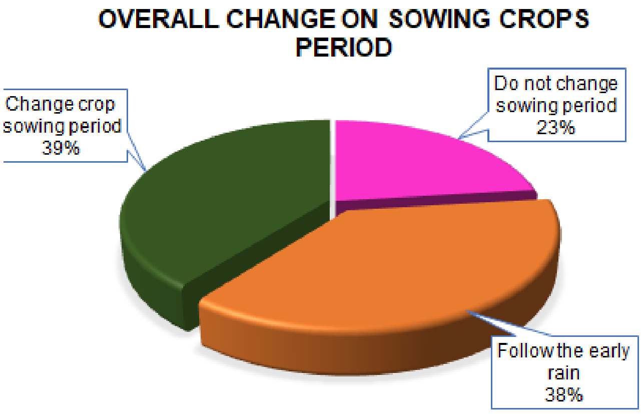

Figure 5.23 - Overall subsistence householder farming change in crop sowing period in Huambo region to mitigate the impact of climate change.

- *Householder farming apply chemical and organic fertilizers and soil liming to increase soil moisture and fertility.*

Animal manure is particularly important in the subsistence agriculture system, providing nutrients to plants; it also increases the soil organic matter content and the soils water holding capacity. A combination of inadequate soil moisture and low soil fertility presents a challenging environment. It is therefore not surprising that a variety of locally adaptable soil fertility management strategies can be developed over time as farmers continue their efforts to meet subsistence needs. The proportion of respondent farmers that used animal manure to manage soil fertility on their crop lands in study region are presented in figure 5.24; in the region only 23% claimed apply manure to the soil.

The decline in soil fertility in the Huambo region is one of the main causes of the decline in crop yields and per capita food production in rural communities as argued by (Schramski *et al.*, 2019) the food self-sufficiency dilemma in terms of per capita food production on a country. Food production and family income needs subsistence farmers and this cannot occur without investing in soil fertility Materechera, (2010) has argued. The declining fertility of soils because of soil nutrient mining for agriculture is a major cause of decreased crop yields and per capita food production.

It is clear from the farmers who responded that few farmers use animal manure because the region lacks a cattle kraals system and with a low level of livestock in the region, the manure available from out with the subsistence farm can be very expensive and subsistence farmers cannot obtain manure this way thus greatly affected the ability to improve soil fertility and crop yields. This has negatively influenced subsistence agriculture and the likelihood of using manure which can contribute to improving soil fertility, soil water holding capacity, soil moisture content and increasing crop yields (Moharana *et al.*, 2012)

Even those farmers who own some animals do not accumulate sufficient amounts of their own manure. For the most part, the number of animals is still too small to generate enough volume of their own farm manure, as on average they never exceed 2 cows used in field work. The region is characterized by the absence of large and industrial kraals for cattle, goats and sheep, even chickens, which could be a source of manure for subsistence family farming.

The loss of soil fertility, due to the continuous depletion of nutrients by crops without adequate replacement, represents an immediate threat to food and environmental security. Applying manure in the soil can play an important role in vitalizing soil nutrients and the soil's water-holding capacity. The reduced use observed in subsistence householders farming in Huambo contributes to soil degradation and reduces crop productivity and leads to the deterioration of social, economic and environmental conditions of the rural community.

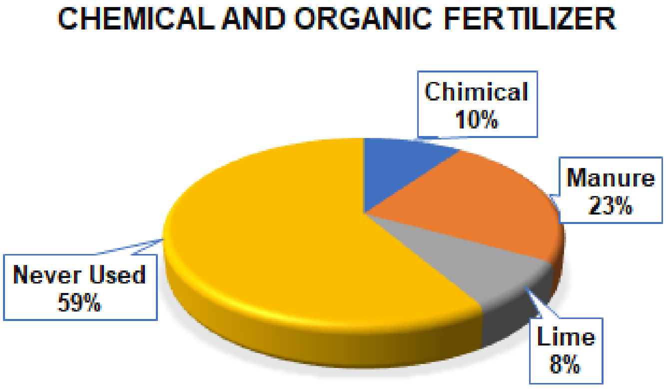

Figure 5.24 - Subsistence family farming - overall use of chemical, organic fertilizers and lime in Huambo province, Angola

The use of chemical fertilizers in subsistence agriculture in Angola and Huambo province in particular, can be considered negligible. This is due to the lack of a sustainable fertilizer market, meaning that availability and access of fertilizers by subsistence farmers is aggravated by the high price charged and also by the lack of habits and customs in the use of these products. The proportion of subsistence family farmers who used chemical fertilizers at least once is visualized in figure 5.24, with 9.8% of subsistence farmers saying they used chemical fertilizers at least once, 8%

liming the soil, 23% apply manure and 59% never having used any type of chemical and organic fertilizers and lime.

According to the results of the analysis presented in table 5.7, it is observed that the application of chemical fertilizers reaches only 9.8%, of which 82.3% being applied by farmers who have their own land. In general, manure is the most applied fertilizer with 23.2%, followed by chemical fertilizers with 9.8% and finally limestone with 8.4%, and the remaining 58.5% do not apply any fertilizer. Therefore, the relationship between dependence on land ownership and fertilizer application is not statistically significant for those who do not use it, despite the chi-square analysis with $X^2_{(6,417)}=2.474$, P=0.871 with significance level of P=0.05. (Appendix 5.11). It can be noted that application of fertilizers is not dependent on land ownership. This can be related to the fact that for subsistence agriculture systems, farmers include in their knowledge and traditional practices, availability of fertilizers and their individual economic situation, which presupposes a preconceived activity in their daily agricultural practice activity and, therefore, a lower level of knowledge about the use of fertilizers and economic results (Figure 5.25).

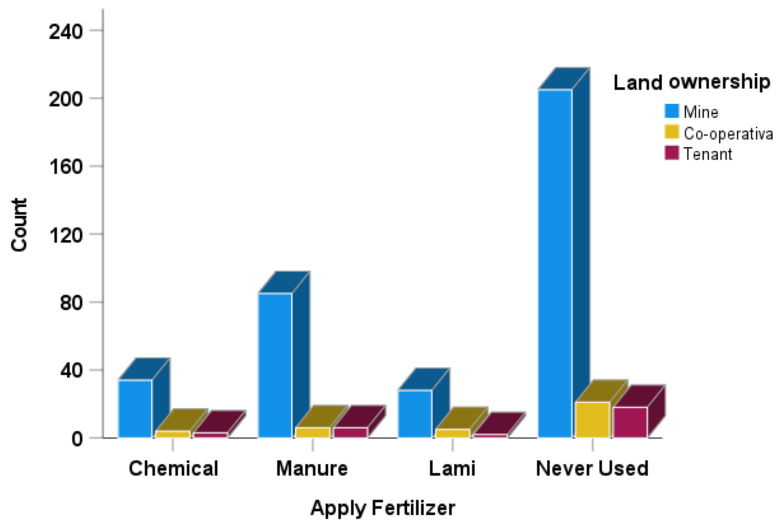

Figure 5.25 - Use of chemical and organic fertilizers by subsistence farmers in the Huambo region

Table 5.7 - Subsistence farming system - application of organic, chemical and soil liming fertilizers

			Land Ownership			
			Mine	Cooperativa	tenant	Total
Apply fertilizer	Chimical	Count	34	4	3	41
		% Within apply fertilizer	82,9%	9.8%	7.3%	100%
		% Within land ownership	9.7%	11.1%	10,3%	9.8%
		% of total	8.2%	1.0%	0.7%	9.8%
	Manure	Count	85	6	6	97
		% Within apply fertilizer	87.6%	6.2%	6,2%	100%
		% Within land ownership	24.1%	16.7%	20.7%	23.3%
		% of total	20.4%	1.4%	1.4%	23.3%
	Lime	Count	28	5	2	35
		% Within apply fertilizer	80.0%	14.3%	5.7%	100%
		% Within land ownership	8.0%	13.9%	6.9%	8.4%
		% of total	6.7%	1.2%	0.5%	78.4%
	Never use	Count	205	21	18	244
		% Within apply fertilizer	84.0%	8.6%	7.4%	100%
		% Within land ownership	58.2%	58.3%	62.1%	58.5
		% of total	49.2%	5.0%	4.3%	58.5
Total		Count	352	36	29	417
		% Within land ownership	84.4%	8.6%	7.0%	100%
		% Within land Ploughing	100%	100%	100%	100%
		% of total	84.4%	8.6%	7.0%	100%

Although the use of mineral fertilizers is commonly applied to overcome nutrient depletion in soils, their use by most subsistence family farmers in Huambo is still limited due to various socioeconomic constraints that rural communities face and aggravated by factors such as weak agricultural extension services, insufficient knowledge in the use of fertilizers among farmers, available and inappropriate fertilizer packaging sizes, low farmer literacy and poverty and lack of knowledge on soil types and crop needs. In the case of subsistence farmers, due to various economic factors, knowledge of sustainable use of chemical fertilizers and, the levels applied do not often meet the demands and needs that the plant requires. Chianu, Chianu and

Mairura, (2012) have noted that fertilizer use is far less in Sub-Saharan Africa than it is in the rest of the world

Soil fertility is dynamically influenced by climate and cultural practices, in which mineral fertilizers, liming and organic matter are the main factor in maintaining soil fertility. However, the loss of soil nutrients is one of the main components of soil degradation. The excessive cultivation practiced by family subsistence farmers and the inadequate application of mineral fertilizers impair the replacement of nutrients in the soils. Similarly, nutrient loss can also be attributed to soil erosion, where increased runoff removes nutrients in solution or as sediment through the wind. Mineral fertilizers are necessary for sustainable food production, but their widespread use also contributes significantly to the increase in greenhouse gases and climate degradation. As argued by Ayoub, (1999) the unbalanced use of fertilizers has created a number of environmental problems.

The decline in soil fertility is the main cause of the decline in per capita food production. The use of chemical and organic fertilizers is essential to ensure the production of sufficient food by rural communities since, in addition to producing enough food for the family, they also produce for other purposes, such as for markets. Thus, in order to improve the productive capacity of soil properties and the viability of crops at the level of subsistence family agriculture - it is essential to use strategies that guarantee sustainable production with the adoption of technologies by farmers including integrated fertility management.

- Use of machinery in agricultural cultivation

For householder family farmers in Angola in general and in Huambo in particular, almost all agricultural operations are carried out manually and based on traditional knowledge and experiences accumulated over generations, although a large part of rural agricultural communities is illiterate and the lack of mechanization in the agricultural activities of subsistence farmers leads to weaknesses in sustainability for social, economic and environmental development.

Results obtained on the use of agricultural machinery in subsistence agriculture indicate that 6.5% do use machinery, while and 93.5% never use machinery, using animal power and manually power with rudimentary technics (Figure 5.26).

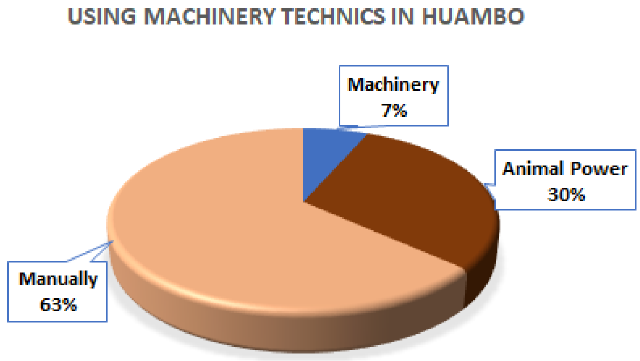

Figure 5.26 - Use of machinery by subsistence family farmers in Huambo.

The application of agricultural machinery in subsistence agriculture can improve agricultural work by contributing to land productivity. Machinery is a fundamental input in any agricultural system, it increases productivity per unit of area, improves the timeliness of agricultural operations and can expand the cultivated area. (Shimeles, Verdier-Chouchane and Boly, 2018) have argued that land mechanization is a key input in any farming system.

Kienzle and Sims, (2014) argued that farmers at or close to, subsistence levels face several major problems generating income for investment in mechanization. The lack of incentives and support from government and financial institutions limits investment in technologies to improve production, which leads to a continuous situation of low agricultural incomes. This lack of investment in production improvement technologies has resulted in very low levels of productivity. Mechanization can transform the economies of subsistence family farming by facilitating and increasing production technology systems and reducing the drudgery of manual production.

- Burning weed and crop residues practice

Sustainable increases in agricultural productivity are needed to ensure the availability of food and livelihoods for subsistence family farming. These increases will likely be largely due to better use of land already in production, in controlling soil degradation using sustainable agricultural practices, which increase the productive capacity of soils adapted to environmental conditions and as a mitigation response to climate change. In figure 5.27 the results showing how subsistence farming manages crop residues in the four studied localities.

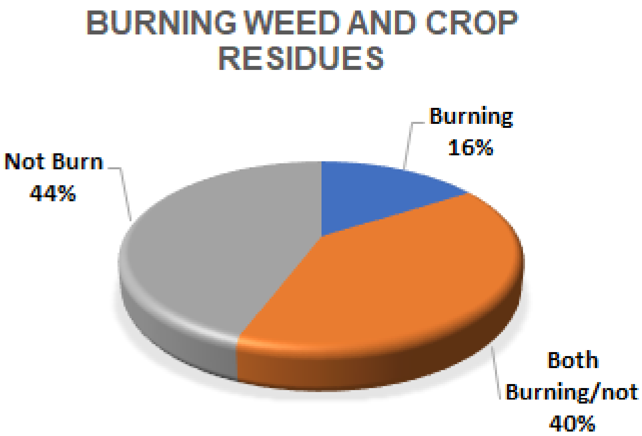

Figure 5. 27 - Subsistence farming practice of plant residues conservation into soil to improve soil moisture and organic matter content and mitigate to climate change impact

5.3.9 Householder farming limitations and institutional and governmental insufficiency in adapting to climate variability

- *Householder farming limitations in adapting to climate variability.*

Subsistence farmers, despite the experience acquired from generation to generation and the natural adaptability characterized by human beings, continue to have difficulties in adapting to the new conditions imposed by climate change, and there are several factors that negatively impact on adaptation strategies. Emerging from the questionnaire study of subsistence farmer responses in the study region, the absence of bank credit and householder farmers low financial capacity is evidenced as being a most critical factor. Bank credit is a key to change and adaptation, allowing access to and introduction of new production technologies for subsistence family farmers. This can allow the supply of subsistence family farmers with new resources and adequate equipment that can contribute to the rapid adaptation and acceptance of new production technologies. This can include the ability to acquire small irrigation systems with water collection and storage facilities, including catch run-off in small dams or waterholes, and which are important strategies for adapting to drought (Fisher, Chaudhury and McCusker, 2010). It may also include new agricultural inputs including the introduction of animals to interact with agricultural production, fertilizers and seeds with better tolerance to drought and more variable climatic conditions. The absence and inexistence of possibilities for subsistence agricultural bank credit, in cash or in kind, currently constitute an insurmountable barrier that greatly limits the process of adaptation of subsistence farmers to the new environmental realities.

- *Weak agricultural technical support from -Institutional and governmental organization is insufficient.*

The implementation of sustainable policies that increase crop productivity with the support of research institutions and other governmental institutions with credible rural extension services, bank credit in kind, construction of small water reservoirs with small irrigation systems can contribute to mitigating the impacts of climate change.

The results presented in Figure 5.28 show the proportion of subsistence family farmers who have received some support from any government institution. 23% of respondents in the study region agreed they had received support by any governmental institution, 52% claimed never to have received any support by and 25% did not know whether they had received support from government institutions (Figure 5.28).

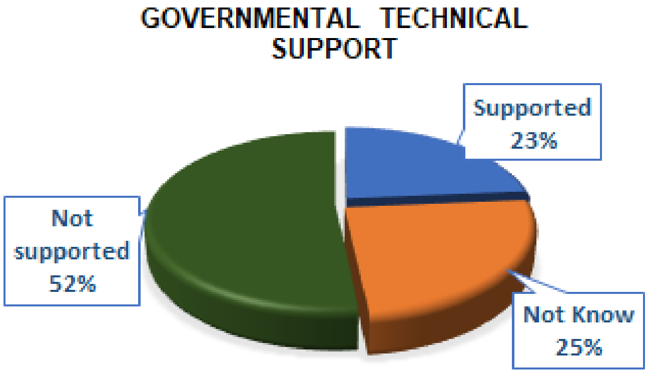

Figure 5.28 - Overall average of governmental institution technical support subsistence family farmers

Governmental, Universities and non-governmental institutions (NGOs) play an important role, now and in the future, in implementing strategies that enable subsistence agricultural producers to adapt sustainably to climate change in the agricultural production process. Many subsistence farmers confirmed that they received at least one support input from one institution, governmental or non-governmental. Currently, the Agrarian Development Institute (IDA) of the Ministry of Agriculture and Forestry, through the Agrarian Development Stations (EDAs), is the governmental entity dedicated to the support and development of agrarian activities for subsistence farming and rural communities related to agriculture productive process; it is responsible for the transfer of new technologies and agricultural extension services.

Universities play a key role in the production and dissemination of scientific knowledge. However, the scarcity of academic literature on the effectiveness, sustainability, and contribution to resilience of adaptive subsistence farming practices that are entirely dependent on natural resources and the environment is a major limitation. The lack of information on adverse climatic events, how to manage in these scenarios and that are explained in clear language to rural communities being able to understand is also a key limitation. Hence the ways in which rainfall variability, increased drought, intense heat in the region, the availability of meteorological information in the province and the evidence of increases in erosion would be a major contribution of university researchers to subsistence agriculture in adapting agricultural production systems to current climatic conditions.

NGOs are non-governmental institutions dedicated to the humanitarian and productive support of rural community activities. The introduction of new technologies in the region does not always find a satisfactory response in implementation due to the lack of guidance and mentoring for the sustainability of the adaptation, the scarce information on climate data and availability to the community about the potential risks to subsistence farmers caused by changes in weather conditions. Therefore, the absence of these NGOs in the communities adds to the challenge in the implementation of different adaptation strategies and in the renewal of productive technologies.

Evidence from the questionnaire demonstrates a lack of support from financial institutions together with associated increases in the price of agricultural inputs such as seeds, hoes, machetes, inorganic fertilizers and which constitute a significant constraint on moving towards adaptability to climate change. Lack of finance contributes to the low availability of high-quality seeds, preventing the cultivation of new varieties adapted to new environmental realities, thus limiting the implementation of adaptation. Delays in making available new and enhanced agricultural inputs creates a barrier to adapting to climate change as farmers cannot implement sustainable strategies to deal with changing conditions.

The lack of infrastructure to support family farming, such as sustainable irrigation systems that allow the conservation of water resources, adequate access to communication routes and sustainable government support for adaptative strategy are determining factors to the adaptability of family farmers. For example, subsistence farmers still use traditional and rudimentary irrigation canals to direct water to the crop, which leads to inefficient water use as much of the water is wasted along the canal.

Rural communities are often governed by their cultural, traditional beliefs and religious on which their principles of agricultural and artisanal production and coexistence between them and the environment are based. For this, whatever the decision to be taken when correctly involving the householder farmers community in implementation of adaptability strategies, it is important to consider the unconditional participation of all community members. The lack of involvement of farmers in decision-making, especially in the design of government driven agricultural strategies, can become an impediment to involvement in the management of agricultural activities defined as adaptation strategies to climate change conditions.

In adaptability processes where marginalized rural livelihood communities are involved, the planning of any strategy must be mutually related between the decision-making part and the practical implementer of the strategies. More precisely, the specialized research bodies, the first is to know which types of inputs are relevant and usable by subsistence farmers as well as the types of seeds that can have a good performance, need to gain acceptance by the community, and consider the existing knowledge about the type of soil and socio-environmental conditions of rural communities including their needs, customs and environmental conditions. Although strategies may theoretically look good, their implementation may fail and be denied by producers because they do not meet the needs of subsistence family farmers. The incompatibility of institutions with the cultural and customary conditions of the local community results in the failure of adaptation strategies. From the discussions with subsistence farmers in Huambo province, planning can neglect anticipated resulting in anticipated beneficiaries' rejection or limited support for the implementation of a given adaptation strategy.

Agricultural methods used in subsistence farming are passed on from their ancestors and based on traditional farming methods. This constitutes a fundamental statement to consider in planning climate compatible development for the adaptation strategy that encourage uptake of new agricultural technologies. Therefore, for most householder farmers, traditional farming practices considered useful throughout life, which have allowed subsistence farmers to survive various adverse of climatic conditions, are preserved but can be a limiting factor in the implementation of the climate adaptation strategy when not considered in the introduction of modern agricultural technology.

Governmental, university, researchers institutions, financial organizations, and non-governmental organizations are also key elements in successfully implementing the adaptability of subsistence agriculture with regard to capacity building, providing climate information and extreme weather events, conducting research to adapt to changes to minimize the impact of climate change on subsistence agriculture and its contribution to making it an integral part of climate compatible development in rural communities. The correct and appropriate involvement of universities, research, and financial institutions in collaborating with a multidisciplinary approach that allows the exchange of knowledge and the development of adaptability strategies of agricultural production systems in rural areas for subsistence family farming can contribute to greater efficiency in its acceptability and implementation. The acceptance and adherence of subsistence farmers to new technologies and adaptation strategies depends, to a large extent, on community involvement in planning the strategy together with the decision-making institutions involved.

- *weak extension services assistance.*

Rural extension services play a key role in information dissemination and technology transfer between research institutions and rural subsistence communities. The deficit in the services provided by institutions linked to rural extension would imply a barrier in the transmission and transfer of new technologies that allow subsistence family farmers to adapt to the new realities of climate change.

The results obtained in Figure 5.29 show that the general average of the provision of extension services covers only 23.4% of respondents. The results obtained indicate that of the total number of subsistence farmers who benefit from extension services, only 13.1% receive information about climate through rural extension services, while 86.9% receive this information from other sources. The circulation and availability of meteorological information and the efficiency of rural extension services in the circulation of climate information is directly associated with the adaptation of subsistence farmers to climate change. In table 5.8 in each aspect analysed, most subsistence farmers perceive climate change from other sources, and this is evidenced by statistical analysis emphasizing that these aspects can apparently be directly related to each other. with $X^2_{(2;417)}$=13.877, p<0.001 with a significance level of P<0.05. (Appendix 5.12)

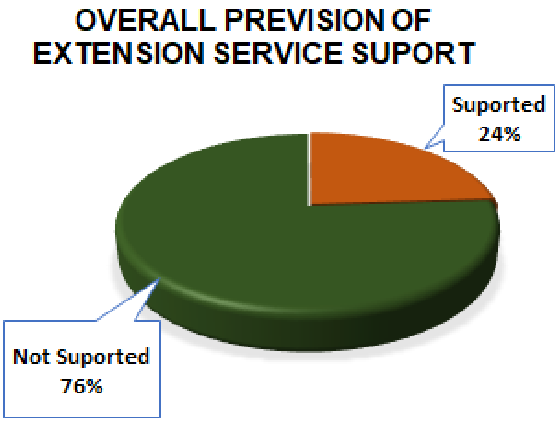

Figure 5.29 - General average coverage of rural extension services provided to subsistence family farming in the study site.

Table 5 8 - Subsistence farmers weak extension service support and lack of weather information for climate change adaptation

			Extensión service		
			Supported	Not supported	Total
Weather Forecasting Suport	Available	Count	8	53	61
		% Within weather forecasting	13.1%	86.9%	100%
		% Within supported service	8.0%	16.7%	14.6%
		% of total	1.9%	12.7%	14.6%
	Not Available	Count	69	152	221
		% Within weather forecasting	31.2%	68.8%	100%
		% Within supported service	69.0%	47.9%	53.0%
		% of total	5.5%	26.9%	32.4%
	Do Not Know	Count	23	112	135
		% Within weather forecasting	17.0%	83.0%	100%
		% Within supported service	23.0%	35.3%	32.4
		% of total	5.5%	26.9%	32,4%
Total		Count	100	317	417
		% Within weather forecasting	24.0%	76.0%	100%
		% Within supported servise	100%	100%	100%
		% of total	24.0%	76.0%	100%

Government support in new technologies is essential for sustainable adaptation in the production process and development of rural communities. The adoption of improved technology based on best agricultural management practices and technological innovation will increase the crop production and reduce greenhouse gases (GHG) emissions. However, for subsistence farmers considering anticipatory adaptation strategies, the role of Government institutions is seen as weak with limited agricultural technical support (Fisher, Chaudhury and McCusker, 2010).

Government institutions such as universities, agricultural research institutions, meteorological, rural extension services and non-governmental institutions, represent an important element in the planning of climate change adaptability strategies for subsistence farmers, including enhancing adaptation strategies in agriculture that have long been used by subsistence family farmers; agricultural and rural development strategies would benefit from increased collaboration between government and non-governmental development organisations (NGOs) (Bebbington and Farrington, 1993).

The unsatisfactory performance of research and teaching institutions, the unavailability of meteorological information at all levels of society and specifically to the production system of subsistence family farming, the lack of rural extension services that allows the introduction of new technologies and varieties of cultures obtained by the institutions of research are limiting factors that impede the adaptability of rural communities and their productive development. There is therefore an opportunity to be taken to build resilience to the impact of climate change in the future, and that are important to take given the substantial challenges that climate variability poses to agricultural production. Every adaptability approach and process require multi-sector teams that act in an interconnected manner - decision makers, researchers, educators and beneficiary communities - and where these adaptation strategies are implemented, careful integration must be part of the planning so that the strategies are accepted with satisfaction within the beneficiary communities.

The Government has the responsibility to guarantee the most disadvantaged communities with the minimum conditions for survival. Weak support from government institutions (Table 5.9) can significantly limit strategies for rural communities to adapt to climate change.

- *Climate factors variability (rainfall, drought and temperature).*

Family farming for subsistence is totally dependent on environmental factors. Any change in these factors will significantly impact the lives of communities that rely entirely on subsistence agriculture. Prolonged droughts and floods cause crops to dry up, wash out and reduce productivity altogether. Farmers' mastery of advance information on natural phenomena related to the behaviour of rainfall and temperatures in their communities is a fundamental instrument in strategies for adapting to climate change. The poor circulation of meteorological information to communities leads to a total lack of knowledge on the part of subsistence farmers about the state of the climate, who are limiting only to their traditional forecasting knowledge acquired throughout their lives. The results presented in Figure 5.30 show the overall average of farmers who received at least some meteorological information through rural institutions support service.

In the region is 66% of subsistence farmers feel that climatic factors are changing, and this is constituting a great difficulty in agricultural production and is constituting a limiting factor in the adaptation of farmers to these new realities. 16% feel that there are no problems and that these factors are not preventing them from adapting and 18% do not know if they are whether climatic factors are limiting their adaptability.

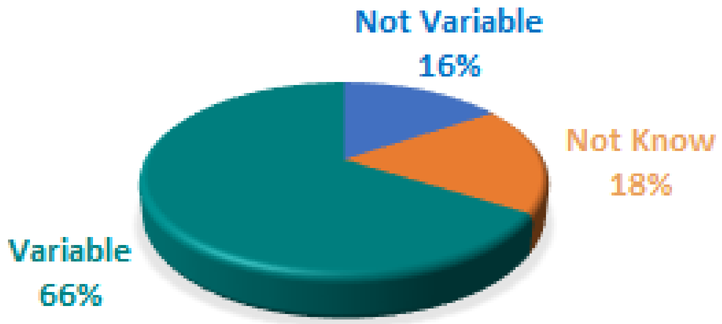

Figure 5. 30 - Overall average of climate factor variability -limiting subsistence farmers in adapting climate change in *Huambo province.*

Subsistence agriculture productivity is totally dependent on natural climate conditions, especially rainfall, both in quality and distribution. Rising temperatures, droughts and floods are also climate factors that directly determine agricultural productivity of livelihoods. Householder farmers in the study region considers that the variability of climatic factors is a limiting factor in adaptability to environmental variations. One response to climate change could be the introduction of small irrigation systems and could be extremely important in the subsistence family farming production system in rural communities in Angola in general and in the province of Huambo in particular. These systems can positively influence adaptability and mitigation to the impact of climate change, increasing crop productivity and family income. However, It is evident that changes in the rainfall regime, increased temperatures and extreme events such as the emergence of prolonged droughts and floods represent one of the greatest risks for food production in rural families (Waha *et al.*, 2013**,** Yaro, 2013) and that even with irrigation systems in place changes in the onset of rainfall altering the normal rainfall pattern may jeopardise these initiatives and seriously affect crop yields. Acceptable technical assistance is going to be required for the effective introduction of local irrigation systems that will -mitigate prolonged droughts.

- Limited availability of access to weather forecasting information

The dissemination of meteorological information is a key element in the effectiveness of rural community adaptability strategies (Sansa-Otim *et al.*, 2022) and is a case in point. The availability of reliable information on weather forecasting, specifically on environmental factors with a direct effect on subsistence agriculture, such as the amount of rainfall, temperatures, onset of rains, seasonal events, can help in the effectiveness of adaptation strategies for householder farming. The dissemination of meteorological information must be done in appropriate language that allows for better understanding acceptance and usefulness to marginalized communities. This information must be linked to the characteristics of climate change in the localities, but which is often a common barrier to the adaptation by subsistence agriculture. There is a real weakness in that weather information does not specifically target vulnerable groups and is often not tailored to meet subsistence farmers' interests in content, providing mostly a probabilistic forecast information rather than a definitive forecast for the region.

The availability and accessibility of meteorological data at all times for subsistence family farmers is a preventive measure to help avoid or minimize the risks caused by climate variability; access to information can create awareness about adaptation and mitigation to climate change (Adenle, Azadi and Arbiol, 2015). Table 5.9 presents results showing the proportion of subsistence farmers who claimed to have had at least some level of meteorological information. For Huambo region 14.6% of subsistence producers claim to have access to meteorological information, 53% said they never had information related to climate data and 32.4% perhaps are not aware of meteorological information.

Table 5.9 shows that the perception of climate change is in accordance with the local context and the traditional knowledge and practices acquired as an inheritance from previous generations. The results demonstrate that for each aspect analysed, most of the availability of information on climate data does not come from specialized institutions with only 14.6% having access to weather forecasting information. The majority of subsistence farmers, which corresponds of 53%, do not have access of weather forecasting information and 32.4% do not know anything about weather forecasting. Mostly they perceive climate change with 51.3% considering that the climate is hotter than in the past while 20.6% say that it is colder and 28.1% consider that it is the same as before, and this is evidenced by the statistical analysis carried out, highlighting that these two aspects in the study carried out are independent, with no apparent direct relationship between them.

Table 5.9 - Householder farmers perception and access of weather information

			Climate			
			Warming	**Cold**	**Remain**	**Total**
Weather Forecasting	**Available**	**Count**	39	13	9	61
		% Within weather forecasting	63.9%	21.3%	14.8%	100%
		% Within climate	18.2%	15.1%	7.7%	14.6%
		% of total	9.4%	3.1%	2.2%	14.6%
	Not Available	**Count**	117	45	59	221
		% Within weather forecasting	52.9%	20.4%	26.7%	100%
		% Within climate	54.7%	52.2%	50.4%	53.0%
		% of total	28.1%	19.8%	14.1%	53.0%
	Do Not Know	**Count**	58	28	49	135
		% Within weather forecasting	43.0%	20.7%	36.3%	100%
		% Within climate	27.1%	32.6%	41.9%	32.4%
		% of total	13.9%	6.7%	11.8%	32.4%
Total		**Count**	214	86	117	417
		% Within weather forecasting	51.3%	20.6%	28.1%	100%
		% Within climate	100%	100%	100%	100%
		% of total	51.3%	20.6%	28.1%	100%

The circulation and availability of detailed meteorological information to all levels of society is essential for understanding the changes taking place in the environment. As explained by Wafula Wamalwa, Mburu and Mang'uriu, (2016) agro-weather information plays and important role in efforts towards adaptation to climate change. Understanding the changes happening in the environment through meteorological information can contribute to the development of sustainable planning strategies that mitigate the impact of changes on subsistence agriculture.

The limited availability of access to meteorological information in rural communities in detail about their areas of residence, contributes to misunderstandings within the community about climate change and the risks to which they are exposed. The availability of meteorological data that reflect the environmental reality in detail allows for better management of natural resources by rural communities who can act to anticipate possible risks. In subsistence agriculture, this information requires an adequate language that is better understood by the community and improves strategies to mitigate the risks they are exposed to.

The dissemination by meteorological institutes of accessible meteorological data as an innovative approach in responding to the challenges of climate change to rural subsistence communities might include the following communication mediums that are easily accessed by rural communities: wall newspapers, murals, projectors, cell phones, local radios, television. Creative and innovative methods for the expansion of metrological data might also include the use of more advanced robust technologies such as information and communication technologies (ICTs) and geographic information systems (GIS).

- *The limited level of education of the farmer*

A key finding of the study is the limited local literacy level (Table 5.10) with 25.2% of subsistence farmers in the study region literate, indicating that 74.8% of subsistence farmers in the study area have limited schooling. Furthermore, for individual older than 51 years, this increases by 86.1%. In general, as age increases the likelihood of having less education can increase. The age group between 18-25 has a higher proportion of educated people compared with other age groups (Figure 5.31, Table 5.10 and Appendix 5.2). These results demonstrate an association between young people being more educated than other groups (significance difference from $X^2_{(2,N=417)} = 15.413$, $p<0.001$ with significance level $P<0.05$ - Appendix 5.13).

Table 5.10 - Overall distribution of literate subsistence farmers demographic groups in Huambo region

			Age Groups			Total
			18-25 Years	26-51 Years	>51 Years	
Education	Be Able to write	Count	17	69	19	105
		% Within Age Group	25,0%	32,5%	13,9%	25,2%
	Not be Able to Write	Count	51	143	118	312
		% Within Age Group	75,0%	67,5%	86,1%	74,8%
Total		Count	68	212	137	417
		% Within Age Group	100,0%	100,0%	100,0%	100,0%

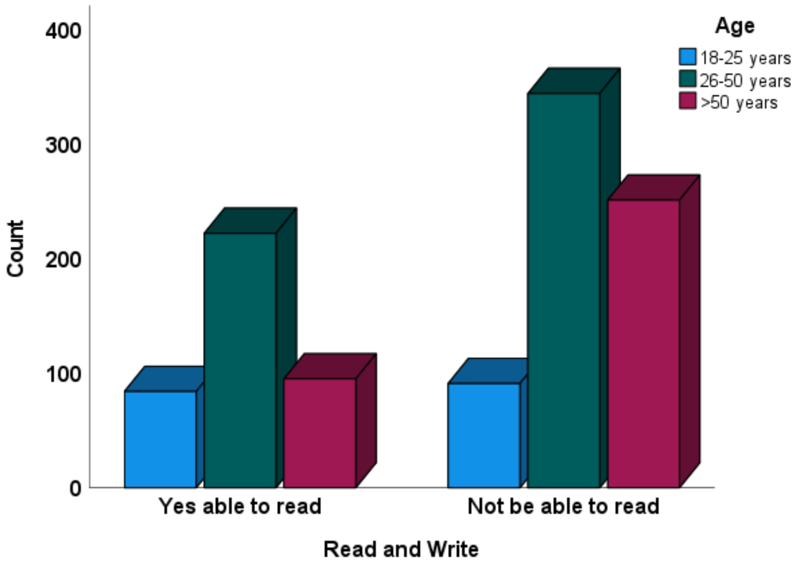

Figure 5.31 - Overall proportion of farmers literate by age groups in Huambo Province

It is clear that the majority of participants who practice subsistence agriculture are illiterate. The limited level of education evident in rural communities perhaps constitutes a challenge for a better understanding of the phenomena of environmental changes that occur in their surroundings in the most scientific way possible. The recognition, acceptance and understanding of these changes within the community can provide the basis for rapid response for communities to adapt to the changes and create effective resilience mechanisms for the new reality imposed by climate change.

Literacy of subsistence farmers can contribute to a better understanding of natural phenomena (Roncoli, Ingram and Kirshen, 2002; Ali, 2021), sustainable soil management and water conservation for family farming and innovation in production techniques that contribute to the resilience of natural resources (Ali, 2021). However, understanding and interpreting the adaptive skills acquired over time by subsistence farmers through their ancestors from generation to generation, associated with the introduction of new technologies in their production process and suitable extension service, can also provide strong mechanisms in the adaptability of subsistence farmers to risks and the dissemination of information about environmental variations in various forms, whether oral, written or printed in catalogues.

Another important observation about the demographic characteristics of family farmers in the study area is the predominance within the age groups from 26 to 50 years a group of younger people less than 35 years old (Appendix 5.2). This indicates that fewer young people work in agriculture and depend on productivity income. This may be due to mediocre access to rural extension services, which contribute to the low knowledge and skill of smallholders in the application of technologies and practices that increase resilience and productivity, considered essential to improve food security, reduction in extreme poverty and increase access to the basic public services. This is perhaps it can be taken as evidence that young people who know how to read tend to migrate to cities in search of new opportunities and to continue studying (Table 5.11) leaving a less literate community skewed towards the over 50s.

These limitations make agriculture unviable for the younger demography and the great social difficulties experienced in rural areas placing many constraints on the adaptability of young people may be due to the existence of few employment opportunities and few schools that can offer a higher-level education. All of this encourages the acceleration of rural young emigration to the cities where more opportunities exist to find work or schools for studying. As argued by Kienzle and Sims, (2014) not all family members are available for farm work. The younger generation is increasingly earning off-farm income to seek a better life, are increasingly migrating from rural areas to urban centres (Figure 5.31).

Raising the educational level of rural subsistence communities would constitute a significant advance in the interpretation and perception of the transfer of new technologies and mitigation of adaptation to current climate changes. Figure 5.32 shows the regional situation 25.5% of small subsistence producers can read and write and the remaining 74.5% constitute the group that are unable to read. In this research, the individual level of education of each interviewee was not evaluated, it was only to verify if it was possible to read or write.

The lack and limitation of the educational level of subsistence farmers can be a limiting factor in the interpretation, and implementation of adaptive strategies. It constitutes a barrier both in the perception of climate information and in the interpretation of strategic implementation plans.

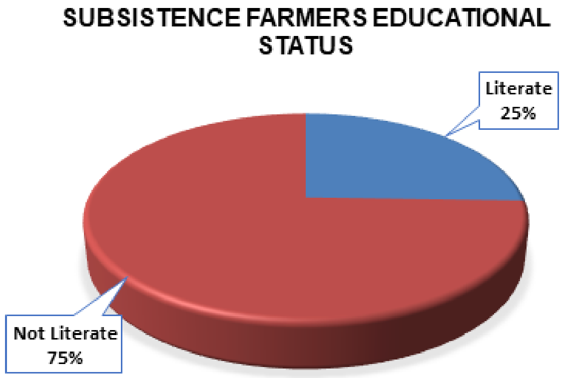

Figure 5 32 - Overall average of the literacy level of subsistence family farmers in the province of Huambo.

• *Soil erosion and fertility depletion*

Soil erosion reduces the long-term productivity of soils. Soil loss negatively affects characteristics associated with crop productivity, including soil water holding capacity, nutrients, organic matter, and soil density. the loss of soil water holding capacity is a primary effect that contributes to lost productivity. Figure 5.33 shows awareness of the overall proportion of soil erosion and fertility depletion in Huambo province, with 59% of respondents saying the soil is not eroded, 21% cannot explain or have no notions of soil erosion and 20% say there is erosion.

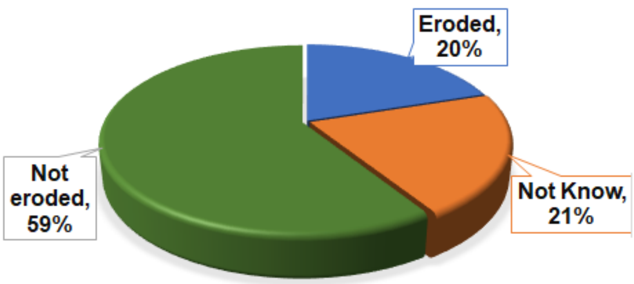

Figure 5.33 - Subsistence farmers awareness of soil erosion and fertility depletion in Huambo province.

Soil erosion and depletion of fertility are serious problems for soil health. The use of agricultural techniques that contribute to erosion control is essential to keep the soil healthy and suitable for agricultural production. Subsistence agriculture has limited resources and poor access to inputs. Land degradation has diminished soil ecosystem services and constrained economic growth for subsistence family farmers and food production, as well as damage to the environment. Although the region's soils are considered susceptible to erosion and inherently poor in nutritional elements for crops it is essential to maintain agricultural practices that contribute to the increase and conservation of essential nutrients for the development of agricultural production. Subsistence farmers often use techniques that reduce soil disturbance due to the use of rudimentary and manual techniques in soil preparation, which allows them to keep the soil less eroded. However, constant use of the same plot of land contributes to the depletion of micronutrients and macronutrients in the soil that reduces soil fertility with soil degradation implying a decline in soil quality with an attendant reduction in ecosystem functions and soil physical and chemical degradation (Lal, 2015).

- Absence of bank credit and householder farmers low financial capacity

Agricultural rural bank credit is considered important to promote technological changes and increase agricultural production that can benefit a large number of subsistence family farmers. The effectiveness of policies for the development of subsistence family farming to adapt to climate change and generating sustainable social, economic and environmental development, may largely depend on government institutions and bank credit. As can be seen from the results (Figure 5.34) from the sites studied, only 3% of subsistence producers claim to have received at least some support from banks and 97% say they have never received financial or input support from banks. These regional percentages are replicated at the local study site scale.

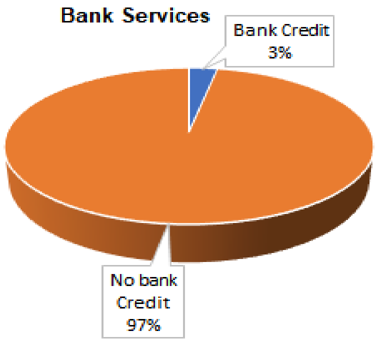

Figure 5.34 - Overall average of bank credit for subsistence farming system in studied site.

In practice, family farmers lack financial support mainly from banks. The creation of policies for the sustainable development of rural communities on the most marginalized fringes of society and dependent on subsistence agriculture requires the promotion of credible programs such as subsidizing the prices of agricultural inputs with public resources and with the participation of banks, this can be a way to manage climate change. Active participation of banks in granting credits for the development of production in rural communities would also help bring stability to these areas. Adaptation to climate change has resulted in renewed incentives for investment in agricultural research and the development of innovation priorities for subsistence family farming in Angola, especially in the marginalized rural subsistence communities of Huambo.

5.3.10 Impact of climate change on social repercussions on subsistence family farming.

The impact of climate change that is happening in the region may cause serious health problems in rural communities and subsistence producers. The emergence of diseases linked to poor sanitation and the consumption of non-drinking water have been the main sources of contamination, associated with changes in the environment. Changes in temperature and precipitation patterns have also had direct and indirect effects on human health. Interviews with traditional authorities asked the question "*which diseases most affect the population of the village?*" In all the places studied, the arguments were similar citing how the main disease is malaria (local name paludism) most affecting communities, followed by diarrhoea usually due to low or even lack of basic sanitation in the community (Figure 5.35), inadequate water consumption for human health, and respiratory diseases where many populations are affected and feel shortness of breath (diseases respiratory). Included in the list is malnutrition in children, directly linked to the productivity - success or failure - of crops.

Climate change contributing to increases in the intensity of heat waves has been associated with the increase of diseases, particularly respiratory, in rural populations who live in miserable conditions, without access to an adequate health system and an inability to prevent the spreading diseases. The increase in heat waves contributes to the decomposition of many food products, which are mostly kept outdoors due to the lack of refrigeration conditions. The rise in temperature favours the emergence and increase of some vectors and microbes responsible for a range of diseases that affect subsistence family farmers and contribute to the increase in the effects of malaria. The increase in the intensity of the rains, more than usual creates problems in increasing the population of mosquitoes that transmit malaria due to the appearance of a lot of stagnant water left by floods and heavy rains.

Subsistence farmers also claimed that a few years ago, in addition to diarrheal and respiratory diseases, there were outbreaks of cholera. However, they considered cholera to be seasonal effects caused by water quality, precipitation and temperature.

Figure 5.35 - Village with different householder houses.

The terrible housing conditions experienced by many subsistence producers at risk to climate change is contributing to the degradation of the social situation of life in rural communities. A deficit of public health institutions and infrastructure around villages, lack of public and domestic electricity, the low education levels for householder farmers and reduced crop productivity are all negatively contributing to the poor well-being of subsistence farmers. Environmental changes during prolonged droughts or floods contribute to increased food and water shortage thus food insecurity, with increased malnutrition and human health weaknesses with reduced human immune system against infections and diseases are exacerbating these conditions and limiting the scope for effective responses to climate change.

5.4 Chapter Conclusion

Agriculture is especially vulnerable to climate change as it relies on climatic conditions for its productivity and in Angola family subsistence farming is particularly dependent on water resources. Any change to water availability poses productivity vulnerability and risk to these farmers and will be accentuated by poor adaptability to adverse changes resulting from environmental change.

The impact of climate change on the quantity and quality of rainfall is now causing losses in subsistence agriculture in many regions of Angola. Limited soil water holding capacity and the resulting soil moisture deficiency and water scarcity for plants are one of the main factors contributing to reduced agricultural productivity in subsistence farming in Angola and Huambo in particular. The fundamental question considered in this chapter is whether there is scope to ameliorate the effects of changing precipitation patterns (evidenced in chapter 3) and low soil water holding capacities (evidenced in chapter 4) through enhanced or different approaches to agricultural land management. The evidence from this chapter suggests that there is, given current land management, but that there is much work to achieve this and that it must involve researchers, agricultural technologies and innovation, with agricultural extension workers playing a core role in giving opportunities to subsistence family producers to address the major challenges of climate change.

The climate, more specifically the wet and dry season sequence or the distribution pattern of rainfall during the year, is the key factor for adapting management techniques to local conditions. The duration and the number of dry seasons determine whether one or more cropping cycles will be possible annually and if irrigation should be considered.

New technologies including new crop varieties, fertilizer application and expansion in agriculture of various types of irrigation systems can contribute to a rapid increase in agricultural productivity around the subsistence farming system by providing excellent management of natural resources including water for agriculture, soil erosion control and the development of the rural environment. Efforts should be directed towards improving integrated land management and soil organic matter status through practices such as: Planting cover crops, agricultural waste management, application of organic fertilizer, introducing techniques to make organic compost from local material such as plant residues, application of manures to significantly help improve soil fertility and prevention of indiscriminate fires. Adopting these practices will not only improve the chemical and physical properties of soils, but also improve microbial activities, and crop productivity.

Soil conservation in an integrated way can be a sustainable agricultural production system for subsistence family farming, both for socioeconomic and environmental development. However, it is important to consider soil conservation intervention as fundamental for soil water holding capacity, moisture content and for the reduction of soil degradation. The direct involvement of agricultural extension workers and local communities with interventions, explaining cause and effect on soil degradation, water conservation and soil water holding capacity should be addressed with more participatory and integrated conservation approaches to natural resources, discussed together with rural subsistence communities as part of the process.

The incorporation and integration of crop residues and plant residues into the soil that are often considered unusable residues in terms of their economic importance, constitutes a fundamental tool for mitigation and resilience in the conservation of the physical characteristics of the soil. They provide elemental carbon in the soil and offer a variety of mechanisms for recycling nutrients in the soil. Crop residue management helps maintain soil moisture content, protecting the soil surface and increasing irrigation efficiency and increasing the soil's ability to hold water.

To mitigate and build sustainable resilience for subsistence family farmers, government institutions and banks should create policies to subsidize agricultural inputs specifically for subsistence agriculture through public funds to reduce the prices of inputs and services through agricultural subsidies. It is an effective climate change adaptation tool, and when well-targeted and implemented, it can bring about economic, social and environmental changes in rural subsistence communities. In this way, subsidies could function as a transfer of social security to rural subsistence communities, serving as a policy instrument for agricultural transformation and adaptation to current climatic conditions.

Subsistence family farming is an important food production sector for marginalized communities, which directly depends on family labour to produce food for their families and beyond. However, in terms of strengths, weaknesses, opportunities and threats Political and institutional changes are imperative if subsistence agricultural innovation systems are to be seriously thought of as the main means of producing enough food and face climate change in subsistence family farming. However, future studies should investigate "**how policy measures, as well as technological innovations, can affect subsistence farmers to mitigate and adapt to climate change**". All of this will help to understand more clearly the relationships between subsistence farming policies and practices that are necessary for the future development of mitigation and adaptation strategies to deal with the impacts of climate change in the subsistence family farming sector.

It is evident that the social conditions observed in the four study locations that the rural subsistence communities dependent on subsistence agriculture and require a lot of support and attention. Because the health conditions of the populations are directly related to the precariousness of basic sanitation and consequent environmental degradation, it is necessary to make municipal managers aware of effective actions for sanitary improvements that ensure sustainability in the supply of water compatible with quality for health protection. Water also neds to be in sufficient quantity for agriculture, especially vulnerable to climate change as it relies on climatic conditions for its productivity, and in Angola family subsistence farming is particularly dependent on water resources. Any change to water availability poses productivity vulnerability and risk to these farmers and will be accentuated by poor adaptability to adverse changes resulting from environmental change.

The impact of climate change on the quantity and quality of rainfall is now causing losses in subsistence agriculture in many regions of Angola. Limited soil water holding capacity and the resulting soil moisture deficiency and water scarcity for plants are one of the main factors contributing to reduced agricultural productivity in subsistence farming in Angola and Huambo in particular. The fundamental question considered in this chapter is whether there is scope to ameliorate the effects of changing precipitation patterns (evidenced in chapter 3) and low soil water holding capacities (evidenced in chapter 4) through enhanced or different approaches to agricultural land management.

The questionnaire indicates that many subsistence farmers in Huambo Province are aware of the changing climate conditions and the effect it is having on their livelihood. There is a recognition that change in practice is needed and so in this cohort at least, there is a willingness to adopt new approaches. For the significant minority not recognising or acknowledging climate change, outreach is needed to help all in the community understand the nature of climate change and its potential impact. A focused role for the extension services is needed here as a way of enhancing land management to give resilience to climate change impacts.

It is evident too that while there is much evidence of good general land management practice in the region including good ground preparation, cover cropping, double cropping, composting, fire reduction, erosion control. These good practices, while not an explicit adaptation to climate change, enhance the prospect of good productivity even under conditions of changing rainfall patterns. The questionnaire survey does however indicate that particular attention should be given to integrated soil conservation practices and the use of organic residues.

Soil conservation in an integrated way can contribute to a sustainable agricultural production system for subsistence family farming, both for socioeconomic and environmental development. It is important to consider the soil conservation intervention as fundamental for soil water holding capacity, moisture content as well as for the reduction of soil degradation. The direct involvement of agricultural extension workers and local communities with interventions explaining cause and effect on soil degradation, water conservation and soil water holding capacity should be addressed with more participatory and integrated conservation approaches of natural resources, discussed together with rural subsistence communities as part of the process.

Furthermore, the incorporation and integration of crop residues and plant residues into the soil, which is often considered unusable residues in terms of their economic importance, is a fundamental tool for mitigation and resilience in the conservation of the physical characteristics of the soil. These residues provide organic matter to the soil and offer a variety of mechanisms for recycling nutrients in the soil. Crop residue management helps maintain soil moisture content, protecting the soil surface and increasing irrigation efficiency and increasing the soil's ability to hold water.

Irrigation is one of the most important adaptation measures in response to climate change. The introduction of small-scale irrigation systems can be a powerful adaptive measure in subsistence family farming due to the availability of adequately supplying water to crops. In addition, irrigation can generate several benefits, mainly in terms of efficiency in water use, low cost and increase in crop yields and greater influence on the management of water resources and stimulates economic and social growth in the development of rural communities.

There is however a significant minority of farms evidenced in the questionnaire where land management is poor with limited or no understanding of effective land management practices and so increases the land degradation that accentuates the impact of climate change. Here again, a focused land management advisory role for the extension services would reduce vulnerability to climate change in the region.

Enhancement of good, general land management practices would be supported by new technologies including new crop varieties, fertilizer application and expansion in agriculture of various types of irrigation systems can be contributed to the rapid increase in agricultural productivity around the subsistence farming system. To help with the introduction of new technologies to mitigate and build sustainable resilience for subsistence family farmers, government institutions and banks should create and implement policies to subsidize agricultural inputs specifically for subsistence agriculture through public funds, reducing the prices of inputs and services through subsidies. This type of approach is explicitly highlighted as lacking in the questionnaire survey. It can be an effective climate change adaptation tool when well-targeted and implemented.

Subsistence family farming is an important food production sector for marginalized communities, which directly depends on family labour to produce food for their families and beyond. However, in terms of strengths, weaknesses, opportunities and threats it is explicitly evident in the questionnaire survey that political, financial and institutional changes are imperative if subsistence agricultural innovation systems are to be seriously thought of as the main tool to produce enough food and face climate change in subsistence family farming. Future studies should investigate “how policy measures, as well as technological innovations, can help subsistence farmers mitigate and adapt to climate change”. All of this will help to understand more clearly the relationships between subsistence farming policies and practices that are necessary for the future development of mitigation and adaptation strategies to deal with the impacts of climate change in the subsistence family farming sector.

It is also emerging from the questionnaire evidence that the social conditions observed in the four locations under study require a lot of attention. The health conditions of the populations are directly related to the precariousness of basic sanitation, the ability to work the land and the often-consequent environmental degradation. It is necessary to make municipal managers aware of effective actions for sanitary improvements that ensure sustainability in the supply of water-compatible with quality for health protection and in sufficient quantity to guarantee basic conditions of comfort. The level of education and health knowledge of the exposed population is also important, as all the diseases that most affect the community are related to basic sanitation.

6. Key findings: Assessing climate change and its mitigation, Huambo province Angola.

Agriculture is significantly influenced by climate change, and this has already had direct effects on agricultural production in Angola and the broader Southern Africa region (Adenle, Azadi and Arbiol, 2015). Subsistence family farming is very sensitive to climatic and environmental conditions and is especially dependent on regularity in rainfall. Variability in agricultural soil properties - particularly texture - influences soil water holding capacities and the proportion of rainfall water that can be held for crops. Sustainable land management and changes in agricultural practices in the subsistence farming community play a decisive role in mitigating and adapting to these factors but they require learning and knowledge input to avoid accentuating the risks and damage caused by the impact of climate change (Thorlakson and Neufeldt, 2012).

The research presented in this thesis has adopted a local-based approach to assessing climate change and whether it can be mitigated by the inherent nature of soil properties and by farmer adaptation (figure 6.1). This approach has highlighted the nature of local data sets - climate, soils and social - their limitations as well as the advantages they offer. Identification and exploration of local data sets should be further encouraged. They bring a local nuancing to the more general regional climate change analyses more normally undertaken; furthermore, they bring a relevance to local communities as they bring information that can be presented from places that are known and recognised.

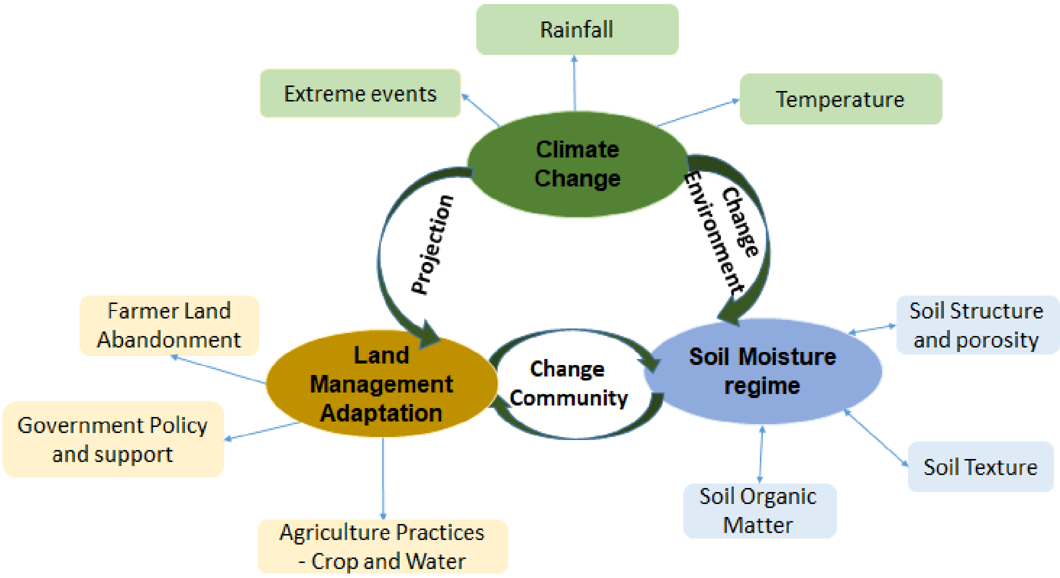

Figure 6.1: Interlinking factors influencing subsistence agriculture productivities: Climate parameters, soil water holding capacities and land management

Climate change: Climate change is now a limiting factor in the production process of subsistence family farming - dependent on rain-fed agriculture - in the province of Huambo. The analyses presented in chapter 3 were based on quantitative historical meteorological data which enabled an assessment of climate variability as a way of considering climate change in relation to subsistence agricultural activity. The analyses indicate that the farmers in Huambo Province, Angola, are facing major climate change parameters within this century. This continues a trend of change that stretches back to at least 1960, which show decreasing rainfall and increasing temperatures in the region and has contributed to the scarcity of water for crops that depend entirely on rainfall. Of particular significance is the decline in rainfall and the contraction of, and variability within, the rainy season, which has influenced sowing and crop development timings and brings major challenges for subsistence agriculture to ensure crop production and productivity.

Soil water holding capacity: Subsistence family farming systems in Huambo province currently suffer from several interconnected stressors, in addition to climate change and climate variability and further accentuating climate change effects. Slope and soil characteristics accentuate precipitation effects. The variability in the distribution of morphological and physical properties of the Huambo soil is influenced by the topography of the profile's landscape features and varies from upper to lower slope positions. The topography of the landscape influences the movement of water across the landscape with the valleys accumulating more water with the upper and middle slopes losing water (Chapter 4).

The physical soil characteristics of the soils of Huambo further compound the reduction and variability in rainfall issue facing subsistence farmers. With a higher prevalence of the textural class of silt loam soils that have a predominantly granular structure and high frequencies of composite void porosity together with a low content of OM found are factors that contribute to soils having a low soil moisture and water holding capacity. Rainfall readily drains from these soils although in some sloped areas water may accumulate in valley bottoms for longer periods during the rainy season (Chapter 4).

These physical conditions, despite the fact that the soils are favourable to the practice of agriculture, require greater care in their management to ensure sustainable management of soil water holding capacity and moisture content, not least because there has been significant loss of productive soil quality due to soil erosion. It is evident that most soils in the studied region have very little ability to retain (store) water in the soil for a long period, which would otherwise prolong water availability in the dry season and maintain soil with a level of moisture that allows the production of certain crops. In addition, vulnerability to limited soil water is exacerbated for many subsistence family farmers and rural extension institutions due to the precariousness of the services provided and that do not contribute to the search for locally sustainable solutions such as the practice of innovative techniques in the management to increase the capacity of water retention water in soils.

Recent historical rainfall patterns indicate decreases in the region, including the annual total. Furthermore, the irregularities observed in the annual distribution of precipitation contributes to the reduction of soil moisture content affecting the beginning of the rainy season, which is now having disastrous effects on food production in rural communities that depend only on the rains to moisten their crops,

Land Management. The majority of subsistence farmers are aware of changes in climate, especially unpredictable rainfall rates and extreme temperatures, and the effect it is having on their systems of production and livelihoods. There is however no strong indication that subsistence farmers have introduced new land management practices to mitigate climate change effects. However, there is a recognition that good farming practices, appropriate under any circumstances, will go some way to offsetting the effects climate change and limited water holding capacities may have on production. There is also a substantial minority of subsistence farmers who are not aware of climate change, and a related set of farms where land management is poor and has led or is leading to degradation.

Adaptation and mitigation capacity is more evident in the subsistence producers of Bailundo and Ngongoinga in terms of socioeconomic development and in the diversification of crops and introduction of new cultivars. In the case of Mungo and Longonjo there is less evidence of adaptation; this presents greater difficulties with a reduced level of crop diversification. In such areas, poverty, vulnerability and food insecurity are high, and the direct impacts of climate change are particularly evident.

It is these farms where the greatest impact of climate change will be felt and where greater support form external agencies will be required (Chapter 5).

Support needed from external agencies: Virtually all farmers recognised the need for external support to sustain themselves in a climate changed future (Chapter 5). Interventions from external agencies to help subsistence farmers include a key role for weather forecasting. Similarly, mitigating the impacts of climate change in the rural community is a challenge for researchers, academics, extension workers and government departments. An interdisciplinary, inter-organisation and inter-sector vision is needed, contributing to the understanding of the effects of climate-related risks in complex systems of householder farming. This is needed to identify and implement adaptive strategic policies through the introduction of new approaches that contribute to the sustainable management of subsistence family farming and natural resources in a climate changed future.

The availability of agro-meteorological information is essential for the prediction of climate impact, thus constituting a fundamental tool for the adaptation and planning of future agricultural production practices for subsistence householder farming that adapt to the new climatic realities. This will help with sustainable management of the land, improving soil water holding capacity and soil moisture content that contributes to the maintenance of crop productivity. The weather forecasting institute INMATE (National Institute of Meteorological and geophysics of Angola) could be a fundamental partnership between scientists and farmers and provide timely suitable information for weather conditions, help prevent risks associated with weather disasters and help guide farm management activities. Dissemination of information might include information boards to show to the local community how climate may change, as well as provide up-to-date and real-time information. This approach could also be used in future research to explain the nature of climate change, give scenarios and ask the farmers what this would mean for their farming practice and what they would do to adapt, i.e., as an extension of the questionnaire used in this thesis.

The introduction of small-scale irrigation systems is a second way in which external agencies could support subsistence farmers prepare for climate change futures and hold as much water as possible for crop production. In the dry season, rural communities of subsistence agriculture can introduce innovative techniques, whether individual or collective, such as the construction of small reservoirs, ponds and dams to retain water for periods extending beyond the rainy season, allowing rainwater to accumulate longer or introducing small-scale irrigation systems where there is already enough water. This would significantly contribute to mitigating the vulnerability of communities to precipitation changes and could significantly increase agricultural productivity.

The application of these techniques to mitigate vulnerability could serve as a broad land and water management model and be part of rural extension programs that can be applied at national and regional levels where rainfall conditions require greater attention and where there are soils prone to erosion and low retention capacity of soil water. The incorporation of these techniques into national rural extension programs with the involvement of subsistence family farmers and all members of rural communities will contribute to greater subsistence agricultural productivity and socio-economic development and the well-being of communities and sustainable management of natural resources.

However, in an adaptive process in subsistence family farming, it is important to ensure that good farming practice is maintained and that there is availability of family farm labour throughout the farming season. This should include crop diversification, the use of technologies (new seed variety, building training farmers school, introduction of motorcycle cultivators) for sustainable agricultural practices in maintaining soil moisture, taking advantage of biodiversity in cultivated crops and the incorporation of plant residues into the soil. Increasing the use of mixed crops in subsistence agriculture with greater integration of livestock into agricultural systems is an effective form of soil management in the incorporation of organic matter in the soil that contributes to the improvement of the physical characteristics of the soil. Likewise, the introduction of technologies that humanize agricultural work is also of great importance, in terms of labour per hectare, from the diversification of livelihoods. Family farmers can benefit from discussions between extension services and key farmers, where key farmers are trained in appropriate agricultural practices aimed at improving the management of their local natural resources, acquiring knowledge and improving adaptability. Of particular importance is giving the scope for experimenting with new techniques or technologies before implementing them on individual farms.

Systematic feedback processes are then needed that can assess the effectiveness of interventions. These will further build resilience to climate change, show the potential to increase the buffering capacity of subsistence farmers and family farming systems and enhance their capacities and improve their ability to cope, survival, learn and adapt iteratively. These feedback processes can also serve as a model or guide for the transfer of knowledge to subsistence farmers and show how development partners, government agencies, researchers and universities, rural extension sector operators, non-governmental organizations and rural communities can build the resilience of subsistence farming systems.

This study is the first to attempt a comprehensive local-scale integration of climate, soils and social data sets to identify and explain the issues facing subsistence farmers in a climate changed future. This offers a much more nuanced evidence base, giving robust foundations on which to base mitigation and adaption measures appropriate to immediate localities; in this study of Huambo province, it is precipitation changes and water availability for agriculture that is the focus. This local data-base approach needs to be expanded to other areas of Southern Africa to assist with adaptation to the new climate realities.

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Appendix

Appendix 3.1- Climate Data 1965 – colonial era

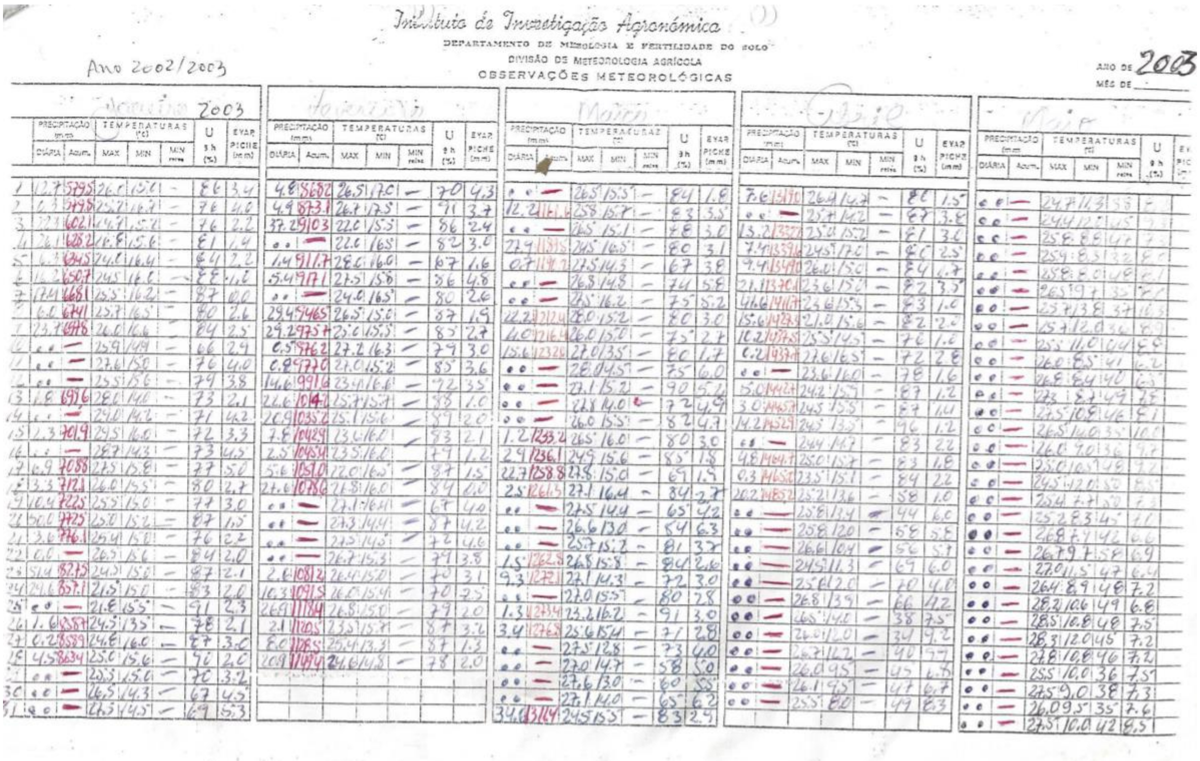
C. E. SACAÁLA

1965

PRECIPITAÇÃO

	J	F	M	A	M	J	J	A	S	O	N	D
1	19,2	. .	. .	5,7	. .	. .	. .	. .	. .	. .	. .	1.5
2	12,2	10,7	33,0	. .	. .	. .	. .	. .	. .	1,0	. .	. .
3	. .	. .	0,5	14,1	. .	. .	. .	. .	. .	1,0	. .	2.2
4	7,7	9,3	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
5	5.5	6.9	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
6	1.2	12,2	13,0	7,4	. .	0,0	. .	. .	. .	5.3	. .	13,1
7	. .	. .	14,0	. .	. .	. .	. .	. .	. .	8.5	72	. .
8	. .	. .	12,0	. .	. .	. .	. .	. .	4.2	. .	. .	. .
9	. .	. .	16,5	. .	. .	. .	. .	. .	. .	. .	. .	. .
10	. .	2,9	7,1	. .	. .	. .	. .	. .	. .	. .	4.8	. .
	45,8	72,0	96,1	27,2	0,0	0,0	0,0	0,0	4,2	15,8	12,0	16,8
11	. .	5.3	7.8	. .	. .	. .	. .	. .	. .	. .	14,6	11.5
12	. .	5,4	12,3	. .	. .	. .	. .	. .	. .	. .	. .	. .
13	. .	6.3	9.2	5.7	. .	. .	. .	. .	. .	26.8	8.8	8,0
14	1,5	. .	7,0	. .	. .	. .	. .	. .	. .		. .	10,2
15	12,0	. .	2,1	1,8	. .	. .	. .	. .	. .		1.8	11.8
16	27,8	9.3	. .	. .	. .	. .	. .	. .	. .	3.5	1.5	2,0
17	30,2	4,0	. .	. .	. .	. .	. .	. .	. .	. .	2.8	4,0
18	12,3	10,5	. .	12,5	. .	. .	. .	. .	. .	3,0	47,3	. .
19	13,0	14,0	1,0	6,8	. .	. .	. .	. .	. .	4,2	13,8	. .
20	. .	14,0	. .	. .	. .	. .	. .	. .	. .		4.5	1,4
	96,8	68,8	39,4	26,8	0,0	0,0	0,0	0,0	0.0	37,5	95,1	48,9
21	. .	31,0	1,7	. .	. .	. .	. .	. .	9,8		3.5	6,7
22	. .	22,6	0,6	2,4	. .	. .	. .	. .	. .		. .	. .
23	. .	6.5	. .	43,2	. .	. .	. .	. .	1,0		29,0	. .
24	14,0	5,0	9,8	. .	. .	. .	. .	. .	. .		8.2	. .
25	18,0	6,5	35,0	. .	. .	. .	. .	. .	. .		7.2	. .
26	44,4	6.2	5,1	. .	. .	. .	. .	. .	. .		7,0	[redacted]
27	20,7	5,4	19,3	. .	. .	. .	. .	. .	. .	2,8	13,0	10,8
28	6.2	50.4	0,5	. .	. .	. .	. .	. .	. .	. .	20,0	. .
29	7,4		. .	. .	. .	. .	. .	. .	9,0	5,7	5,7	. .
30	35,6		. .	. .	. .	. .	. .	. .	. .	. .	7,5	. .
31	. .		29,4							. .		21,3
	146,3	133,6	101,4	45,6	0,0	0,0	0,0	0,0	19,8	8,5	101,1	38,8
	288,9	274,4	236,9	99,6	0,0	0,0	0,0	0,0	24,0	61,8	208,2	104,5

Appendix 3.2- Climate Data – post colonial era



Appendix 4.1- Soil sampling coordinates

Locality	Altitude (m)	Latitude (E)	Longitude (S)	Catena profile
Mungo	1569.1	11.83472	16.23639	Upper profile
	1557.2	12.09167	16.23806	Middle profile
	1551.1	12.08000	16.24139	Lower profile
Bailundo	1551.1	12.28000	15.99889	Upper profile
	1533.1	12.27444	16.02639	Middle profile
	1518.2	12.27306	16.03556	Lower profile
Ngongoinga	1660.2	12.90472	15.73750	Upper profile
	1657.2	12.89694	15.73444	Middle profile
	1656.3	12.89611	15.74056	Lower profile
Longonjo	1642.3	12.93917	15.61361	Upper profile
	1627.9	12.95444	15.60806	Middle profile
	1607.8	12.95806	15.59861	Lower profile

Appendix 4.2- Field visual observation and morphological characteristics of soil in Huambo province

Locality	Catena profile	Depth (cm)	Horizon	colour cod charts		Texture	Structure
Mungo	Upper profile	30	A	5R 6/4	Pale red	ZC	Granular with compound packing voids
		60	B	5R 4/8	Red	ZSC	
		90	B1	5R 5/6	Red	ZSC	
	Middle profile	30	A	5R 4/4	Weak red	ZSC	Granular with compound packing voids
		60	B	5R 4/4	Weak red	ZSC	
		90	B1	5R 3/4	Darky red	SC	
	Lower profile	30	A	5R 4/1	Dark reddish gray	ZSC	Chamber with voids dominated by chambers
		60	B	5R 3/1	Dark reddish gray	ZSC	
		90	B1	5R 5/1	Reddish gray	ZSC	
Bailundo	Upper profile	30	A	10YR 4/1	Dark gray	ZSC	Granular with compound packing voids
		60	B	10YR 4/3	Bown	SZC	
		90	B1	10YR 6/6	Browish yellow	SZC	
	Middle profile	30	A	10YR 5/4	Yellowish brown	SZC	Granular with compound packing voids
		60	B	10YR 7/8	Yellow	SZC	
		90	B1	10YR 7/6	Yellow	ZSC	
	Lower profile	30	A	2.5Y 4/1	Dark gray	ZSC	Chamber with voids dominated by chambers
		60	B	2.5Y 5/2	Grayish brown	ZSC	
		90	B1	2.5Y 6/3	Light yellowish brown	ZSC	
Ngongoinga	Upper profile	30	A	2.5Y 6/6	Olive yellow	ZSC	Granular with compound packing voids
		60	B	2.5Y 6/8	Olive yellow	ZSC	
		90	B1	2.5Y 8/6	Yellow	ZSC	
	Middle profile	30	A	10YR 5/6	Yellow brown	ZCS	Chamber with voids dominated by chambers
		60	B	10YR 6/8	Brownish yellow	ZCS	
		90	B1	10YR 6/8	Brownish yellow	ZC	
	Lower profile	30	A	10YR 6/4	Light yellow Brown	ZCS	Granular with compound packimg voids
		60	B	10YR 6/6	Brwnish yellow	ZC	
		90	B1	10YR 6/8	Brownish yellow	ZC	
Longonjo	Upper profile	30	A	7.5R 4/3	Weak red	ZC	Granular with compound packing voids
		60	B	7.5R 4/6	Red	ZC	
		90	B1	7.5R 4/6	Red	ZC	
	Middle profile	30	A	5R 3/2	Dusky red	ZCS	Granular with compound packing voids
		60	B	5R 4/4	Weak red	ZC	
		90	B1	5R 3/6	Dark red	ZC	
	Lower profile	30	A	5R 5/2	Weak red	ZCS	Chamber with voids dominated by chambers
		60	B	5R 6/2	Pale red	ZCS	
		90	B1				

Appendix 4.3- Soil profile of a transect on the steep cultivated hillslope showing changes in water holding capacity by volume and soil moisture content in catena sampling points

Catena part	Depth (cm)	Horizons	OM %	BD (g /cm³)	SMC %	SWHC %
			Mungo			
	30	A	2.1	1.46	9.2	65.0
	60	B	2.3	1.43	8.5	65.0
Upper part	90	B1	2.1	1.15	9.5	67.5
	Mean		**2.20**	**1.35**	**9.05**	**65.83**
	Std		**0.10**	**0.14**	**0.41**	**1.18**
	30	A	2.0	1.14	8.0	70.0
	60	B	1.9	1.17	12.6	65.0
Middle part	90	B1	2.0	1.07	15.8	60.0
	Mean		**1.97**	**1.13**	**12.13**	**65.00**
	Std		**0.03**	**0.04**	**3.17**	**4.08**
	30	A	2.0	1.43	13.1	65.0
	60	B	1.9	1.43	16.7	77.5
Lower part	90	B1	1.9	1.46	9.4	70.0
	Mean		**1.94**	**1.44**	**13.07**	**70.83**
	Std		**0.02**	**0.01**	**2.97**	**5.14**
			Bailundo			
	30	A	1.8	1.96	0.5	50.0
	60	B	1.8	1.64	6.0	52.5
Upper part	90	B1	1.8	1.70	7.8	50.0
	Mean		**1.82**	**1.77**	**4.76**	**50.83**
	Std		**0.01**	**0.14**	**3.11**	**1.18**
	30	A	1.8	1.17	1.3	37.5
	60	B	1.9	1.34	4.7	27.5
Middle part	90	B1	1.9	1.17	3.1	52.5
	Mean		**1.85**	**1.23**	**3.04**	**39.17**
	Std		**0.00**	**0.08**	**1.38**	**10.27**
	30	A	1.8	1.17	8.6	65.0
	60	B	1.9	1.20	2.9	57.5
Lower part	90	B1	1.9	1.17	3.4	50.0
	Mean		**1.86**	**1.18**	**4.96**	**57.50**
	Std		**0.03**	**0.01**	**2.59**	**6.12**

(WHC = Soil water holding capacity, SMC=Soil moisture content BD = Bulk density, OM = Organic matter and StD = standard deviation).

Appendix 4.4- Soil profile of a transect on the steep cultivated hillslope showing changes in water holding capacity by volume and soil moisture content in catena sampling points. (Continuation)

Catena part	Depth (cm)	Horizons	OM	BD (g/cm^3)	SMC %	SWHC %
			Ngongoinga			
Upper part	30	A	1.8	1.30	3.8	72.5
	60	B	1.8	1.35	8.6	75.0
	90	B1	1.8	1.33	6.9	75.0
	Mean		**1.83**	**1.33**	**6.41**	**74.17**
	Std		**0.01**	**0.02**	**2.00**	**1.18**
Middle part	30	A	1.8	1.69	3.4	55.0
	60	B	1.9	1.48	9.4	50.0
	90	B1	1.9	1.46	7.4	52.5
	Mean		**1.86**	**1.54**	**6.75**	**52.50**
	Std		**0.03**	**0.10**	**2.47**	**2.04**
Lower part	30	A	1.8	1.07	1.9	55.0
	60	B	1.9	1.17	8.6	55.0
	90	B1	1.9	1.14	11.3	50.0
	Mean		**1.9**	**1.13**	**7.3**	**53.3**
	Std		**0.0**	**0.04**	**3.9**	**2.4**
			Longonjo			
Upper part	30	A	1.8	1.33	8.4	75.0
	60	B	1.8	1.43	10.2	52.5
	90	B1	1.9	1.38	10.9	70.0
	Mean		**1.85**	**1.38**	**9.81**	**65.83**
	Std		**0.02**	**0.04**	**1.04**	**9.65**
Middle part	30	A	1.9	1.43	5.7	52.5
	60	B	1.9	1.46	6.5	70.0
	90	B1	1.9	1.43	6.8	52.5
	Mean		**1.87**	**1.44**	**6.33**	**58.33**
	Std		**0.02**	**0.01**	**0.46**	**8.25**
Lower part	30	A	2.0	1.66	4.0	50.0
	60	B	1.9	1.69	4.2	40.0
	90	B1	-	-	-	-
	Mean		**1.94**	**1.68**	**4.09**	**45.00**
	Std		**0.06**	**0.02**	**0.11**	**5.00**

(SWHC = Soil water holding capacity, SMC=Soil moisture content BD = Bulk density, OM = Organic matter and StD = standard deviation).

Appendix 4.5 Analise of variance of soil Water holding capacity (%) by catena

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Between Groups	2	662.473	331.236	2.673	0.084
Within Groups	32	3966.098	123.941		
Total	34	4628.571			

Appendix 4.6- Analise of variance of soil Water holding capacity (%) by locality

	DF	Sum Sq	Mean Sq	F Value	Pr(>F)
Between locality	3	1492.547	497.516	4.918	0.007
Within Locality	31	3136.024	101.162		
Total	34	4628.571			

Appendix 4. 7- Multiple comparison of the Effect of Horizons on Soil Water Holding Capacity (%)

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Horizons	2	32.532	16.266	0.125	0.883
Locality	3	1488.747	496.249	3.811	0.024 *
Horizons*Locality	6	111.574	18.596	0.143	0.989
Error	23	2994.792	130.208		

a. R Squared = 0.353 (Adjusted R Squared = 0.044)

Appendix 4.8- Analyses of variance of the effects of catena on SWHC by locality

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Catena	2	689.824	344.912	7.000	0.004**
Locality	3	1521.348	507.116	10.291	0.001***
Catena-Locality	6	1338.866	223.144	4.529	0.004**
Error	23	1133.333	49.275		

a. R Squared = 0.755 (Adjusted R Squared = .638)

Appendix 4.9- Multiple comparison of Soil Moisture Content (%) variability by catena-locality

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Catena	2	1.214	0.607	0.072	0.930
Locality	3	240.838	80.279	9.576	0.001*
Catena-Locality	6	74.327	12.388	1.478	0.230
Error	23	192.816	8.383		

a. R Squared = .620 (Adjusted R Squared = 0.439)

Appendix 4.10- *Multiple comparison of Soil Moisture Content (%) interaction locality horizons*

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Locality	2	237.727	79.242	9.927	0.001*
Horizons	2	55.330	27.665	3.466	0.048*
Locality-Horizons	4	31.246	5.208	0.652	0.652
Error	26	183.595	7.982		

a. R Squared = 0.638 (Adjusted R Squared = 0.465)

Appendix 4.11- *Analise of variance of soil moisture content (%) by catena*

	DF	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Between Groups	2	2.159	1.080	0.068	0.934
Within Groups	32	505.519	15.797		
Total	34	507.679			

Appendix 4.12- Analise of variance of the effect of horizons on Soil moisture content

	DF	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Between Group	2	54.850	27.425	1.938	0.161
Within Group	32	452.829	14.151		
Total	34	507.679			

Appendix 4.13- Analysing multiple comparison of Soil Moisture Content (%) variability by horizons-cate*na*

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Horizons	2	54.057	27.028	1.593	0.223
Catena	2	2.336	1.168	0.069	0. 934
Horizons-Catena	4	8.987	2.247	0.132	0. 969
Error	26	441.146	16.967		

a. R Squared = 0.131 (Adjusted R Squared = -0.136)

Appendix 4.14- Distribution of the proportion of soil particle size of the catena toposequence at the study site, Huambo province, Angola

Catena part	Horizons	Depth (cm)	Proportion of soil particle %			Ratio	Textural Class
			Clay	Silt	Sand	Silt/Clay	
Mungo							
Upper part	A	30	26.24	67.91	5.85	2.59	Silt loam
	B	60	16.34	63.73	19.93	3.90	Silt loam
	B1	90	15.88	42.86	41.26	2.70	Silt loam
		Mean	**19.49**	**58.17**	**22.35**	**3.06**	**Silt loam**
		Std	**4.78**	**10.96**	**14.56**	**0.59**	
Middle part	A	30	13.13	62.27	24.60	4.74	Silt loam
	B	60	18.83	47.07	34.10	2.50	loam
	B1	90	25.91	73.80	0.29	2.85	Silt loam
		Mean	**19.29**	**61.05**	**19.66**	**3.36**	**Silt loam**
		Std	**5.23**	**10.95**	**14.24**	**0.99**	
Lower part	A	30	6.09	53.38	40.53	8.77	Silt loam
	B	60	8.47	61.47	30.06	7.26	Silt loam
	B1	90	6.08	51.41	42.51	8.46	Silt loam
		Mean	**6.88**	**55.42**	**37.70**	**8.16**	**Silt loam**
		Std	**1.12**	**4.35**	**5.46**	**0.65**	
Bailundo							
Upper part	A	30	6.39	30.15	63.46	4.72	Sandy loam
	B	60	5.25	19.81	74.94	3.77	Loamy sand
	B1	90	5.22	21.11	73.67	4.04	Loamy sand
		Mean	**5.62**	**23.69**	**70.69**	**4.18**	**Loamy sand**
		Std	**0.54**	**4.60**	**5.14**	**0.40**	
Middle part	A	30	11.19	57.95	30.86	5.18	Silt loam
	B	60	4.12	15.59	80.29	3.78	Loamy sand
	B1	90	19.14	52.23	28.63	2.73	Silt loam
		Mean	**11.48**	**41.92**	**46.59**	**3.90**	**Silt loam**
		Std	**6.14**	**18.77**	**23.84**	**1.00**	
Lower part	A	30	11.12	66.94	21.94	6.02	Silt loam
	B	60	12.60	62.45	24.95	4.96	Silt loam
	B1	90	15.14	68.54	16.32	4.53	Silt loam
		Mean	**12.95**	**65.98**	**21.07**	**5.17**	**Silt loam**
		Std	**1.66**	**2.58**	**3.58**	**0.63**	

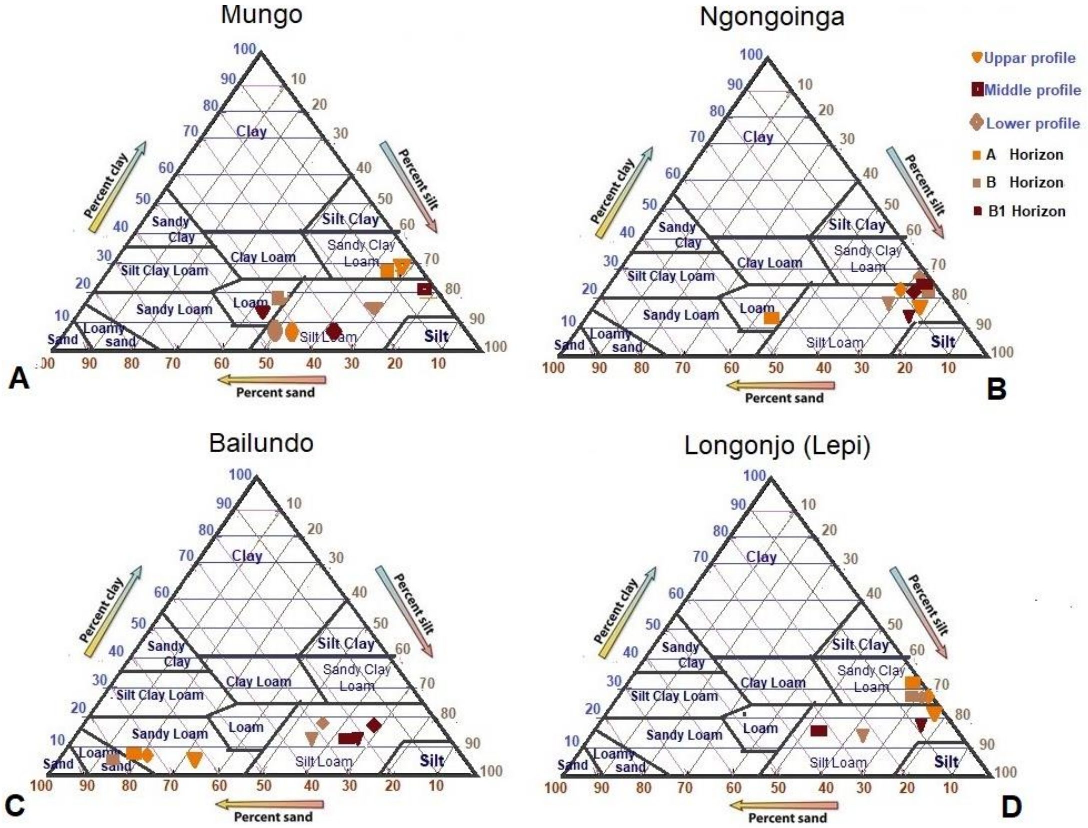
StD = Standard deviation

Appendix 4.15- Distribution of the proportion of soil particle size of the catena toposequence at the study site, Huambo province, Angola (Continuation).

Catena part	Horizons	Depth (cm)	Proportion of soil particle %			Ratio	Textural Class
			Clay	Silt	Sand	Silt/Clay	
Ngongoinga							
Upper part	A	30	18.03	73.54	8.43	4.08	Silt loam
	B	60	13.87	42.09	44.04	3.03	Sandy loam
	B1	90	24.97	66.87	8.16	2.68	Silt loam
		Mean	**18.96**	**60.83**	**20.21**	**3.26**	**Silt loam**
		Std	**4.58**	**13.53**	**16.85**	**0.59**	
Middle part	A	30	19.05	69.92	11.03	3.67	Silt loam
	B	60	24.66	74.14	1.20	3.01	Silt loam
	B1	90	28.63	71.34	0.03	2.49	Silt clay loam
		Mean	**24.11**	**71.80**	**4.09**	**3.06**	**Silt loam**
		Std	**3.93**	**1.75**	**4.93**	**0.48**	
Lower part	A	30	13.61	75.05	11.34	5.51	Silt loam
	B	60	29.47	70.53	0.00	2.39	Silt clay loam
	B1	90	28.30	71.70	0.00	2.53	Silt clay loam
		Mean	**23.79**	**72.43**	**3.78**	**3.48**	**Silt loam**
		Std	**7.22**	**1.92**	**5.35**	**1.44**	
Longonjo							
Upper part	A	30	24.54	74.90	0.56	3.05	Silt loam
	B	60	30.62	69.38	0.00	2.27	Silt clay loam
	B1	90	26.82	72.27	0.91	2.69	Silt loam
		Mean	**27.33**	**72.18**	**0.49**	**2.67**	**Silt clay loam**
		Std	**2.51**	**2.25**	**0.37**	**0.32**	
Middle part	A	30	13.13	62.27	24.60	4.74	Silt loam
	B	60	30.80	69.19	0.01	2.25	Silt clay loam
	B1	90	33.85	66.15	0.00	1.95	Silt clay loam
		Mean	**25.93**	**65.87**	**8.20**	**2.98**	**Silt loam**
		Std	**9.13**	**2.83**	**11.59**	**1.25**	
Lower part	A	30	18.86	72.54	8.60	3.85	Silt loam
	B	60	15.42	50.65	33.93	3.28	Silt loam
	B1	90		-	-	-	
		Mean	**17.14**	**61.60**	**21.27**	**3.57**	**Silt loam**
		Std	**1.72**	**10.95**	**12.67**	**0.28**	

StD = Standard deviation

Appendix 4.16- Distribution of the soil texture of the Mungo, Ngongoinga, Bailundo and Longonjo database illustrated in a textural triangle.



Appendix 4.17- Analise of variance of the effect of catena on soil bulk density (%) variability

	DF	Sum Sq	Mean Sq	F Value	Pr(>F)
Between Group	2	0.123	0.061	1.428	0.255
Within Group	32	1.374	0.043		
Total	34	1.497			

Appendix 4.18- Analise of variance of the effect of horizons on soil bulk density (%) variability

	DF	Sum Sq	Mean Sq	F Value	Pr(>F)
Between Group	2	0.055	0.028	0.611	0.549
Within Group	32	1.442	0.045		
Total	34	1.497			

Appendix 4.19- Analysing multiple comparison of soil Bulk Density (g /cm) variability by locality-catena

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Catena	2	0.099	0.049	6.080	0.008++
Locality	3	0.181	0.060	7.407	0.001++
Catena-Locality	6	1.050	0.175	21.519	0.0001+++
Error	23	0.187	0.008		

Appendix 4.20- Analysing multiple comparison of soil Bulk Density (g /cm) variability by locality-horizons

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Locality	3	0.130	0.043	0.772	0.522
Horizons	2	0.045	0.22	0.399	0.676
Locality-Horizons	6	0.015	0,002	0.044	1.000
Error	23	1.293	0.006		

a. R Squared = .137 (Adjusted R Squared = -.276)

Appendix 4.21- Analise of variance of the effect of catena on organic matter (%) content

	DF	Sum Sq	Mean Sq	F Value	Pr(>F)
Between Group	2	0.010	0.005	0.408	0.668
Within Group	32	0.386	0.012		
Total	34	0.395			

Appendix 4. 22- Analise of variance of the effect of horizons on soil organic matter (%) content

	DF	Sum Sq	Mean Sq	F Value	Pr(>F)
Between Group	2	0.002	0.001	0.70	0.932
Within Group	32	0.394	0.012		
Total	34	0.395			

Appendix 4.23- Analise of variance of multiple comparison of the effect of soil organic matter (%) content by locality

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Locality	3	0.212	0.071	35.172	<0.001
Catena	2	0.009	0.005	2.290	0.124
Locality-Catena	6	0.124	0.021	10.267	<0.001
Error	23	0.046	0.002		

a. R Squared = 0.883 (Adjusted R Squared = 0.827)

Appendix 4.24- Analise of variance, multiple comparison of soil organic matter (%) content by locality by horizons

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Locality	3	0.214	0.071	10.067	<0.001
Horizons	2	0.002	0.001	0;126	0.880
Locality-Horizons	6	0.015	0.003	0.363	0.895
Error	23	0.163	0.007		

a. R Squared = 0.557 Adjusted R Squared = 0.390)

Appendix 4.25- Relationship between the soil water holding capacity and soil moisture content with bulk density and soil organic mater their effect on soil moisture content

Correlations

		Organic Matter (%)	Bolk Density (g /cm)	Soil Moisture Content %	Soil Water Holding Capacity (%)
Organic Matter (%)	Pearson Correlation	--			
	N	35			
Bolk Density (g /cm)	Pearson Correlation	-.080	--		
	Sig. (2-tailed)	.646			
	N	35	35		
Soil Moisture Content %	Pearson Correlation	.323	-.220	--	
	Sig. (2-tailed)	.058	.204		
	N	35	35	35	
Soil Water Holding Capacity (%)	Pearson Correlation	.232	-.183	.486**	--
	Sig. (2-tailed)	.180	.293	.003	
	N	35	35	35	35

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix 5.1- Survey questionnare

Survey Questionnaires

Province: Huambo Date: / /

Municipality: Huambo Nº ________

Locality (Village):______________________________

A) Sex of the member interviewed.
   1) Male
   2) Female
B) Age of the member interviewed.
   1) 18-25
   2) 26-50
   3) >51
C) The interviewed member can be able to read and write.
   1) Yes, I can read and write.
   2) No is not able to read and write.
D) Marital status of the inquired member.
   1) Married
   2) Single
   3) Divorced
   4) Widow/er
E) Are you the owner or tenant of the land?
   1) Mine
   2) Cooperative
   3) Tenant
F) How many years have you lived in the farm area?
   1) <= 10
   2) 11 – 20
   3) 21 – 30
   4) =>31
G) How many people live with you?
   1) <= 3
   2) 4 – 6
   3) 7 – 10
   4) => 11
H) Total area available that you use to produce your crops.
   1) <=2 ha
   2) 3-6 ha
   3) =>7 ha
I) Technics used for land ploughing by the farmer.

1) Using tractor to plough the land.
2) Using animal power
3) By manual using rudimental equipment

J) Technics used for soil amendment.
1) Yes, I Apply Lime
2) No, I do not apply lime

K) Do you apply any type of Chemical fertilizers?
1) Yes, I apply Chemical.
2) No, I not Use any Chemical fertilizers

L) Principals' crops cultivating
1) Cereals (Maize)
2) Vegetables
3) Roots and tubers (potato or Cassava)
4) Legumes (Beans)
5) All this group of corps

M) Sowing season
1) Rain season (summer)
2) Dry or no rain season (winter)
3) Both seasons

N) Do you use intercropping in your farmer?
1) Yes, I use
2) No, I do not use.

O) Do you use intercropping?
1) Yes, I use
2) No, I do not use

P) Do you use crop rotation?
1) Yes, I use
2) No, I do not use

Q) Do you use cover crop?
1) Yes, I use
2) No, I do not Use

R) Do you use integrated crop animal production?
1) Yes, I use
2) No, I do not use

S) Water Use Management, Period of Start Rainy in Region
1) August
2) September
3) October

T) There were changes in beginning of the rain period.
1) Yes, there are changes.
2) No, are not any change.

U) Where did it rain more in the past or now?
1) In the past was rain more
2) Now is rain more.
3) Remain the same.

V) About Flood and Dry, was there any flood here.
1) Yes
2) No

W) When has it occurred?
1) 1960 – 1979
2) 1980 – 1998

3) 1999 – 2017
4) No

X) Was there Prolonged Dryness here?
1) Yes
2) No

Y) When did this happened?
1) 1960 – 1979
2) 1980 – 1998
3) 1999 – 2017
4) Never happened.

Z) There were already crops that dried up due to lack of rainfall.
1) Yes
2) no

AA) When did this happened?
1) 1960 – 1979
2) 1980 – 1998
3) 1999 – 2017
4) Never being happened

BB) Planning water use, do you use irrigation system?
1) Yes
2) no

CC) Has enough water for irrigation.
1) Yes
2) No

DD) Type of irrigation system can be used.
1) By sprinkler
2) Manually
3) By flood
4) Not use any.

EE) How often do you water the crops?
1) More than 1 per week
2) One per week
3) One per month
4) Never water

FF) It is hotter now than it was in the past?
1) Yes
2) No
3) Still de same

GG) It is colder now than in the past?
1) Yes
2) No
3) Still the same

HH) Land conservation and erosion, the terrain has steep slope?
1) Yes, steep sloped.
2) No, it a flat terrene.

II) Sowing and planting methods used
1) Following the contours of the ground level
2) Cover the soil with plant residues.
3) Direct sowing.

JJ) Do you use any technique to conserve soil moisture?
1) Yes

2) No

KK) Which technique should you use to conserve soil moisture?

1) Cover the soil with plant residues.
2) Use watering.(irrigation)
3) Use intercropping and crop cover
4) others

LL) The water you and your family drink, where do you get it?

1) River
2) Poco (pipe)
3) Channels
4) Potable water.

MM) What are the main diseases you usually have here?

1) Malaria (Paludism)
2) Diarrhoea
3) Breathing problems
4) Others

NN) Subsistence farmers perception on climate change

Statement	Completely disagree	Disagree	Not sure	Agree	Strongly agree
C1-The weather seems to be hotter Now than in past					
C2-The weather seems to be colder now than in past					
C3- Average temperature seems to be higher than in the past					
C4- Average temperature seems to be the same					
C5- Changes observed at the beginning of the rainy season					
C6- Rainfall seems to be more variable than in the past					
C7-The rains are more intense than in the past					
C8-The frequency of rainfall Increases than in past					
C9-Decline in rain fall amount					
C10- Floods seem to be more frequent than in past					
C11- Prolonged drought increasing now than in past					
C12- Crops dryness seems to be more frequent than in past					
C13- Growing season seems to be shorter than in past					
C14- Decreases in crop productivity					
C15- Increase crop productivity					

OO) Crop Harvesting and trade (Commercialization)

Statement	Very low (1)	Low (2)	Neida Low high (3)	High (4)	Very high (5)
P1. Cereals (maize)					
P2- Legumes (Beans Cowpea)					
P3- Vegetables					
P4- Roots and tubers					
P5- Other crops Fruits					
P6- Sale of surplus(kg)					
P7- Do you bought cops to sustaining the family					

Very low (1)= < 300 kg, Low (2) = 300-500 kg, Neida Low- high (3) , High (4)=500-1000k, very high (5) >1000 kg.

PP) Householder Limitations to Adaptability to climate change

Statement	Completely disagree	Disagree	Not sure	Agree	Strongly agree
L1- Climate factors variability (Temperature, rainfall and drought)					
L2- Weak agricultural technical support from the government					
L3- Absence of bank credit and householder farmers low financial capacity					
L4- Limited availability of access to weather information					
L5- Soil erosion and fertility depletion					
L6- Weak extension services assistance					
L7- The limited level of education of the farmer					

QQ) Householder farmers changes in farming practices to maintaining soil water moisture content and adaptability strategy to climate change.

Statement	Completely disagree	Disagree	Not sure	Agree	Strongly agree
M1- Changed in sowing and planting crop period					
M2- Conservation agriculture practices, less tillage and zero tillage					
M3- Apply manure to increase soil moisture and fertility					
M4- Retaining and conserving crop residues in soil					
M5- Maintain crop weed control					
M6- Burning weed and crop residues practices					
M7- Use of pesticide and chemical fertilisers					
M8- Use machinery cultivated technics					
M9-Use intercropping technics					
M10-Sowing more diverse type of crops now than in past					
M11- Grow newer crop variety than in past					

Frequently used acronyms

%	Percentages
<	Less Than
>	More Than
BD	Bulk Density
C	Clay
CC	coefficient of Correlation
CC	Climate Change
CO_2	Carbon Dioxide
EDA	Agrarian Development Station (Angola)
E_v	Evaporation
FAO	Food and Agriculture Organization
IDA	Institute of Agrarian Development (Angola)
IIA	Institute for Agricultural Research (Angola)
INE	National Institute of Statistics (Angola)
INMATE	National Institute of Meteorological and geophysics of Angola (*Instituto Nacional de Meteorologia e Geofísica*)
mm	Millimetres
N	Number of respondents
Nº	Number
OM	Organic Matter
P	Precipitation
S	Sand
SMC	Soil Moisture Content
SPP	Soil physical properties
SSA	Sub-Saharan Africa
SWHC	Soil Water Holding Capacity
T_{max}	Maximum temperature
T_{mean}	Annual Mean temperature
T_{min}	Minimum temperature
USDA	United States Development of Agriculture
WRB	World Reference Base
Z	Silt

Appendix 5.2 - Demographic characteristics of the target householder involved in research

Locality	Total of respondent	Gender %		Age (years) %			Number of residents per family				Write and read %
		Male	Female	< 25	26-50	>50	< 3	4- 6	7-10	> 11	
Bailundo	100	48.0	52.0	18.0	43.0	39.0	16.0	42.0	31.0	11.0	19.4
Mungo	94	31.9	68.1	8.5	54.3	37.2	8.5	35.1	42.6	13.8	34.0
Ngongoinga	113	41.6	58.4	27.4	35.4	37.2	12.4	45.1	32.7	9.7	36.9
Longonjo	111	50.5	49.5	18.9	47.7	33.3	15.3	40.5	36.9	7.2	29.7

(%)=Percentage, (<) = Less than, (>) = More than

Appendix 5.3. Subsistence farmers literate proportion analyses

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	15.413[a]	2	<.001
Likelihood Ratio	16.334	2	<.001
Linear-by-Linear Association	6.465	1	.011
N of Valid Cases	417		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 17.12.

Appendix 5.4 – Chi-square non-parametric statistical test on the demographic difference in land farming

	DF	Value	Asymptotic significance (2-sided)
Pearson Chi-Square	4	6.559[a]	0.161
Likelihood Ratio	4	6.242	0.182
Linear-by-Linear Association	1	0.78	0.780
N of valid Cases		417	

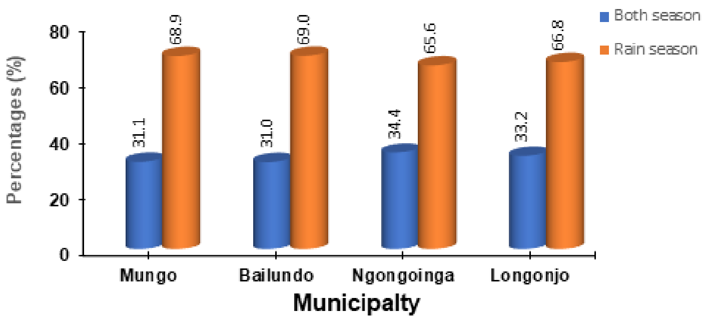
a. 1 cell (11.1%) have expected count less than 5. The minimum expected count is 4.40

appendix 5.5 – Chi-square non-parametric statistical test on the land ploughing techniques

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	56.296[a]	4	<.001
Likelihood Ratio	50.617	4	<.001
Linear-by-Linear Association	34.163	1	<.001
N of Valid Cases	417		

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 1.81.

Appendix 5.6- Subsistence family farmers crop sowing season by municipality



Appendix 5.7 – Subsistence family farmers crop productivity and harvesting

Farmers many crop harvesting (%)						
Many crops	Less Than (<500 kg)		Between (500 kg-900 kg)		More Than (>900 kg)	
Mungo (N=94)	**N**	**%**	**N**	**%**	**N**	**%**
Cereals	32	34.5	36	37.8	26	27.7
Legumes	31	32.9	27	28.6	36	38.5
Vegetables	44	46.3	23	29.5	27	24.2
Roots/tubers	32	33.6	25	26.6	37	39.8
Other crops	35	37.2	28	30.1	31	32.7
Bailundo (N= 100)						
Cereals	38	38.0	38	38.0	24	24.0
Legumes	40	40.0	27	27.0	33	33.0
Vegetables	43	43.0	28	28.0	29	29.0
Roots/tubers	46	46.0	22	22.0	32	32.0
Other crops	37	37.0	33	33.0	30	30.0
Ngongoinga (N=113)						
Cereals	40	35.4	44	38.7	29	25.9
Legumes	45	39.4	30	26.8	38	33.8
Vegetables	47	41.6	33	28.9	33	29.5
Roots/tubers	41	36.6	30	26.5	42	36.9
Other crops	37	32.7	34	30.1	42	37.2
Longonjo (N=111)						
Cereals	42	37.8	40	35.9	29	26.3
Legumes	41	36.9	40	36.1	30	27.0
Vegetables	47	42.6	32	28.7	32	28.7
Roots/tubers	40	36.3	30	26.5	41	37.2
Other crops	37	33.4	42	37.4	32	29.2

N = Number of respondents; **kg** = Kilograms ; **%** = Percentages

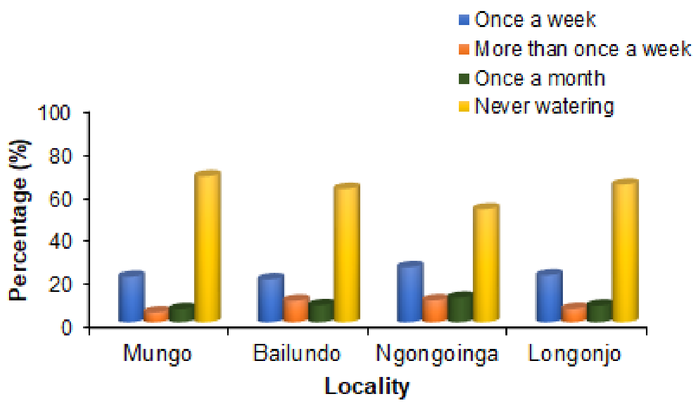
Appendix 5.8 - Subsistence family farmers statistical analyses for water availability and use of irrigation to watering crops

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	192.605[a]	1	<.001		
Continuity Correction[b]	189.739	1	<.001		
Likelihood Ratio	248.366	1	<.001		
Fisher's Exact Test				<.001	<.001
Linear-by-Linear Association	192.143	1	<.001		
N of Valid Cases	417				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 66.95.

b. Computed only for a 2x2 table

Appendix 5.9 - Householder farming Crop watering frequency by Municipality per week and month



Appendix 5.10 - Householder farmers harvesting new types of beans introduced in region.

Appendix 5.11 – Statistical analyses of use of fertilizers by subsistence farmers

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	2.474[a]	6	.871
Likelihood Ratio	2.337	6	.886
Linear-by-Linear Association	.121	1	.727
N of Valid Cases	417		

a. 4 cells (33.3%) have expected count less than 5. The minimum expected count is 2.43.

Appendix 5.12 - Analysis of support of rural extension services to subsistence family farmers, Chi-square tests

	Value	DF	AsyptoticSignificance (2-sided)
Pearson Chi-Square	13.877[a]	2	< 0,001
Likelihood Ratio	14.342	2	< 0,001
Linear by Linear Assciation	0.226	1	0,635
N de casos válidos	417		

a. 0 cells (0.0%) have expected count less than 5 The minimum expected count is 14.63.

Appendix 5.13 - Chi-Square tests analyses for overall literate demographyc group for subsistence farm family

	Value	df	AsyptoticSignificance (2-sided)
Pearson Chi-Square	15.413[a]	2	<0,01
Likelihood Ratio	16.334	2	<0,001
Linear by Linear Assciation	6,465	1	0,011
N de casos válidos	417		

a. 0 cells (0.0%) have expected count less than 5 The minimum expected count is 17.12.