Climate Vulnerability Assessment for

Selected Value Chain commodities in Zambia

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Alliance

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List of abbreviations and acronyms

AER	Agroecological Area
AR5	Fifth Assessment Report
CCAFS	Climate Change, Agriculture and Food Security Program (CGIAR)
CDD	Consecutive Dry Days
CGIAR	Consultative Group on International Agricultural Research
CHIRPS	Climate Hazards Group Infrared Precipitation with Station data
CIAT	International Center for Tropical Agriculture
CNRM	Centre National de Recherches Météorologiques (France)
CSA	Climate-Smart Agriculture
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CSO	Central Statistical Office
GDDs	Growing degree-days
GDP	Gross Domestic Product
GHGs	Greenhouse gas emissions
GoZ	Government of Zambia
E-SAPP	Enhanced Smallholder Agribusiness Promotion Programme
E-SLIP	Enhanced Smallholder Livestock Improvement Programme
IFAD	International Fund for Agricultural Development
LGP	Length of growing period
LSU	Livestock units
MoA	Ministry of Agriculture
MSME	Micro-, Small and Medium Enterprise
IPCC	Intergovernmental Panel on Climate Change
NGO	Non-Governmental Organization
NDC	Nationally Determined Contribution
NDP	National Development Plan
7NDP	Seventh National Development Plan (2017-2021)
PCO	Programme Coordination Office
PME	Planning, Monitoring and Evaluation
RCP	Representative Concentration Pathway (greenhouse gas emission modelling scenarios)
THI	Temperature-humidity index
UNFCCC	United Nations Framework Convention on Climate Change

Glossary

Adaptation

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate (IPCC).

Adaptive capacity

The ability of a system to adjust to changes in climate, to moderate potential damages, to take advantage of opportunities or to cope with the consequences (IPCC, 2014)

Climate scenario

A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships and assumptions of radiative forcing, typically constructed for explicit use as input to climate change impact models. A 'climate change scenario' is the difference between a climate scenario and the current climate (IPCC, 2007)

Climate projection

The simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHGs) and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realized (IPCC, 2014)

Climate variability

The variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate and all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability) (IPCC, 2014)

Exposure

Relating to the economic, social, or cultural assets in places and settings that could be adversely affected. Typical exposure factors include temperature, precipitation, evapotranspiration and climatic water balance, as well as extreme events such as heavy rain and meteorological drought. Changes in these parameters can exert major additional stress on systems (e.g. heavy rain events, increase in temperature, or shifts in the period of peak rain) (GIZ). The presence of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in, places that could be adversely affected (IPCC, 2012).

Hazard

Any climate-related physical event or trend or its physical impacts that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption and environmental

damage (IPCC, 2014). In this report the term hazard will be related to climate-related physical events or trends.

Indicator

A sign, or estimate of the state of something and often of the future state of something. Most importantly, indicators are used to identify vulnerable people, communities and regions. In addition, to elucidate information on the nature of vulnerability and to better identify adaptation options. Moreover, they are used to measuring and tracking the process of implementing adaptive actions. Indicators are used in monitoring and evaluation systems but are hard to use in measuring outcomes (Adapted from IPCC; WGII AR5 Chapter 14 – Adaptation Needs and Options).

Nationally Determined Contribution

An embodiment of efforts by each country to reduce national emissions and adapt to the impacts of climate change. NDCs are at the heart of the Paris Agreement and the achievement of these long-term goals.

Representative Concentration Pathways (RCPs)

Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/ land cover (Moss et al., 2008). The word representative signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term pathway emphasises that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome (Moss et al., 2010).

Risk

The potential for adverse consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. In this report, the term risk is often used to refer to the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, ecosystems and species, economic, social and cultural assets, services (including environmental services) and infrastructure (IPCC, 2014)

Risk assessment

A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend (IPCC, 2014)

Sensitivity

The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes (IPCC, 2014).

Vulnerability

The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes.

Acknowledgements

This research has been conducted by the International Center for Tropical Agriculture (CIAT) under an agreement with the Ministry of Agriculture (MoA) with financing from the Government of the Republic of Zambia (GRZ), the International Fund for Agricultural Development (IFAD).

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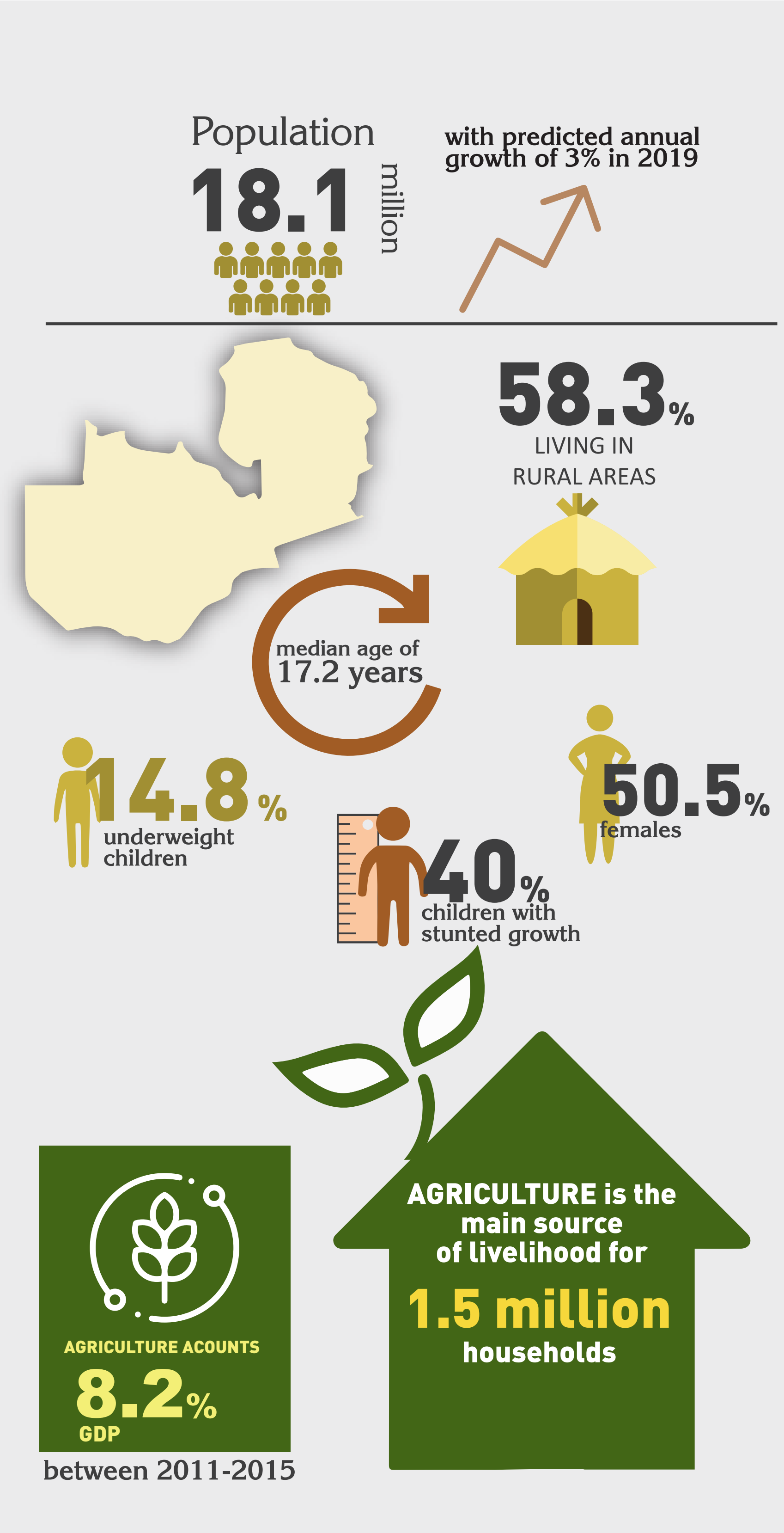
Executive summary



Zambia has a projected population of about 18,137,369 with annual growth of 3 per cent in 2019. It has one of the youngest populations worldwide (median age of 17.2 years) with 50.5 per cent females and more than a half - 58.3 per cent - living in rural areas. There are high rates of stunting and underweight among children (40 per cent and 14.8 per cent, respectively). Zambia's real Gross Domestic Product (GDP) is projected to decrease by 2 per cent in 2019 due to increased deficits, poor agricultural returns and reduced capital inflows. Agriculture is an important sector in Zambia, contributing an average of 8.2 per cent to the national GDP over the period 2011-2015, and constitutes the main source of livelihoods for an estimated 1.5 million households, representing 60 per cent of all households in Zambia. The agricultural sector is likely to become more vulnerable because of climate change.

Climate-related vulnerabilities are threatening agroecosystem resilience because of a strong reliance on rain-fed agriculture, with only 0.65 per cent of agricultural land currently under irrigation. Climate trends from 1960 to 2003 indicate that mean annual temperature has increased by 1.3°C. Moreover, it is projected that the average temperature will increase by between 1.9°C and 2.3°C between 2050 and 2100. The mean rainfall has decreased by an average of 1.9 mm/month (2.3 per cent) per decade since 1960, or a cumulative annual decrease of 22.8 mm in rainfall. The likely scenario of precipitation is a reduction of about 10 to 20 per cent in the Zambezi and Limpopo basins, and an increase in the number of consecutive dry days (CDD). It is therefore important to investigate climate change impacts and vulnerabilities on agricultural value chains and ways of integrating adaptation into development and sectoral planning.

The Government of Zambia (GoZ) is already integrating climate change in its policies and plans. Under the National Policy on Climate Change, the government is envisioning a sustainable climate-change response under which all climate-change actions will need to be environmentally sustainable and contribute positively to national economic growth and social development objectives. Under the Seventh National Development Plan, 2017-2021 (7NDP), adaptation and mitigation strategies to minimize effects of climate change on the agriculture sector are targeted, including promotion of adoption of agricultural and climate-smart and organic techniques. The Zambia Strengthening Climate Resilience Project (PPCR Phase II) aims at strengthening the institutional frameworks for climate resilience while improving adaptive capacity of vulnerable communities in targeted areas. Relevant projects to fast track these outcomes include the Enhanced Smallholder Agribusiness Promotion Programme (E-SAPP) that aims at benefiting smallholder farmers by increasing their incomes, food and nutrition security particularly of rural households that participate in market-oriented agriculture. In addition, the Enhanced Smallholder Livestock Investment Programme (E-SLIP) aims at sustainably improving incomes of rural poor households in selected provinces and districts in Zambia. The S3P Programme aims at improving the income levels and food and nutrition security of those poor rural households in the target areas that depend on agriculture and/or agricultural related activities.

The vulnerability assessment methodology used to prepare this report is drawn from the conceptual framework of climate-related risk from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) Working Group II (WGII) to examine the impacts that climate change is likely to have on agriculture and food security. The IPCC defines vulnerability as “the extent to which a natural or social system is susceptible to sustaining damage from climate change impacts, and is a function of exposure, sensitivity and adaptive capacity”. The impact of climate change on agriculture and livelihoods therefore can be conceptualized as the aggregation of these components. The approach we use in this study is a combination of the following steps:

- Review of historic climate hazards and risks prevailing in the three agroecological zones in Zambia.
- Evaluate climate indices that are potentially relevant for agriculture and other sectors in Zambia.
- Compute historical changes in climate indices using observed historical (1981-2015) weather data.
- Downscale and bias-correct future climate projections from the latest set of IPCC projections, which comprises an ensemble of 20-30 different Global Climate Models (GCMs).
- Distil the initial list of climate indices and categorize them in relation to factors or processes (e.g. heat stress, drought stress).
- Describe the projected changes (exposure) in key climate stressors and their potential impact on three commodity groups (Legumes, Small-livestock and Rice).
- Assess the vulnerability across the E-SAPP beneficiary spectrum (Category A - Strategic linkages of graduating subsistence farmers to markets, Category B - Enhancing Agro-Micro-, Small and Medium Enterprises (MSME) and Category C - Facilitating Pro-Smallholder Market-Pull Agribusiness Partnerships.
- Identify potential adaptation actions for climatic risks and vulnerabilities in the three commodity groups across the E-SAPP beneficiary spectrum.

The vulnerability of selected value-chain commodities in the three Agroecological Regions (AERs) of Zambia was assessed based on their sensitivity to change, coping and adaptive capacities. Engagements with in-country contacts and partners was a core component of the project execution and country-specific climate vulnerability assessments. This ensured that local knowledge and perceptions regarding climate change risks and impacts were incorporated into the climate vulnerability assessment and that the recommendations for building climate resilience were developed and verified with key stakeholders *in situ*.

For Zambia, the most significant meteorological indicators affecting agriculture are linked to the changes in temperature and precipitation. Within the last 33-year period (1982 to 2015), temperatures show an average increase of ~ 0.7^{o} C for the summer (wet season), with a higher rate in the increase for winter (dry season) temperatures at ~ 2.3^{o} C. Warmer temperatures are expected to bring about a devastating effect on the agricultural production exposing crops to heat stress. Annual precipitation for the period between 1981 and 2018 shows a decrease during the dry season and an increase during the wet season. From the general trend an increase of ~100mm, from

900 mm to 1000 mm has been observed during the wet season. The dry season rainfall however shows a continued decline with the total annual precipitation being maintained at ~25 to ~30 mm.. Drought is the most significant climatic hazard for all the selected value chains. Further, moisture stress is the second most significant hazard for legumes and small livestock.

Negative impacts of climate change occur in the north and north-west of the country, towards the semi-humid areas, and hence these areas show the greatest sensitivity across crops. The extent of suitable areas for crops is projected to decrease, with rice and cowpea being the most negatively impacted crops. Similar results are seen for livestock, although with generally less sensitivity as compared to crops. The frequency of heat stress days for livestock increases in the warm semi-arid and warm sub-humid zone. Pig and cattle are the species that experience the greatest increase in severe heat stress days, and hence the greatest sensitivity. We also note that areas with high vulnerability also correlate to high poverty rates, stunting, and limited access to water.

Results also highlight a decrease in the length of the growing period (LGP), which is the average number of growing days, in the wet season. The decrease in LGP not only affects the cropping system, but also livestock by reducing forage availability. More so, the number of observed hot days with temperature greater or equal to 35^{o} C shows a slight increase during the wet season and a substantial increase (up to 15 days) in the dry season. This shows that winters are actually becoming warmer due to climate change. These changes in the growing period and heat stress mean that farmers will need to grow varieties that are drought-tolerant, heat-tolerant and adapted to shorter and warmer growing periods, and more erratic rainfall. Overall, agricultural vulnerability is greatest towards the western, southwestern and northern districts. Crops are most vulnerable towards the west and north-west of the country. In the coming decades, unless adaptive capacity is enhanced, and adaptation strategies are implemented throughout the country, climate change will exacerbate vulnerability even further.

Warm average temperatures and humid conditions favour the prevalence of pests and diseases in the northern and eastern regions of Zambia. Four RCPs are produced from the Integrated Assessment Models, selected from the published literature and used in the Fifth IPCC Assessment as a basis for the climate predictions and projections. RCPs are scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover (Moss et al., 2008). RCP 4.5 partial implementation of Paris Agreement) is an intermediate emission pathway in which radiative forcing is stabilised at approximately 4.5 W m-2 and peak around 2040, then decline. RCP 8.5 (business as usual) is a high emission scenario for which radiative forcing reaches greater than 8.5 W m-2 and continues to rise throughout the 21st century.

Looking at the currently common pests and diseases among the selected value chains, we find that climatic conditions are favouring the larger distribution of the African rice gall midge, legume pod borer and bean flower thrips. For the 2030s, i.e. the period between 2021 and 2040, both RCP 4.5 and 8.5 scenarios indicate an overall increase in the distribution and infestation of pests and diseases in Zambia as warming conditions increase suitability in the west. For 2050s i.e., 2041 to 2060, the results predict a reduction in distribution and infestations of pests and diseases compared to the 2030s. Under RCP 4.5, prevalence reduces because of the underlying technologies adapted to reduce emissions, whereas for RCP 8.5 climatic conditions become unfavourable for the pests and diseases. Adoption of management practices aimed at lowering greenhouse gas emissions and carbon capture, such as use of clean energy, forestry, agroforestry, and bio-pesticides will be beneficial as a long-term response in mitigating climate change, thereby creating unfavourable environmental conditions that inhibit the development and distribution of the pests and diseases.

Inadequate climate-smart knowledge and skills, which is exacerbated by inadequate extension services and limited political will are the main factors that are likely to hinder the effective implementation of climate adaptation actions. In addition, community values, attitudes, beliefs and practices, contribute to inequalities, social exclusion and discrimination based on gender, age or social status. For instance, even though women dominate in the contribution of production activities of small livestock, men are assumed to take control over resources, marketing and the decision-making roles in this commodity group. We recommend efforts to scale off-farm services such as index-based insurance, early warning systems, disease surveillance, credit and financing to enhance climate adaptation. Several areas for work for the Zambian Government and society appear in terms of improving adaptive capacity in the country. Most notably, in the prevalence of stunting in rural areas likely through sustainable agricultural intensification, agri-business development and enhanced resilience, improvements in the capacity of education institutions, and an overall reduction in the incidence of poverty across the country.

A. Overview

The Climate Vulnerability assessment study focused on three commodity groups (legumes, small livestock and rice), that are supported by the Enhanced Smallholder Agribusiness Promotion Programme (E-SAPP). The outcome of the assessment will inform climate-change adaptation interventions, under the Enabling Environment for Agribusiness Development Growth component of the programme. Because of the existing synergies between and among the programmes in the portfolio and overlap in the commodities of focus among the IFAD-supported Programmes in the Portfolio, particularly between the Enhanced Smallholder Livestock Improvement Programme, (E-SLIP) and the Smallholder Productivity promotion Programme (S3P), the results of the study could further inform interventions in these other programmes.

The climate vulnerability assessment aimed to understand and quantify vulnerability of the selected value chains in the three agroecological regions of Zambia using an integrative and responsive methodology. We use the conceptual framework of climate-related risk from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) Working Group II (WGII) to examine the impacts that climate change is likely to have on agriculture and food security (Figure 1).

According to the IPCC, climate change risk results from the interaction of vulnerability, exposure, and hazards.

Vulnerability refers to the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity or susceptibility to harm, and its adaptive capacity (Parry et al, 2007) (GIZ).

The propensity or predisposition to be adversely affected (IPCC), formulated as follows:

Vulnerability = f (Exposure, Sensitivity, Adaptive Capacity)

Hazard refers to climate-related physical events or trends or their physical impacts that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption and environmental damage (IPCC, 2014). While, exposure relates to the economic, social or cultural assets in places and settings that could be adversely affected. For instance, people, livelihoods, environmental

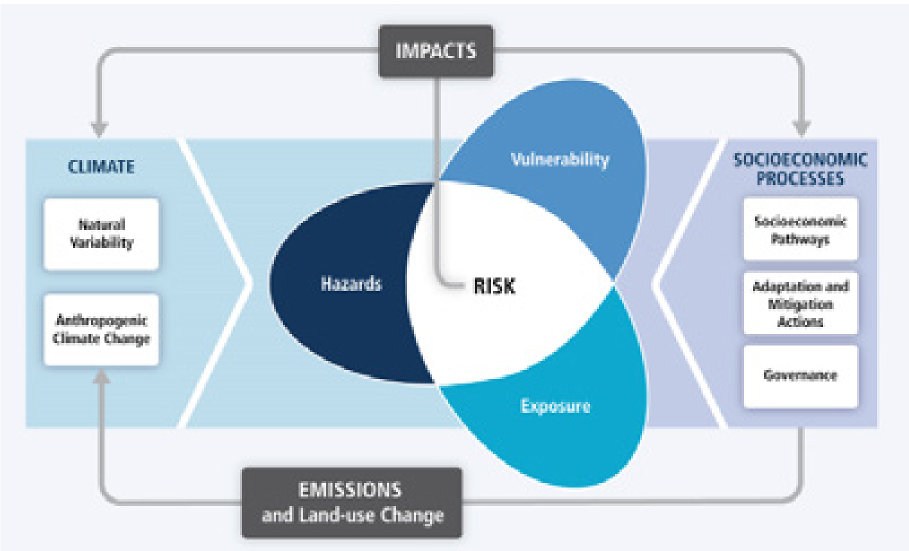


Figure 1: Illustration of the key concepts of climate risk. Source, IPCC 2014, p. 1046

services, resources and infrastructure (IPCC, 2012). Typical exposure factors include temperature, precipitation, evapotranspiration, as well as extreme events such as heavy rain and meteorological drought. Changes in these parameters can exert major additional stress on systems (e.g. heavy rain events, increase in temperature or shifts in the period of peak rain).

The adopted methodology by CIAT provides a framework for policymakers, researchers and stakeholders to assess the impacts of climate risk on selected value-chain commodities and target areas, in order to develop potential adaptation actions that support a climate-resilient development pathway. The vulnerability analyses were undertaken for current climatic conditions and under projected climate change for the decades 2030s and 2050s.

B. Goals and objectives of E-SAPP

The Government of the Republic of Zambia (GRZ) and the International Fund for Agricultural Development (IFAD) finances the Enhanced Smallholder Agribusiness Promotion Programme. The Lead implementing agency for E-SAPP is the Ministry of Agriculture (MoA). The E-SAPP goal is "to increase the income, food and nutrition security of rural households involved in market-oriented agriculture". The Programme's Development Objective (PDO) and the central strategy of E-SAPP is "to increase the volume and value of agribusiness outputs sold by smallholder producers". The Programme has a multiple commodity focus and a nationwide coverage. The selected commodities define the geographic focus of interventions. This study focused primarily on three commodity groups: Legumes (groundnut, soybean, bean and cowpea); Small livestock (poultry, goats, sheep and pigs); and rice.

The E-SAPP beneficiary spectrum includes: Category A - Strategic linkages of graduating subsistence farmers to markets; Category B - Enhancing Agro-Micro-, Small and Medium Enterprises (MSMEs); and Category C - Facilitating Pro-Smallholder Market-Pull Agribusiness Partnerships. The programme also supports commodities that present agribusiness potential and market opportunities under its sub-component on facilitating Pro-Smallholder Market-Pull Agribusiness Partnerships. The sub-component supports inclusive investments by large-scale private agribusinesses that increase the profitability and sustainability of smallholder farmers and rural Agro-Micro-, Small and Medium Enterprises (MSMEs).

B.1 Study Objectives

The overall objectives of this study were to:

1. Collect and synthesize available biophysical and socio-economic maps and data
2. 2. Analyse the occurrence of climate-related hazards in the prospective target area of the project (including a historical analysis of hazard types, intensities, frequencies and associated losses and damages)
3. Assess the impact of climate-change effects on the three value-chain commodity groups: legumes, small livestock, and rice
4. Determine the susceptibility and vulnerability of the value chains in the target areas to the most prevalent climate hazards (sensitivity analysis)
5. Provide recommendations on how to manage the climate risks for these commodity groups and ensure increased resilience of the target beneficiaries groups namely Category A, B and C.

Chapter 1: Agricultural context

Chapter authors: *Caroline Mwongera and Collins Odhiambo*

Key messages

- An estimated eighty per cent of the population in Zambia is engaged in the local poultry value chain. Pig and goat engage about 21-40 %per cent of the population. Sheep is the least dominant among the small livestock, employing less than 20 per cent of the population.
- The bean and groundnut value chains engage about 21-40 per cent of the population. Women are mainly involved in the provision of seeds and other inputs. Men dominate the roles in input, production, post-harvest and marketing activities for groundnut. Soybean employs an estimated 41-60 per cent of the population. Women play a central role the input, production and marketing stages.
- The rice value chain engages 61-80per cent of the population in Zambia. The private sector is the main provider for mechanized technologies. Women play a major role in the input acquisition and marketing activities. Men dominate the harvesting, processing and storage, and have a high role during production and marketing.

1.1 Geographic Location

Zambia is a landlocked country in Southern Africa. It covers a total area of 752,618 square kilometres. It is located between latitudes 8° and 18° south and longitudes 22° and 34° east. Its neighbours include the Democratic Republic of Congo to the north, Tanzania to the northeast, Malawi to the east, Mozambique, Zimbabwe, Botswana and Namibia to the south, and Angola to the west. (Central Statistical Office, 2017). Zambia has ten (10) provinces, namely, Central, Copperbelt, Eastern, Luapula, Lusaka, Muchinga, Northern, North Western, Southern and Western. The provinces are administratively subdivided into districts. In all, Zambia has 106 districts, 156 constituencies and over 1,430 wards. Lusaka is the Capital City and seat of the government. The government comprises of the Central and Local Governments.

1.2 Demographics

Zambia's population has been increasing at an annual average rate of 2.8 per cent during the previous intercensal period. The population was estimated at 7,383,097 in 1990, and increased to 9,885,591 in 2000 and to 13,092,666 in 2010. This represented an increase of 33.9 per cent in the 1990-2000 intercensal period. Between 2000 and 2010, the percentage increase was 32.4 per cent. As at 2019, the population is projected at 18,137,369 with annual growth of 3 per cent in 2019 compared to 2.9 per cent in 2018 (The World Bank, 2019c).

With a median age of 17.2 years, Zambia has one of the youngest populations in the world. The female percentage of the total population in Zambia is 50.5 per cent and 49.5 per cent male (The World Bank, 2019d). The gross percentage of school enrolment in 2017 at primary schools was 99 per cent. According to UNESCO (2019), the illiterate population aged 15 years and above was 437,739 males and 828,427 females in 2018. The International Labour Organization (ILO) datasets indicate that 75.2 per cent of Zambians above 15 years of age are participating in labour in different sectors or actively looking for work (ILOSTAT, 2019). However, most of the people (58.3 per cent) live in rural areas compared to 41.7 per cent living in urban areas. The rate of urbanization between 2015 and 2020 was predicted to grow at an annual rate of 4.23 per cent according to the Central Intelligence Agency (CIA) (CIA, 2019). This annual growth rate may put a strain on urban resources, especially on food supply.

According to SADC (2019), food insecurity is on the rise compared to previous years. It is estimated that about 19 per cent of the rural population (1.7 million people) need food safety nets. Malnutrition is also expected to increase. In general, Zambia accounts for 1.2 million of people who are acutely food-insecure and affected by climate shocks (Food Security Information Network, 2019).

1.3 Agro-economic situation

Seventy-five (75) per cent of Zambia's poor live in rural areas and practice smallholder agriculture (The World Bank, 2018). The agriculture sector employed more than half (53.9 per cent) of Zambia's active population by 2018 (ILOSTAT, 2019). It is estimated that over 60 per cent of the total population live in the rural areas. Small-scale farmers are the majority; nearly one million farmer households who in total cultivate about 80 per cent of the total land (Nkhoma & Nangambaaharan, 2019). The farm sizes are small, ranging from 1-5 hectares, with an average area of 2 hectares (*ibid*). The arable land as a share of agricultural land in Zambia was estimated at 15.94 per cent, with cropland being 5.16 per cent (FAOSTAT, 2019a). Irrigation is limited; only 0.65 per cent of agricultural land was under irrigation in 2016. In Zambia, agricultural commodities account for approximately 80 per cent of the value of farm production (Braimoh et al., 2018). In 2018, the growth of the value-added commodities from fisheries, forestry and agriculture declined significantly by up to -21 per cent. This may be associated with inadequate infrastructure and poor enabling policy environments in Zambia that have been cited as hampering dynamic agro-industrial development (FAO, 2017). The decline was also observed on the contribution of these items to the GDP by close to 1.4 per cent from the previous year (2017) (The World Bank, 2019d). This means that agriculture contributed 2.6 per cent to the country's GDP. In development terms, this could be an indication that the country is moving towards manufacturing and away from over-reliance on agricultural output, but due to the declining value-added commodities, this may not fully explain such contributions.

In 2018, the Zambian economy was projected to expand by 3.5 per cent compared to 3.4 per cent in 2017 (The World Bank, 2018). However, agriculture output contracted by large margins of more than 35 per cent, a factor associated with shortage of rains in early 2018 (AFDB, 2019). El Niño forecasted for the 2018-19 season affected the outputs negatively (The World Bank, 2019c). On the other hand, agricultural products accounted for up to 27.7 per cent as a share of Zambia's Non-Traditional Exports (NTEs). The export earnings derived from agricultural products showed a 14.8 per cent upward trend, translating into a financial gain from Kwacha (ZMW) 657.2 Million in May 2019 to ZMW 754.3 Million in June 2019 (Central Statistical Office, 2018).

The IPCC report by Hoegh-Guldberg et al., (2018) gives a robust signal on the likely scenario for climate change, with an increase in average temperature by 1.5°C in Zambia. With a 2°C increase in temperature, the likely scenario of precipitation is a reduction of about 10–20 per cent in the Zambezi and Limpopo basins, an increase in the number of consecutive dry days (CDD) and the reduction in stream flows between 5 and 10 per cent. The temperature is projected to increase between 1.9° C and 2.3° C between 2050 and 2100 (Hamududu & Ngoma, 2019). With rainfall decreasing by about 3 per cent by the 2050s, water availability will be severely affected, decreasing by 13 per cent by 2100 across Zambia.

1.4 Selected commodity value chains

A. Legume commodity group (beans, groundnuts, cowpeas, soybeans)

a) Common Beans (*Phaseolus vulgaris*)

Common bean is the second most important and widely grown food legume crop in Zambia, after groundnut, in terms of its economic importance (GoZ, 2018c). According to Caesar et al. 2019, about 11.2 per cent of households in Zambia, of which 12.0 per cent are rural and 6.0 per cent are urban, grow common beans. The crop is grown in about 32.1per cent of the total area in Zambia under food legume crops; that is, approximately 85,469 ha annually (Hamazakaza et al., 2014). According to the Central Statistical Office's (CSO) 2018 monthly focus, the annual hectarage is on the rise from the 83,635 Ha to 84,566 Ha in 2016 to 2018, respectively (Central Statistical Office, 2018). Common beans are valued for their importance as a source of protein and micronutrients such as Iron (Fe) and Zinc (Zn).

Beans are increasingly becoming a cash crop, shifting from a traditionally women's crop to a joint enterprise in which both men and women participate (GoZ, 2018c). In Zambia, common bean productivity is very low, ranging between about 400 and 500 kg/ha. However, the potential productivity is estimated at about 1.2 t/ha under good agricultural practices (GoZ, 2018c). The actual yield rate increased between the 2016-2018 cropping period from 0.55 MT/ha to 0.62 Mt/ha (FAOSTAT, 2019a). Efforts to increase productivity in the 2017/2018 Crop Survey Forecast showed a production increase by 14.0 per cent for mixed beans according to CSO (2018).

Smallholder formal seed purchases are low, estimated at 5 per cent (Tracy & Don, 2018). More than 80 per cent of these smallholders use their own saved seed from the previous crop season or purchase seeds from neighbours. Fertilizer use is low, and basal fertilizer use in the 2017/18 cropping season was estimated at 212 MT in Zambia. However, FAO estimated NPK fertilizer use for all agricultural crops in Zambia in 2017 at 181,662 MT and Urea at 179,433 MT (FAOSTAT, 2019a). The average fertilizer usage per hectare in Zambia for all crops in 2018 was estimated at 82.1 kg compared to 105.9 kg per hectare in 2016/2017, representing a 22.5 per cent decline (Chapoto, Chisanga, & Mulako, 2018).

b) Soybean (*Glycine max*)

Soybean is grown by about 4.5 per cent of the farmers in Zambia, of which 4.9 per cent are from rural areas and 2.3 per cent from urban areas (Caesar et al., 2019). The Zambia Crop Survey, 2016, estimates the number of small- and medium-scale households growing soybean at around 10047 (Central Statistical Office, 2016). There are few (about 740) large commercial farms along the value chain that focus on soybean production (Alfani et al., 2019).

Soybeans are produced on an area spanning 225,359 Ha (Figure 2) according to FAOSTAT (2019a). The yield rate has been estimated at between 1.47 MT/Ha and 1.52MT/Ha for soybean in 2016-2018 (Central Statistical Office, 2018). Farmers sell 70 per cent of their produce, keeping 30 per cent as seed for the next planting season (Siamabele, 2019). Formal seed purchase is rare, it is estimated that only 20 to 30 per cent of soybean farmers use certified/improved seed (The World Bank, 2012). Price volatility, however, saw a drop in price of grains from 2017 to 2018, where farm gate price was $150 per ton compared to $450 from the previous season. Input use, especially inorganic fertilizer, is low and similar to the case for common beans. In 2017/18, 51.3 per cent of Zambian rural households reported using fertilizer.

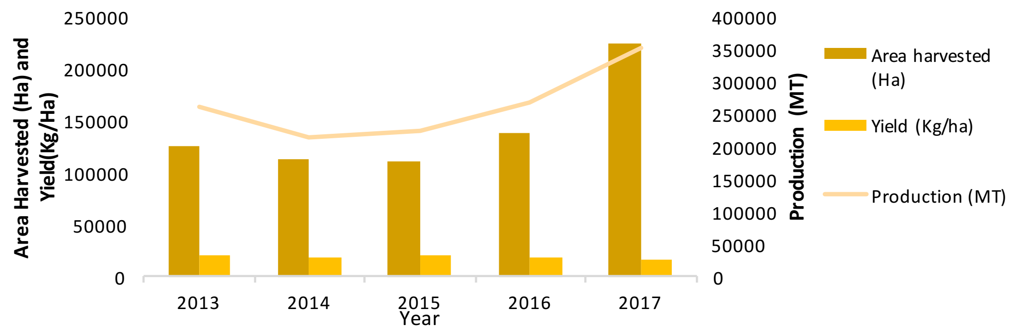


Figure 2: Estimated production, yield and area harvested for soybean in Zambia. Source: (FAOSTAT, 2019a)

c) Cowpea (*Vigna unguiculata*)

Cowpea is produced by less than 10 per cent of farmers in Zambia according to World Bank reports (Braimoh et al., 2018), even though some 387,000 tons are consumed in Africa annually. Statistics from Zambia indicate that 38,929 households engaged in cowpea farming in 2016 (Central Statistical Office, 2016). The crop is important as a seed oil, for feed and nitrogen fixation. The seeds are packed with essential amino acids, possessing protein (up to 24 per cent in dry seeds).

The 2018 National Crop Forecast Survey indicated that the area under cowpea in Zambia was approximately 26,438.14 hectares in the 2017/18 cropping season. The average yield of cowpea in Zambia was 1.46 metric tons per hectare in 2017/18 and reduced by 19.6 per cent to 1.46 metric tons per hectare in 2018/19 cropping season. However, crop surveys indicated that in the same period of 2017/18, the average yield was 0.47 metric tons per hectare (Figure 3) (Central Statistical Office, 2018). In 2018, 23,413 hectares were expected to be harvested, which was a significant improvement on the previous -2016/17 harvest season by 100.28 per cent (ibid). Some of the recent cowpea varieties have a potential yield of 1.4 to 1.5 tons per acre and mature in about 92-94 days (IITA, 2015). African parasitic weeds, especially Striga and Alectra, affect the crop. Drought-tolerant, leaf spot and bacterial disease-resistant varieties are required.

In the 2017/18, cropping season the quantity of basal fertilizer used for cowpea was estimated at 13.20 metric tons, while the quantity of top dressing fertilizer was about 6.71 metric tons.

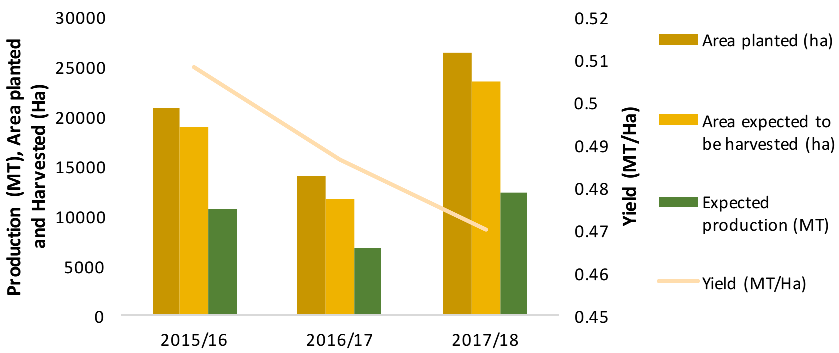


Figure 3: Estimated production, yield and area harvested for cowpea in Zambia. Source: Central Statistical Office, 2018.

d) Groundnut (*Arachis hypogaea*)

Groundnut, also referred to as peanut, is considered a “female crop” in Zambia (USAID, 2018) because women play significant roles in its production and processing. On average, by 2016, there were 709,139 small and medium households engaged in groundnut farming in Zambia (Central Statistical Office, 2016). Groundnut contains 25 per cent protein and up to 50 per cent of the edible oil content. Groundnut is the second largest crop in terms of production in the country, after maize. It accounts for nearly 9 percent of the cultivated land in the country (Chapoto et al., 2018). Groundnut was produced by about half (49.8 per cent) of households in 2018, both smallholder and medium scale farmers (USAID, 2018; Central Statistical Office, 2016). Since it forms part of the diet, about 3.3 per cent of the total food expenditure is used to buy groundnut. On the other hand, when harvested, about 80 per cent of these groundnuts go to household consumption, while 20 per cent are sold to the local markets (USAID, 2014). Yield rates for groundnut in Zambia in 2018 was estimated at 0.64 tons/ha, representing only marginal increase of 2 per cent from the previous 0.63 MT/Ha in 2017 (Figure 4).

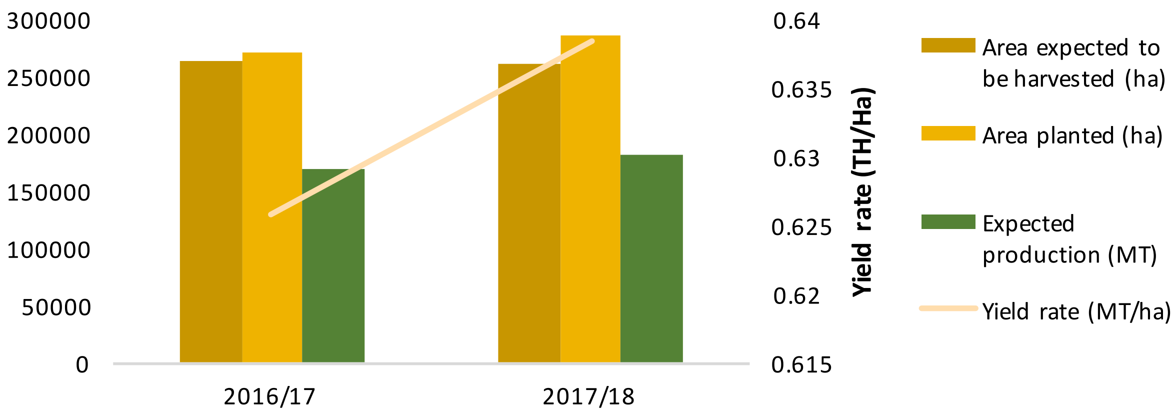


Figure 4: Estimated production, yield and area harvested for groundnut in Zambia. Source: Central Statistical Office, 2018

B. Rice (*Oryza Sativa L.*)

Rice is grown on Zambezi flood plains of Western province, along Kafue River, the Luangwa flood plains in Eastern province, around the lake basins, especially Mweru and Bangweulu in Luapula, and sporadically grown in Chambeshi flats in the Northern Province. In addition, some is grown at Copperbelt in the dambo (shallow wetland) sites and seasonal streams. Approximately, 66,592 small- and medium-scale households were engaged in rice farming in Zambia as at 2016 (Central Statistical Office, 2016). It is estimated that about 31 per cent of these farmers growing rice are women. Area under rice in 2016/17 was 33,303.33 hectares while in the 2017/18 cropping season, it increased to 34,216.59 hectares. The average farm plot sizes under rice have been estimated to average 0.57 hectares per farmer. Rice is an important food crop and per capita consumption increased from 1.49 kg/year in 2002 to 4.11/year kg in 2014 (Mukwalikuli, 2018).

Each farmer in Zambia produces on average less than one metric ton of rice/year (Styger, 2014), a figure that is lower than the global average production of four metric tons per hectare. The average yield was 1.15 tons per hectare in 2016/17 and showed an improvement to 1.3 metric tons per hectare in 2017/18 cropping year (Figure 5). Production also increased from 38,422.90 metric tons in 2016/18 to 43,063.11 metric tons in 2017/18 (Central Statistical Office, 2018; FAOSTAT, 2019a). Often, farmers retain seeds from previous seasons and, in 2016, farmers retained about 72.24 metric tons (Central Statistical Office, 2016). Farmers use of chemical fertilizers with basal fertilizers for rice was 62.52 metric tons in 2016/17 and 150.07 metric tons in 2017/18. Top dressing fertilizers reduced by 84 per cent in 2018 from the previous 140 metric tons.

It is estimated that more than half (52 per cent) of rice is traded through different channels especially local markets. After harvest, most of the rice is taken to processors, whose capacity is low, with most mills having a production rate ranging from 1.5 to 2.5 metric tons per hour (Government of Zambia, 2016). Most of the small-scale processors (90 per cent) are men (Government of Zambia, 2016).

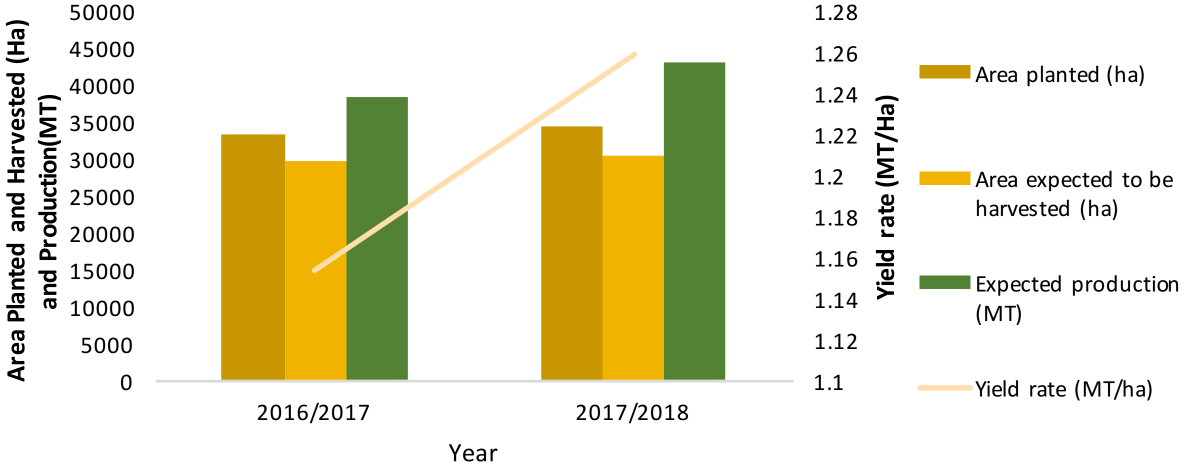


Figure 5: Estimated production, yield and area harvested for rice in Zambia. Source: Central Statistical Office, 2018

C. Small livestock commodity group (poultry, goats, sheep and pigs)

a) Poultry

In Zambia, poultry is an important source of livelihood and currently the main source of meat consumed by Zambians; contributing 50 per cent of the total meat consumption in Zambia. It contributes 5 per cent to the national Gross Domestic Product (GDP) and approximately 47 per cent of the livestock GDP (Bukasa, 2019). From the early 2000s, growth in the poultry industry has been on an upward trend, with average annual growth rates of 8 per cent in Zambia (Samboko, Zulu-Mbata, & Chapoto, 2018). FAOSTAT (2019) estimated the number of live birds, both local and broilers, to be around 40,334,000 birds as indicated in the Figure 6. The figure does not include birds such as turkey, pigeon, duck, goose and guinea fowl. Indigenous chicken are highly valued due to their free foraging. On average, poultry – especially chicken, makes up 13.55 per cent of the total livestock units (LSU) in Zambia and in terms of density per agricultural land area, it takes 0.02 LSU/ha (FAOSTAT, 2019c). On average, 97 per cent of farm households in Zambia have at least one chicken in their backyard (Caesar et al., 2019).

Consumption demand for chicken increased over the years and by 2017 stood at 9.2 kg per capita. By the year 2025, it is predicted that poultry consumption in Zambia will increase by 1.8 kg per person up to 3.1 kg per person compared to 2015 (Ostaszewski, 2018). Ready-to-cook chicken production has been estimated at 50,350 tons in 2019 and is predicted to increase to 55,600 tons by the year 2025 (OECD, 2019). Broiler production is the major subsector, and the biggest driver of the poultry industry. It has about 35,000 smallholder farms and more than180 large commercial broiler farms (Caesar et al., 2019). Smallholders dominate the broiler market (65 per cent), while large commercial producers contribute about 35 per cent.

The layers subsector is also very important in terms of egg production. Between 2017 and 2018, there was a 10 per cent increase in egg production of layers, that is, 37.6 and 41.1 million trays of eggs, respectively. In terms of exports in the same period, 35 per cent of eggs and 9 per cent of broiler chicken were exported to Democratic Republic of Congo. Zambia now has annual output of eggs that exceeds 1 billion, of which at least 10 per cent is exported via informal cross-border trade. Zambians consume 60 eggs per capita per year (McKee, 2019).

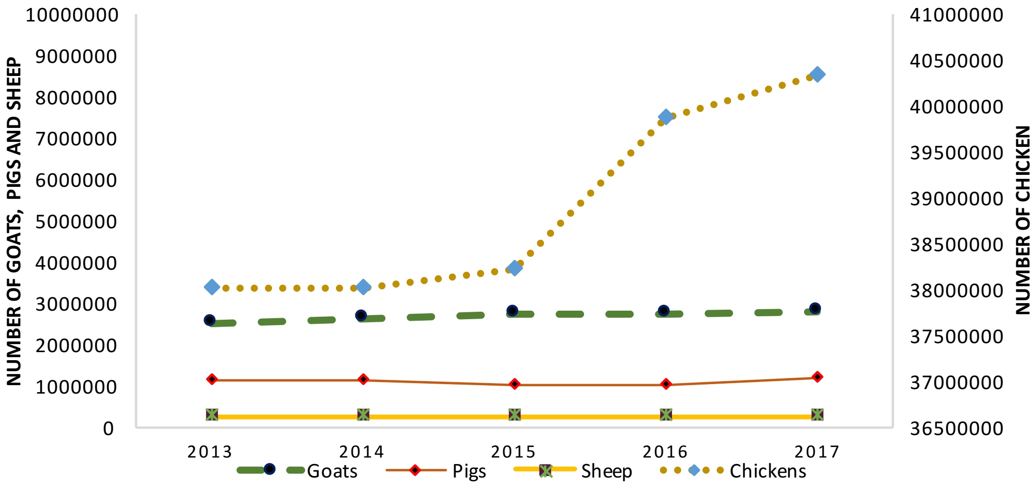


Figure 6: Approximated number of chicken, goats, pigs and sheep in Zambia from 2013 to 2017. Source: FAOSTAT, 2019c

The main risk factors in poultry production in Zambia are linked to diseases associated with antibiotics resistance becoming a hindrance to production. Nevertheless, chicken farming has improved recently. Commercial or large-scale farmers keep up to 100,000 birds per cycle while small-scale farmers have birds ranging from 1-10,000 per cycle (Caesar et al., 2019). Chicken imports are increasing exponentially to meet local demand (Figure 7).

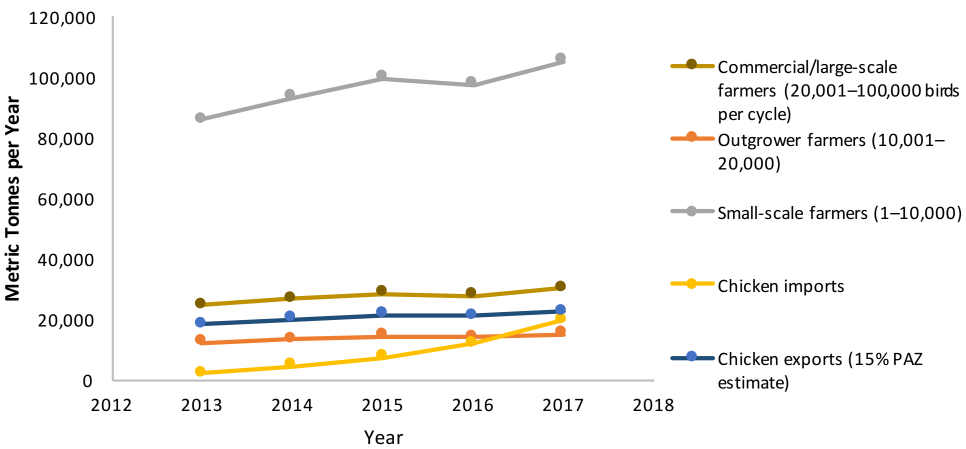


Figure 7: Chicken production, importation and consumption in Zambia. Based on constructed data from the Poultry Association of Zambia (PAZ) and Common Market for Eastern and Southern Africa (COMESA): Adapted from Caesar et al., 2019

During periods of climatic stress, especially hot dry and hot humid seasons in Zambia, a higher incidence of Newcastle Disease Virus outbreaks have been noted (Saelao et al., 2019). Besides, temperatures above 18–19° C have been associated with higher metabolic rates that affect production of poultry. Poultry production has been projected to decrease by 0.17 per cent under climate change scenarios (CIAT; WorldBank, 2017).

b) Pig Production

The 2018 Livestock and Aquaculture Census placed the total number of pigs at 1,082,765, with Eastern Province leading with 28.3 per cent. According to the Living Conditions Measuring Survey, by 2015, 30.9 per cent of the population was rearing pigs, of which 31.3 per cent were from rural areas, while 32.1 per cent was from the urban areas (Caesar et al., 2019). As at January 2018, 178,848 households were rearing pigs with each household having at least 5.8 heads of pigs (Central Statistical Office, 2019). The number ranged from 19.5 per household in Lusaka Province to 2.5 per household in Northern and Luapula Provinces, respectively. In 2016, the per capita consumption of pork was placed at 1.5 kg/capita in Zambia (Soare & Chiurciu, 2017). Between 2007 and 2017, the annual rates of growth in terms of pork consumption in Zambia has increased by more than 9.7 per cent/annum according to IndexBox organization (FastMoving, 2018).

In 2019, pig meat in terms of carcass weight equivalent has been estimated at around 34,980 tons. This is predicted to increase to around 45,190 of pig meat slaughtered in Zambia by 2025 (Figure 8) (OECD, 2019). Pigs' account for 7.83 per cent of the total livestock units in Zambia and 0.01 LSU/ha in terms of density per agricultural land area (Figure 9) (FAOSTAT, 2019c). Under predicted climate change scenarios, pig production is projected to increase by 0.26 per cent (CIAT; World Bank, 2017).

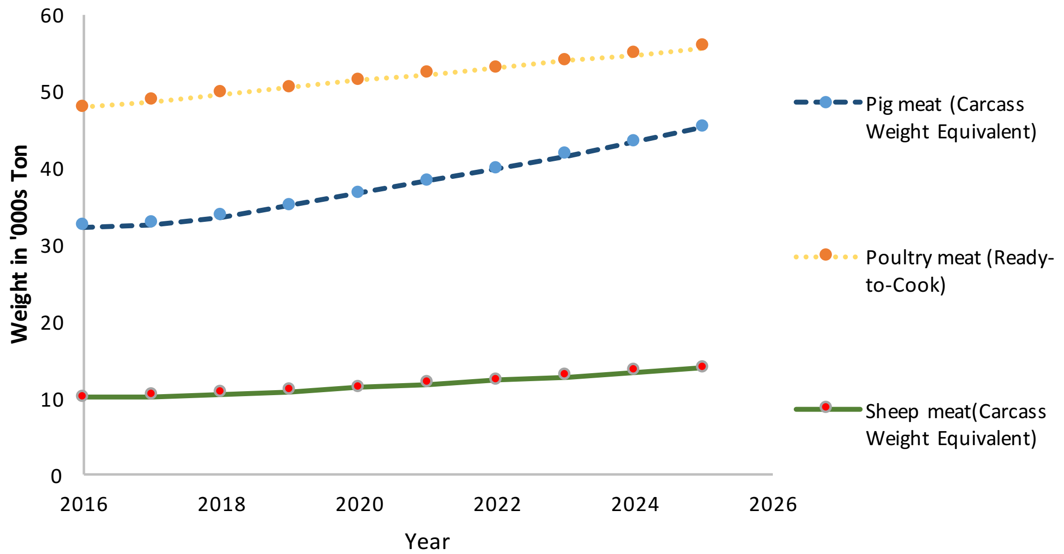


Figure 8: Estimated pig, poultry and sheep production trends in Zambia from 2017 to 2026. Source: OECD, 2019

c) Sheep Production

The 2017 Livestock and Aquaculture Census estimated that the sheep population as at January 2018 was 170,262 heads (148,946 from individual households and 21,539 from established firms). Southern Province was reported to have the highest number of sheep, approximately 62,586 heads; that is 36.8 per cent of the sheep stock nationally. The lowest number of sheep was recorded in the Western Province, which is 0.2 per cent of the total national sheep stock (Central Statistical Office, 2019). According to the FAO datasets, the population of sheep was approximately 257,144 as at 2017, as shown in the Figure 8 (FAOSTAT, 2019c). By January 2018, the Central Statistics Office reported that 19,909 households were raising sheep.

On the other hand, 285 establishments were raising sheep along the value chain (Central Statistical Office, 2019). At household level, the number of sheep was averaged to 7.5 with herds ranging from 1-5 sheep. The number also went up to 12 per household in Lusaka. Established firms had 76 heads on average.

Mutton consumption has been on the rise in Zambia. It is expected to increase by about 0.1 kg/person and reach 0.6 kg/person by the year 2025 according to the OECD-FAO data (Ostaszewski, 2018). In 2019, sheep meat in terms of carcass weight equivalent has been estimated at around 10,900 tons, marking a 27.16 per cent increase in terms of tons of sheep slaughtered in Zambia (OECD, 2019).

d) Goat Production

Zambian animal genetic resources, according to the Ministry of Agriculture and Livestock (MAL), indicate that most of the goats (97 per cent) are indigenous breeds or crosses with exotic breeds (GoZ, 2018b). Zambia's total goat population was estimated at 3,476,790 heads, according to the Livestock and Aquaculture Census (Central Statistical Office, 2019). This census, conducted in 2017, indicated that Southern province accounted for the highest population (1,233,435). This represented 35.5 per cent of the total national stock of goats. Central province had 585,277 representing 16.8 per cent. The lowest numbers were in Western Province, which accounted for 1.9 per cent. On average, the number of heads per household was estimated at 7.4. Most households in the census raised goats - 71,872 households. As at January 2018, these households had a herd size of 1-5 heads of goats, although herd sizes were larger than 30 heads in only 10,000 households. In 2017, the density of goats per agricultural area in Zambia, that is, the average rates of goats per agricultural land area stood as low as 0.01 LSU/ha. Furthermore, the data indicated that goats shared 9.27 per cent of the total livestock units in Zambia (Figure 9) (FAOSTAT, 2019c).

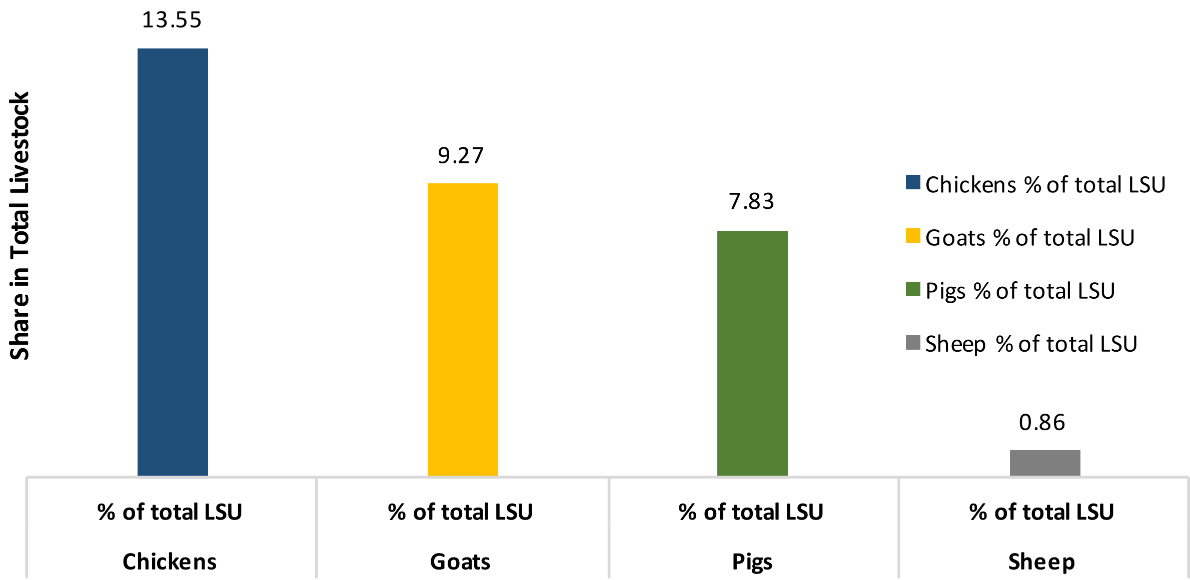


Figure 9: Density of small livestock per agricultural land unit in Zambia: Source: (FAOSTAT, 2019c)

1.5 Value chain Characterization

A. Legumes commodity group

The bean value chain engages about 21-40 per cent of the population. Women are mainly involved in the provision of seeds and other inputs, while men are the main actors in the on-farm production, harvesting, storage and processing stages. Women and youth play a minor role at the product marketing stage of the value chain. Input suppliers are mainly small- and medium-scale service providers. Small-scale farmers dominate the production stage, whereas both small and medium processors dominate the processing stage. Small-scale wholesalers support linking farmers to buyers, pricing and marketing activities (Figure 10).

About 20 per cent of the population is currently engaged in cowpea production. Men tend to drive the value chain at the input, production and marketing stages, with women and youth playing a medium role at the marketing stage. Small-scale and medium scale service providers are the suppliers of seed and other inputs. For the these three stages of production, post-harvest and marketing, small-, medium- and large-scale actors are engaged; these are farmers, processors and wholesalers, respectively (Figure 10).

Soybean is an important value chain in the legume commodity group for Zambia and employs an estimated 41-60 per cent of the population. Medium-scale and large-scale service providers are involved in the supply of inputs for this value chain. There are small, medium and large scale actors involved in the soybean production, processing and marketing stages (Figure 10). Women play a central role the input, production and marketing stages of the value chain. Men also play a medium role in production, harvesting, storage and processing. Youth are currently involved in marketing activities, alongside women.

The groundnut value chain currently 21-40 per cent of the population. Men dominate the roles in input, production, post-harvest and marketing activities. Small and medium-scale service providers are the main actors for the provision of seed and other inputs. For the activities at the input and production stages, both women and youth have a low involvement. At the post-harvest and marketing stages, women and youth both play a medium role. Small-scale and medium scale farmers mainly engage in the production activities. In the harvesting, storage, processing and marketing activities, small, medium and large-scale actors are present (Figure 10).

Key activities at the input stage for the legume commodity group are seed sourcing by farmers. In addition, the government provides seed certification, and pesticide supply is by agro-dealers. Land preparation, harvesting, and pest and disease control are the major activities during production. The most important activities at processing are packaging, storage and crop protection by farmers and cooperatives. There is also aggregation and processing which is mainly the role of farmer groups and traders. At the marketing stage, the most important activities include linkage to buyers by extension group leaders and traders, and selling and transportation both supported mainly by traders and farmers (Figure 10).

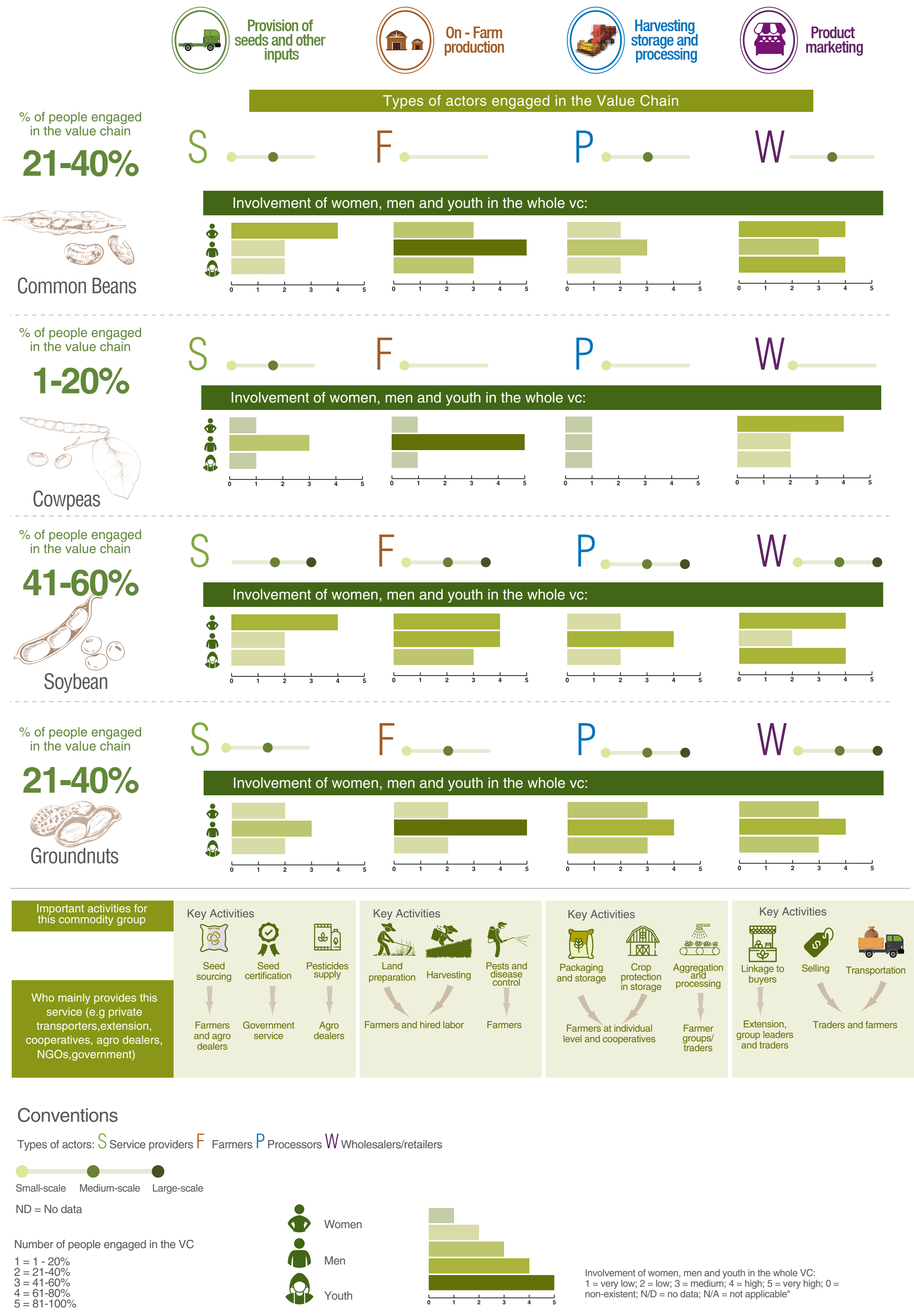


Figure 10: Characterization of the activities and the actors involved in the legume commodity group

B. Rice

The rice value chain engages 61-80 per cent of the population in Zambia. Major input activities are sourcing of certified seed provided by agricultural dealers and cooperatives. ZARI is the main supplier of the basic seed. Government/private institutions such as world vision, CAMCO and TLC, provide extension services. The private sector is the main provider for mechanized technologies. The key activities during on-farm production are land preparation, planting, weeding and spraying which farmers provide. Women play a major role in the input acquisition and marketing activities in the rice value chain. Men dominate the harvesting, processing and storage, and have a high role during production and marketing. Young people have little engagement in input provision, medium contribution to the processing, and high involvement in production and marketing.

Small and medium-scale scale farmers mainly engage in the sourcing of seed and other inputs. The production activities are land preparation, planting, weeding and harvesting. In the processing stage, medium-scale processors who are mainly the cooperatives and private sector, perform bulking, transportation, and processing. Key activities in the marketing stage are grading, market linkage, pricing, negotiation and selling by small, medium and large-scale wholesalers. Cooperatives and non-governmental organizations (NGOs), such as CAMCO, provide the marketing services (Figure 11).

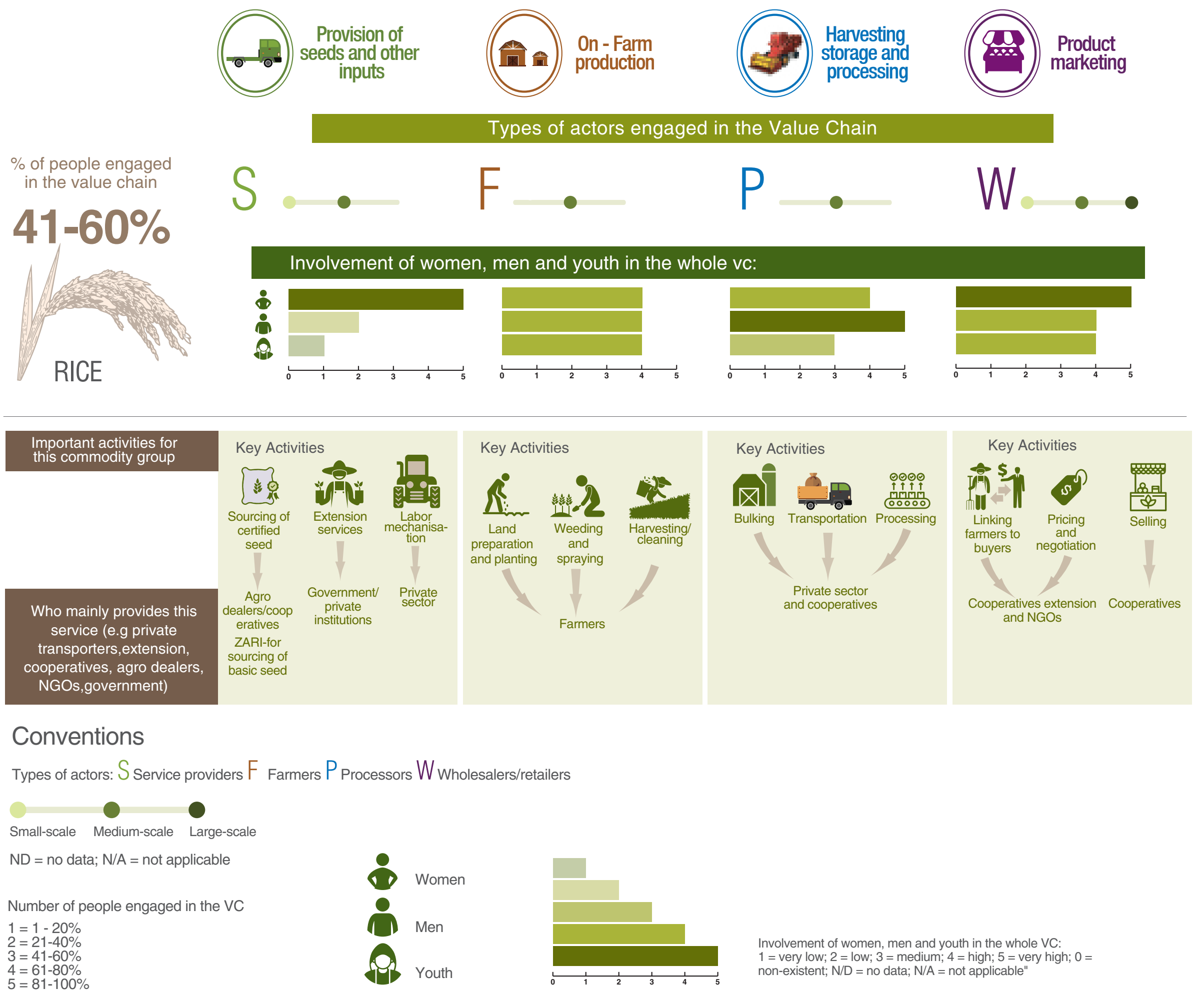


Figure 11: Characterization of the activities and the actors involved in the rice value chain

C. Small livestock

An estimated 80 per cent of the population in Zambia is engaged in the local poultry value chain. Small-scale farmers, who are mostly the men, dominate the production stage activities. Most input providers are small-scale (Figure 12). Women are majorly responsible for sourcing of feed and other inputs. The youth also play a medium role in the input and on-farm production stages. Harvesting and processing employs a lower number of people compared to the other stages of the local poultry value chain because of the limited activities. Thereby men and youth both have a low involvement in these activities. There is a very high involvement of men in the marketing, followed by a medium contribution by the youth. Contrary to the significant contribution made by women to sourcing for feed and other inputs, they have a very low involvement in the marketing. The majority of the wholesalers are small-scale, with only a few large-scale processors.

The pig value chain engages about 21-40 per cent of the population. Input suppliers are mainly medium-scale. Medium-scale farmers dominate the production stage, with men having a very high contribution in the activities. There are few large-scale processors, and wholesalers. Women are very actively engaged in the pig value chain, with a very high involvement in input, production and post-harvest stages. The main contribution of men is in the marketing, and they play a medium role in production and input acquisition activities. Young people have a low involvement in the activities at the four stages of the value chain.

An estimated 21-40 per cent of the population in Zambia is engaged in the goat value chain. Medium-scale service providers are involved in the provision of inputs. Women are dominant in the sourcing of feed and other inputs. Small and medium-scale farmers, who are mostly men, are involved in production activities. Similar to poultry and sheep, processing and marketing is carried out by large-scale actors, although few in number. Most input providers are small-scale. Women are majorly responsible for sourcing of feed and other inputs. The youth also play a medium role in the input and on-farm production stages. Both women and youth have a very high involvement in the marketing activities (Figure 12).

The sheep value chain is the least dominant among the small livestock, employing less than 20 per cent of the population. Women play the most dominant role in all the value chain stages, which include: provision of feed and other inputs, on-farm production, harvesting, storage and processing, and product marketing. Processing activities are negligible in this value chain. Medium-scale service providers are involved in the supply of inputs. There are medium- and large-scale farmers involved in the production. The wholesalers are mainly medium-scale.

The key activities at the input stage for the small livestock commodity group are stocking of inputs, transportation and feed formulation. Input suppliers and the private sector are the main providers of these services. At the production stage, main activities are extension services, breeding and disease control that are supplied by the government and some NGOs. Processing, storage and transportation are the major post-harvest activities provided by individual farmers, farmer groups and cooperatives. For small livestock marketing, extension group leaders and traders support retailing, while packaging and transportation involves both farmers and traders (Figure 12).

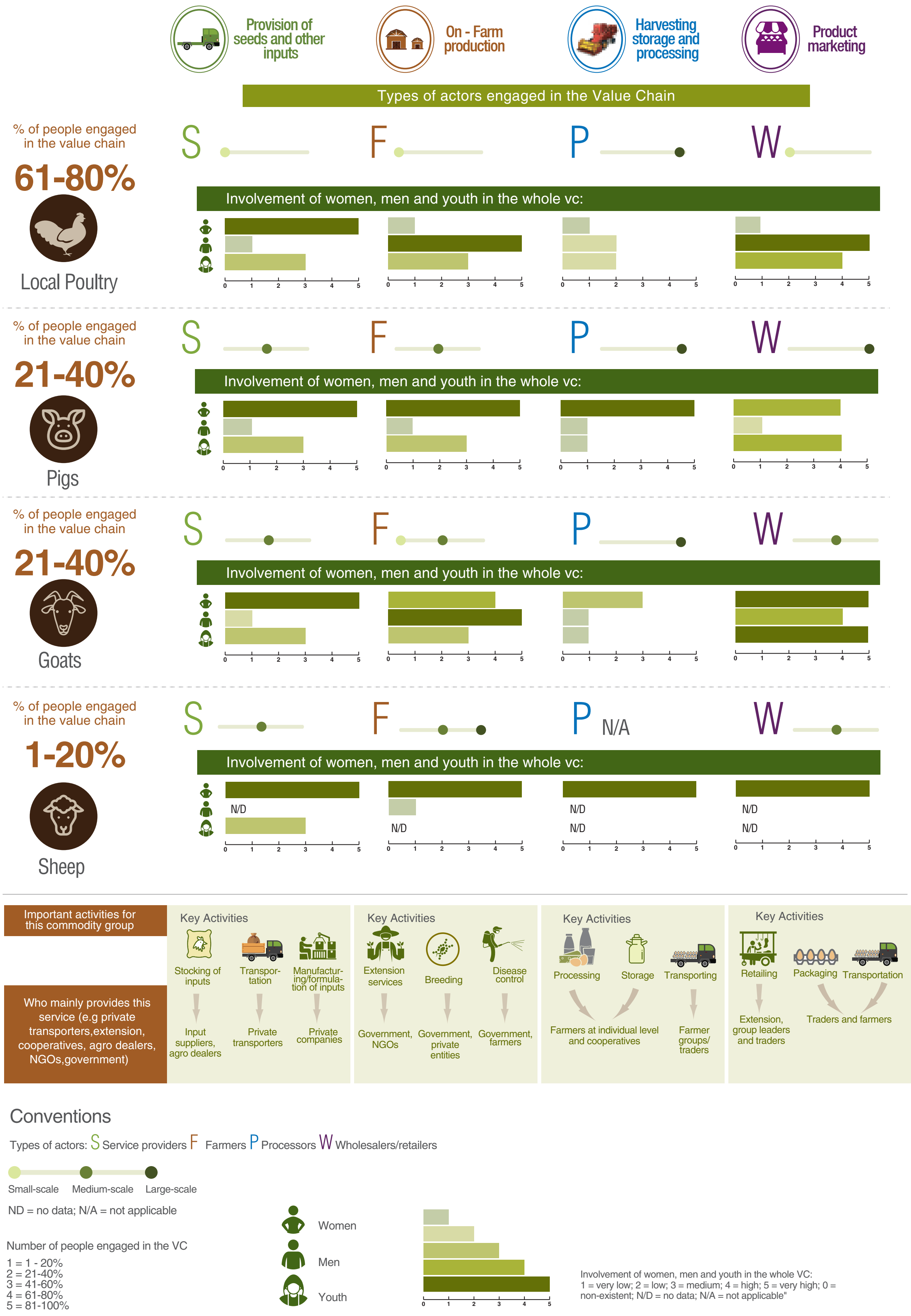


Figure 12: Characterization of the activities and the actors involved in the small livestock commodity group

Conclusions for Chapter 1

Small scale and medium scale actors dominate the value chain activities. Processing activities are limited and there are few large-scale processors, and wholesalers. Young people have little engagement in input provision, medium contribution to the processing, and high involvement in production and marketing.

Chapter 2: Climate hazard analysis

Chapter authors: Wilson Nguru and Caroline Mwongera

Key messages

- For Zambia, the most significant meteorological indicators affecting agriculture are linked to the changes in temperature and precipitation.
- Long-term observations indicate that Zambia's territory has been warming in the last few decades. Average temperatures within the last period of 33 years (1982 to 2015), show an increase of ~ 0.7^{0} C for the summer (wet season), and a higher rate in the increase for winter (dry season) temperatures at ~ 2.3^{0} C
- Warmer temperatures are expected to bring about a devastating effect on the agricultural production exposing crops to heat stresses.
- The length of the growing period (LGP), which is the determined as the average number of growing days has been decreasing during the wet season.
- Heat stress is increasing in intensity, and will lead to reduced animal and crop production.
- Annual precipitation for the period between 1981 and 2018 shows a decrease during the dry season and an increase during the wet season.

2.1 Introduction

Zambia lies within the tropics but due to its high altitude, enjoys a subtropical climate rather than tropical conditions for most of the year characterized by two seasons (Camerapix, 1996).

Zambia is characterized by two seasons:

a. The cool and hot dry season (May to October) - Rainfall is usually absent while temperatures vary from 16 °C to 21 °C. This season is split into a 'dry cool period' from May to July, called midwinter season, that experiences low average temperatures of up to 16 °C and a 'dry hot period' with average temperatures of 24 °C (Food and Agriculture Organization of the United Nations, 2005). Maximum daily temperatures between 30 °C and 40 °C are common especially in the low-lying valley areas such as the Zambezi, Gwembe and Luangwa valleys. Therefore, these areas enable irrigation of winter-maize. During the dry cool period, frost is common.

b. The wet season (November to April) – This period receives rainfall with December and January/February being the wettest months. Average temperatures during this season are around 21 °C. Rainfall is unimodal and is mainly influenced by the Inter-Tropical Convergence Zone (ITCZ) with variations due to altitude, latitude, temperature, relative humidity and control of air masses (Food and Agriculture Organization of the United Nations, 2005). The ITCZ is essentially a low air-pressure zone or belt that attracts the moist north easterly/westerly winds, bringing rainfall to the area. This low-pressure zone mostly lies over the Democratic Republic of the Congo and the northern parts of Zambia for a long period during summer, bringing about the rainy season between the months of November and April. Mean annual rainfall is approximately 1 020 mm. it is lowest in the south, at 750 mm, while the central parts of the country experience between 900 and 1 200 mm and the north about 1 400 mm (Food and Agriculture Organization of the United Nations, 2005).

Hazard refers to climate-related physical events or trends or their physical impacts that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption and environmental damage (IPCC, 2014). In this study, we consider hazards that may affect agriculture activities or cause loss to livelihoods directly linked to agriculture.

A. Climate Indices

Exposure variables are strictly climatic phenomena, such as the magnitude, rate of change or variation in rainfall and temperature or meteorological events such as drought or flooding. We use desk research and stakeholder consultations to identify relevant indicators for the study context.

i) Temperature

Daily temperature data was downloaded from NASA power (https://power.larc.nasa.gov/data-access-viewer/) for 10 weather stations in each province across Zambia and within all the four agro-ecological zones. The data was averaged to produce a whole country average dated from Jan 1982 to December 2015. The output data was the average temperature for the country per year as shown in Figure 13.

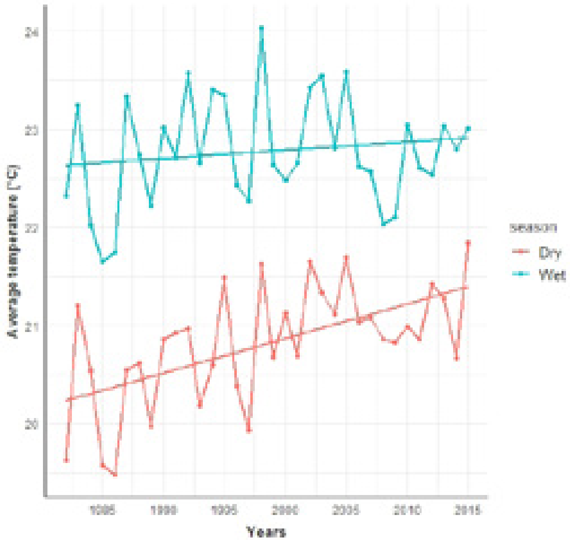


Figure 13: Observed temperature trends in Zambia (1982 - 2015)

Zambia's average annual temperature trend between 1982 and 2015 is highly significant. This gives a period of 33 years of data, which can effectively be used to monitor climate change. The wet season occurs during summer, while the dry season occurs during winter. During the wet season, the average observed annual temperature in 1982 was ~22.3⁰ C, which over the years increased to 23⁰ C in 2015. This is an average increase of ~0.7⁰ C within a period of 33 years, which is attributed to climate change in recent decades with a maximum average annual temperature of 24.1⁰ C in 1998. The observed average temperature trend in the dry season, however, increased drastically from ~19.6⁰ C in 1982 to 21.9⁰ C in 2015, bringing an average increase of ~2.3⁰ C over the years (Figure 13). This observation shows that summer temperatures are increasing, as well as winter temperatures, but at a higher rate because of global warming.

ii) Precipitation

Total annual precipitation per season in Zambia was obtained from Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) for the whole country at a resolution of 0.05⁰ for 1981 to 2018. The data was daily gridded precipitation. The daily precipitation was averaged for the whole country and added for the years from 1981 to 2018.

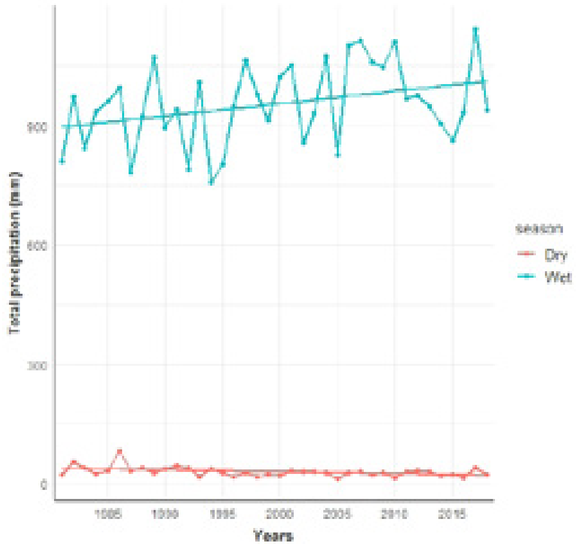


Figure 14: Observed precipitation trends in Zambia (1981 - 2018)

The total annual precipitation in Zambia for the period between 1981 and 2018 shows both a decrease during the dry season and an increase during the wet season. The wet season rainfall over the years varies from the lowest at ~750 mm in 1981 to the highest event at ~1150 mm in 2017 (Figure 14). From the general trend observed during the wet season, an increase of ~100mm, from 900 mm to 1000 mm has been recorded. However, consultation with stakeholder reveal a contrary perception that the amount of precipitation has been decreasing over the years. This can be explained by the fact that the country is experiencing increased rainfall intensity over a very short period of time (Gannon et al., 2014). This reduction of the frequency of rainy days means that there are longer dry spells interspersed by more intense heavy precipitation events. Therefore, rainfall is recorded showing increased total amounts. The dry season rainfall however shows a continued decline with the total annual precipitation being maintained at ~25 to ~30 mm. These outputs indicate the influence of natural annual variability on precipitation, suggesting that climate change has affected intensity, duration and distribution of rainfall.

B. Climate hazards

Climate change results into various extreme events that constraints crop and animal production. In crop and fodder production, increased moisture and heat stresses are considered the most critical (FAO, 2019). Changes in both temperature and precipitation determine the availability of moisture. Higher or warmer temperatures increase water losses resulting from evapotranspiration (Mortsch, 2005). Growing periods with warmer and longer temperatures result in heightened extremes resulting in acute water stresses and consequently drought. Drought stress accelerates the number of days to maturity leading to shortened crop reproduction stage, pollen sterility, reduction in leaf area and ultimate reduction in crop yields (Barnabás et al., 2008; Alqudah et al., 2011).

i) Drought Stress

In this study, the maximum number of Consecutive Dry Days (CDD) is analysed seasonally and in each year as a proxy for within-season dry spell length. This is a good indicator of drought stress. Seasonal Maximum number of consecutive dry days were taken as days with rainfall less than 1 mm/day.

The frequency of CDD relative to the base period 1981 to 2018 has slightly increased with an average of 15 CDD across the wet season. In the wet season, greater peaks were observed in 1981, 1999 and 2009 (Figure15). The overall maximum number of CDD pattern is in general consistent with the historical drought occurrences in Zambia since 1981 with a major drought occurring in 2005 and the most recent 2017/2018 season having prolonged dry spells (Funder et al., 2018; Reliefweb, 2019; Mulenga et al., 2017).

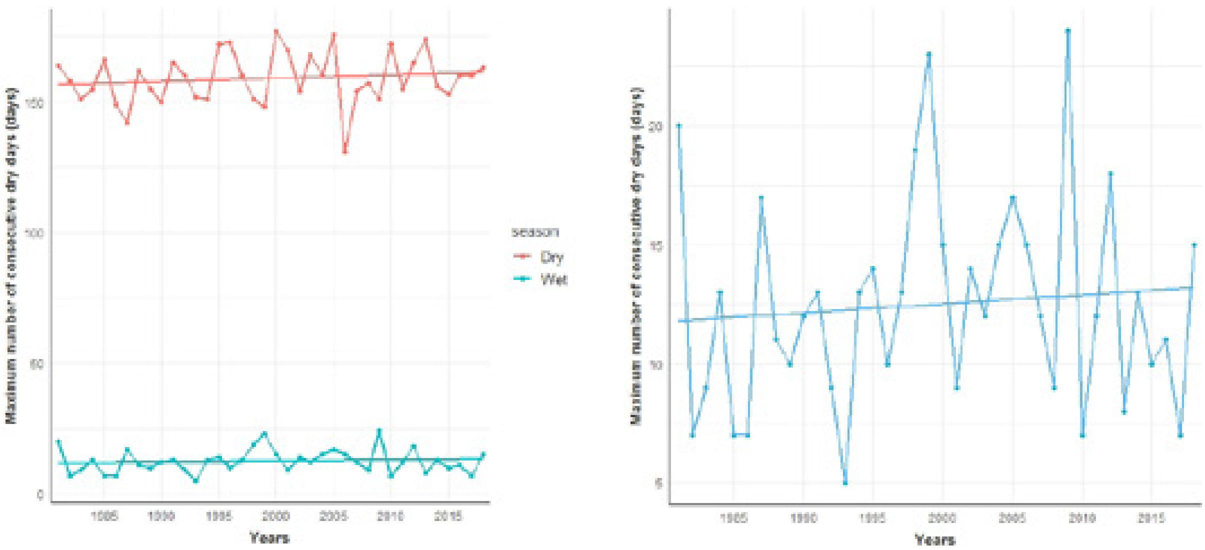


Figure 15: Maximum number of consecutive dry days (CDD) in Zambia for the period 1981-2018 derived from observed climatic data. Right panel is the maximum number of CDD for the wet season only.

Zambia's agricultural sector is highly dependent on rain-fed production and therefore vulnerable to weather shocks. Few farmers use mechanized irrigation and climate change therefore, has the potential to significantly reduce agricultural production and exacerbate poverty and food insecurity (Mulenga and Wineman, 2014). Drought has been the major threat to food security, with large declines in crop yields occurring consistently in seasons having below than normal rainfall (Muchinda 2001) Drought has been the major threat to food security, with large declines in crop yields occurring consistently in seasons having below than normal rainfall (Muchinda 2001).

Due to its high reliance on rainfed agriculture, Zambia food production is highly vulnerable to intolerably longer and intense dry spells. Increased temperatures together with frequent droughts has led to declining access to food, causing starvation and poverty. For example, the strong drought in 2015/2016, due to a strong El-Niño, weakened the adaptive capacity of small-scale farmers and lowered their resilience towards the following seasons' dry spells (Reliefweb, 2019) pushing people below the poverty line. Frequent droughts together with increased temperatures affects forage quantity and quality, water accessibility and increases heat stress on livestock therefore, leading to reduced livestock production.

ii) Flooding

With climate change in Zambia, small-scale farmers started experiencing unpredictable rainfall, which involved experiencing heavy rains and floods (UNDP, 2010). Over the past two decades, flooding in the wet season has been on the rise leading to, loss of lives and property. The rainfall intensity has increased, resulting in associated consequences of flooding and soil erosion (Funder et al., 2018). Flooding occurrences in Zambia were recorded in the period between 1997 and 1998 as well as 2005 and 2009.

The characterization of extreme precipitation used in this study is determined by the 95th per centile threshold and maximum 5-day moving average applied to daily precipitation values. The analysis is carried out on a daily-yearly basis on the same location, across the two seasons for the observed and predicted precipitation values during all the wet events.

The ***95th per centile rainfall*** event is the event whose precipitation total is greater than or equal to 95per cent of all storm events over the given period of record. This was carried out for each season for the years involved;

a. Removing all observed values less than 2.54 mm as they do not cause runoff and could potentially cause the analyses of the 95th per centile storm runoff volume to be inaccurate.

b. Calculating the 95per cent rainfall event and used it as the 95th per centile storm event for each season. (Environmental Protection Agency, 2009)

A graph of 95th per centile of daily precipitation over the years was plotted as shown in Figure 16(a).

The ***maximum 5-day running average*** represents the highest 5-day running average precipitation in each season or the highest rainfall average for five consecutive days from the start of season (Figure 16(b).

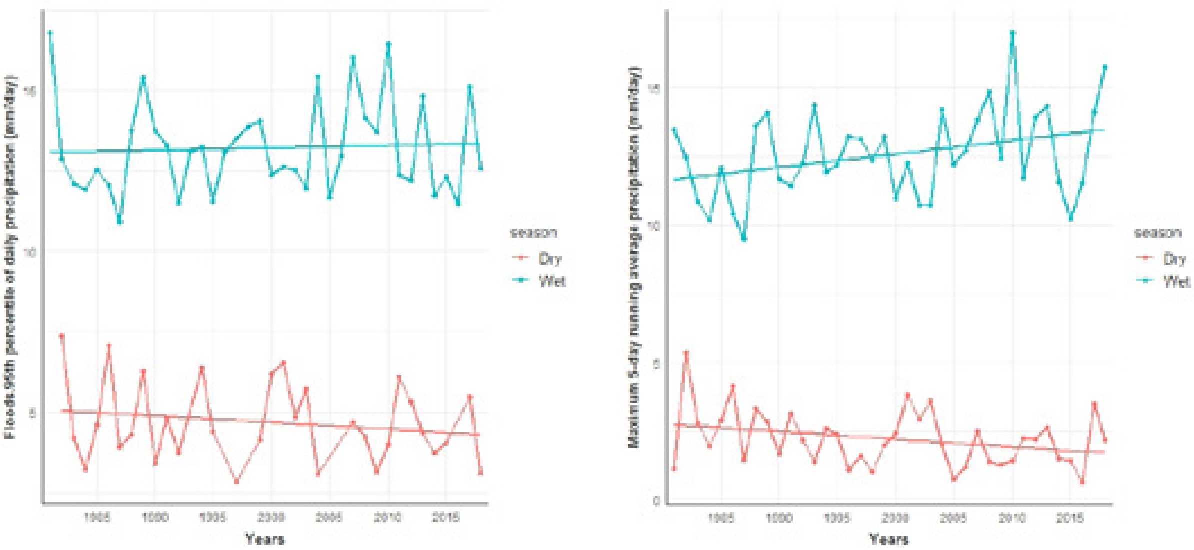


Figure 16: Extreme precipitation events; (1982-2015). On the left is the 95th per centile (a) and on the right is the maximum 5-day running average derived from gridded average precipitation values (b)

Observed extreme precipitation pattern during the wet season is more variable at an increasing trend generally matching calculated precipitation pattern (Figure 16*)*. At 95th per centile, extreme daily precipitation events are steadily maintained at ~13 mm/day during the wet season. The trend shows a steady increase of rainfall in the maximum 5-day rolling average in the wet season with an increase of ~17mm. Analysis of the inter-annual variability of the extreme rainfall events shows that the wettest events were recorded in the period between 1997 and 1999 as well as 2005 and 2010 which coincides with the historical flooding occurrences (Umar and Nyanga, 2011; Mubaya et al., 2010). Previous studies also show that the frequency, intensity and geographic distribution of flood incidents have increased over the past two decades (UNDP, 2010). Historical floods have occurred in Zambia over the years causing loss of lives and property. For example, the floods in 1998/99, there was total loss of harvests, which led to increased unemployment and a 10per cent poverty incidence (Stern, 2007).

iii) Moisture Stress

Observed moisture stress was determined as the maximum number of consecutive days with the ratio of Et (**actual evapotranspiration**) to Ep (**potential evapotranspiration**) below 0.5. Typically, this is a measure of plant water supply in relation to plant water requirement.

Potential evapotranspiration (Ep) defines the maximum possible water loss from a vegetation covered land surface while actual evapotranspiration (Et) is the actual water loss from soil.

Ep was calculated using the FAO ***Penman-Monteith equation***

Where:

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a}{\Delta + \gamma(1 + 0.34u_2}$$

ET_O is the reference evapotranspiration (mm/day),
R_n is net radiation at the crop surface (MJ/m^2/day),
G is soil heat flux density (MJ/m^2/day),
T is mean daily air temperature at 2 m height (°C),
u_2 is wind speed at 2 m height (m/s)
e_s is saturation vapour pressure (kPa),
e_a is actual vapour pressure (kPa),
e_s - e_a saturation vapour pressure deficit (kPa),
slope vapour pressure curve (kPa/ °C),
■ psychrometric constant (kPa /°C).

Et on the other hand was calculated using **Brutsaert and Strickler** equation (Brutsaert and Strickler, 1979 (McMahon et al., 2013)potential, reference crop and pan evaporation covers topics that are of interest to researchers, consulting hydrologists and practicing engineers. Topics include estimating actual evaporation from deep lakes and from farm dams and for catchment water balance studies, estimating potential evaporation as input to rainfall-runoff models, and reference crop evapotranspiration for small irrigation areas, and for irrigation within large irrigation districts. Inspiration for this guide arose in response to the authors' experiences in reviewing research papers and consulting reports where estimation of the actual evaporation component in catchment and water balance studies was often inadequately handled. Practical guides using consistent terminology that cover both theory and practice are not readily available. Here we provide such a guide, which is divided into three parts. The first part provides background theory and an outline of the conceptual models of potential evaporation of Penman, Penman-Monteith and Priestley-Taylor, as well as discussions of reference crop evapotranspiration and Class-A pan evaporation. The last two sub-sections in this first part include techniques to estimate actual evaporation from (i

Where:

$$E_{Act}^{BS} = (2\alpha_{PT} - 1)\frac{\Delta}{\Delta + \gamma}\frac{R_n}{\lambda} - \frac{\gamma}{\Delta + \gamma} f(u_2)(v_\partial^* - v_\partial)$$

E_{Act}^{BS} is the actual evapotranspiration estimated by Brutsaert and Strickler equation (mm/day),

α_{PT} is the Priestley-Taylor coefficient,

Δ is the slope vapour pressure curve (kPa/°C),

γ is the psychrometric constant (kPa/°C),

R_n is the net radiation at the crop surface (MJ/m2/day),

$v_\partial^* - v_\partial$ is vapour pressure deficit (kPa),

u_2 is wind speed at 2 m height (m/s).

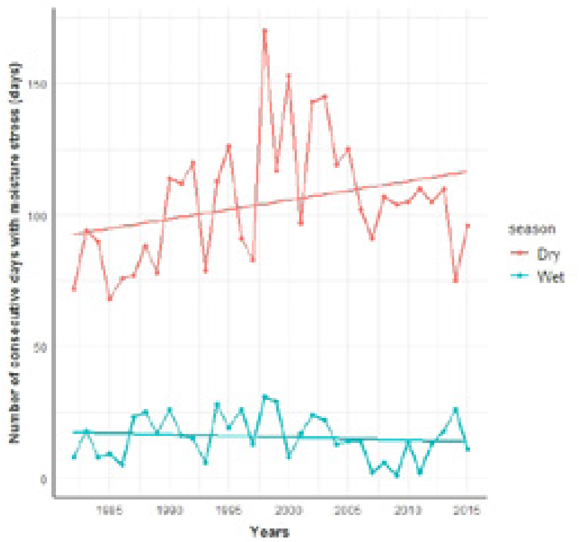


Figure 17: Observed moisture stress determined as the maximum number of consecutive days with the ratio of Et to Ep below 0.5

Patterns of moisture stress in Zambia show a decreasing general trend in the wet season and an increasing general trend in the dry season. In the wet season however, our analysis indicates increased variability over the years with 1990, 1994, 1996, 1998, 1999 and 2014 showing high moisture stresses. These coincides with the 1991-1994, 1999-2000 and 2014-2016 drought events. The general trend of moisture stresses in the dry season records an increase of approximately 20 days since 1982 (Figure 17). This could be attributed to reduction in the dry season precipitation and the overall temperature increase over this period. The high rainfall during this period can explain the drop in the moisture stress in 2004-2005 and up to 2009, and the reduction in 2015 was due to El Nino/flood events respectively experienced in Zambia during this period.

iv) Season Onset

Start and of length of growing period is determined by 5-consecutive growing days (GD), where GD is estimated using a moisture-limiting and temperature-limiting approach. Growing days are the days during a season when average temperatures are greater than or equal to 5°C and precipitation exceeds half the potential evapotranspiration (FAO, 1980; Fischer et al., 2008).

The variations in the onset date between the years could be up to 29 days (4 weeks) (Figure 18). A delay of 1 or 2 weeks in the onset is sufficient to destroy the expectations of a normal harvest. A false start of a season results into planting, encouraged by a false start of rainfall, which may be followed by prolonged dry spells whose duration of 2 weeks or more may be critical to plant germination and/or growth (Leclerc et al., 2014). For instance, in 1984 and 2009, season onset was earlier in Zambia (Figure 18) which could have led to a risk of farmers sowing too late. To most subsistence farmers, having prior information about the onset of a season has strong implications for their agricultural activities and hence on crop yields later in the season. Enough soil moisture is required to meet the needs of a crop during sowing. Therefore, information on the onset of the season is significant in planning the timely preparation of farmlands and in reducing the risks involved in planting too early or too late (Omotosho et al., 2000).

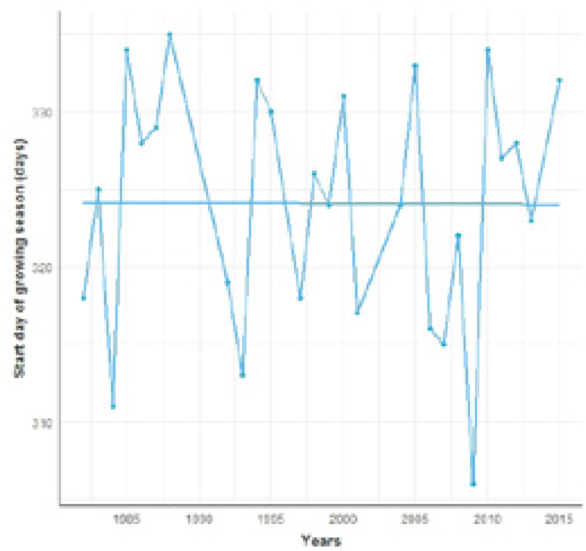


Figure 18: Starting of the growing season in Zambia, 1982-2015 determined by 5-consecutive growing days

The starting of rains is a very crucial factor in the development of agriculture and in adapting to climate change. For example, earlier planting can avoid the mid-season dry spell or nitrogen-removing excessive rainfall for crops such as maize when it is in its most vulnerable growth phase. The impact of rainfall variability on crop production is therefore clearly tied to the planting date and timing with respect to the crop phenological phases (Tadross et al., 2009).

v) Length of Growing Period

The length of the growing period (LGP) is determined as the total number of growing days. Growing days are estimated using moisture-limiting and temperature-limiting approach. Growing days are the days during a season when average temperatures are greater than or equal to 5^{o} C and precipitation exceeds half the potential evapotranspiration (FAO, 1980). The length of the growing period can be viewed as the entire period in which growth can theoretically take place. LGP variations are a useful climatic indicator and have several important climatological applications (Robeson, 2002).

In Zambia, the length of the growing period from 1982 to 2015 varied from the highest at 140 days in 1986 and the lowest at 90 days in 1994 (Figure 19). The year 1994 can be explained by the presence of a drought. Going back to the question of, "is precipitation increasing or decreasing over the years in Zambia?" Using the length of the growing period, the general trend shows that the growing days are actually decreasing during the wet season. This means that growing days or the days in which precipitation exceeds half the potential evapotranspiration are decreasing. This supports the argument that there is a reduction in the frequency of rainy days bringing about seasons with longer dry spells interspersed by more intense heavy precipitation events.

A decrease in LGP could result, for example, in alteration of planting dates determining lower yields of traditionally planting crops, which may not fully mature. The decrease of LGP will not only affect crops in Zambia, but also livestock keeping, as growing days affect forage availability (Thornton et al. 2011). Fluctuations in the annual rainfall series and the episodes of above and below average rainfalls have previously been identified in Africa.

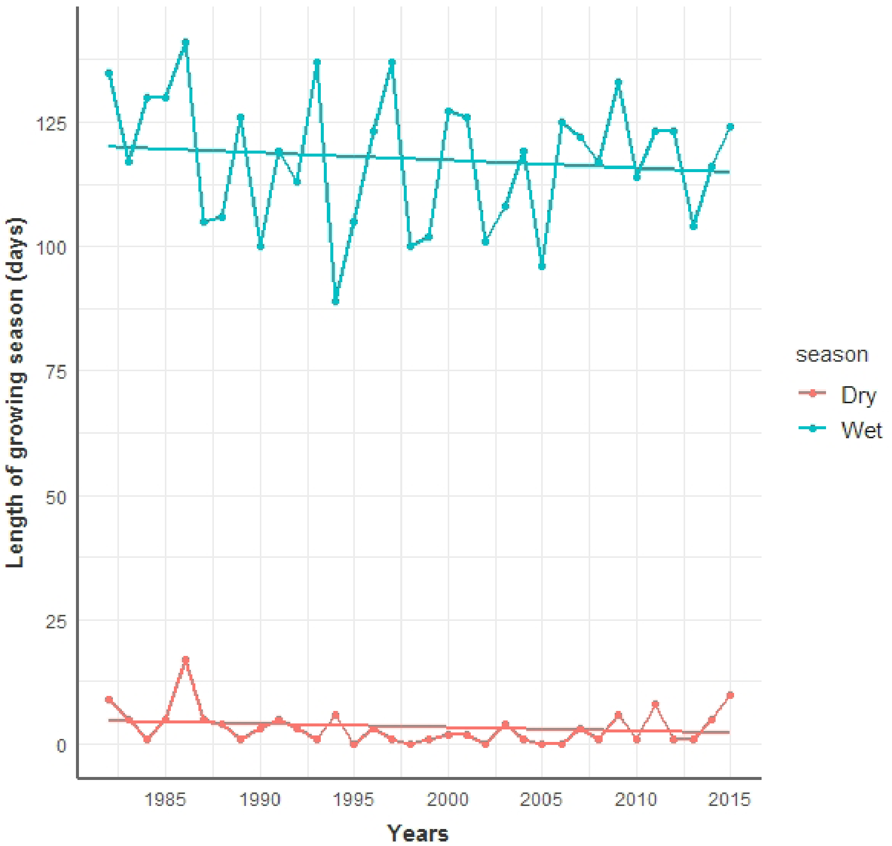


Figure 19: Length of the growing period in Zambia, 1982-2015 determined as the total number of growing days growing days

vi) Heat Stress

In the coming years, temperatures across all of Southern Africa are expected to increase gradually. This is expected to bring about higher incidences of extreme heatwaves and elevate evapotranspiration rates (US-EPA Climate Change Division, 2016). Rising temperatures have brought a negative impact on the agricultural sector by compromising livestock and crop health (Thurlow et al., 2012) and reducing labour productivity, as well as in the human health (Gannon et al., 2014).

In this study, heat stress is generally determined by looking at three indicators; temperature variability (see discussion on temperature), growing degree-days (GDD) and the total number of days with maximum temperature greater or equal to 35^{o} C. GDD, calculated at a base temperature (T_{base}) of 10^{o} C is a weather-based indicator for accessing/monitoring crop development, and determining suitability of a region for crop production, cutting dates for forage crops and calculation of harvest dates. The base temperature is that temperature below which plant growth is zero. Any daily mean temperature below T_{base} was set to T_{base} and therefore, giving a zero value. Likewise, the maximum mean temperature was capped at 35 °C above which most plants do not grow any faster.

$$GDD = \sum\left(\left(\frac{T_{max} - T_{min}}{2}\right) - T_{base}\right)$$

Or

$$GDD = \sum(T_{mean} - T_{base})$$

Where;

- T_{max} is the daily maximum air temperature
- T_{min} is the daily minimum air temperature
- T_{mean} is the average temperature
- T_{base} is the temperature below which the crop development does not occur

The total GDDs per season were calculated by adding up all the daily GDDs in that season of the year and average was calculated to obtain mean GDDs per day of a season in a specific year in $°C/day$.

Total number of days with maximum temperature greater or equal to 35 °C were obtained per season in a year. This was done by identifying days in which maximum temperature was greater or equal to 35 °C and adding up these days for each season in a specific year.

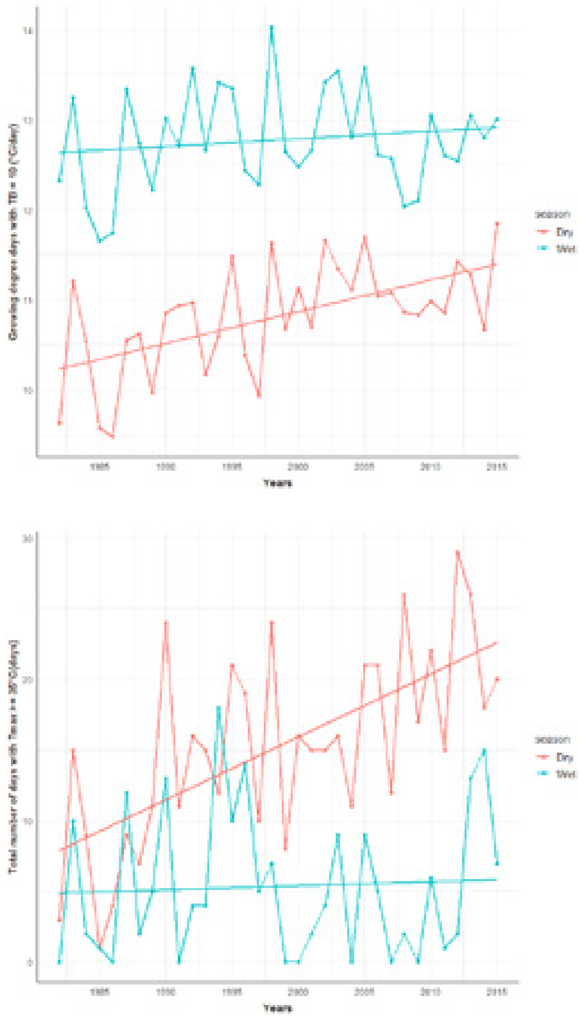


Figure 20: On the left is observed growing degree-days (GDD) in Zambia 1982-2015. On the right, number of observed hot days with temperature capped at 35^{0} C and above

Average GDD trend during the wet season between 1982 and 2005 is highly significant. This clearly coincides with the upward temperature trend observed during the same period. GDD in the wet season varies between 11.6 and 14^{o} C per day over the years while it varies between 5 and 11^{o} C per day during the dry season. The general trend during the wet season shows a gradual increase of GDD in the wet season from

~12.6^{o} C /day to ~12.9^{o} C /day (Figure 20). This is an upward trend of about 0.3^{o} C /day, resulting from the variability in maximum and minimum daily temperature. The dry season shows an extremely high increase in the GDD from 10.2 to 11.4^{o} C /day attributed to an increase in temperature over the years.

The number of observed hot days with temperature greater or equal to 35^{o} C shows a slight increase during the wet season with a general increase from 5 to 6 days, i.e. an increase with one day over the period between 1982 and 2015. In the dry season, an increase of 15 days has been registered.

This shows that winters are actually becoming warmer due to climate change. The conspicuous peak in 1997 is attributed to the 1997/1998 El-Nino event that was accompanied by high temperatures.

Warmer temperatures are expected to bring about a devastating effect on the agricultural production in the sub-Saharan Africa through exposing crops to heat stresses. This will lead to reduced animal and crop production as it increases the intensity, frequency and relative damage due to heat stress (Teixeira et al., 2013).

Conclusions for Chapter 2

The last three decades have been characterized by large inter-annual variability and frequent droughts (Arslan et al., 2015), and are projected to continue (Thurlow et al., 2012). Jain (2007) reports that, for the main growing season (November to April), an increase in the November to December mean temperature and a decrease in the January to February mean rainfall (likely relating to drought levels) have negative impacts on net farm revenue. At the same time, farmers have perceived less predictable rains, later season onsets, and frequent dry spells (Mulenga et al., 2017).

Chapter 3: Vulnerability analysis for selected crop and livestock value chains in Zambia

Chapter authors: Julian Ramirez-Villegas; Brayan Mora; John Mutua; Jeison Mesa; and Caroline Mwongera

Key messages

- The amount of suitable areas for crops is projected to decrease, with rice and cowpea being the most negatively impacted crops. The frequency of heat stress days for livestock increases, with cattle and pig being particularly impacted.
- Several areas for work for the Zambian Government and society appear in terms of improving adaptive capacity in the country. Most notably, a reduction in the prevalence of stunting in rural areas likely through sustainable agricultural intensification and enhanced resilience, improvements in the capacity of education institutions, and an overall reduction in the incidence of poverty across the country.
- Overall, agricultural vulnerability is greatest towards the western, southwestern and northern districts. In the coming decades, unless adaptive capacity is enhanced, and adaptation strategies are implemented throughout the country, climate change will exacerbate vulnerability even further.
- Vulnerability of livestock production is greater than that of crops. Livestock vulnerability is greatest in the warm semi-arid and warm sub-humid zone due to their greatest exposure to heat stress.

3.1 Introduction

Zambia lies within the tropics but due to its high altitude, it enjoys a subtropical climate characterized by two seasons (Mulenga et al., 2017; Stern and Cooper, 2011). During the cool and hot dry season (May to October) rainfall is usually absent, while temperatures vary from 16° C to 21° C; these areas enable irrigation of winter maize. The second season, referred to as the wet season (November to April) receives rainfall with December and January/February being the wettest months. Mean annual rainfall ranges between 750 mm (southern Zambia) and 1400 mm (northern Zambia). Because of these variations, Zambia has been classified into four agroecological zones (Figure 21) (FAO/IIASA, 2002). The wettest areas (warm sub-humid, cool sub-humid) are located towards the north and north-west, towards the border with the Democratic Republic of Congo (DRC). Conversely, the drier semi-arid areas (cool and warm) are located towards the south.

The warm semi-arid zone is a low on rainfall, and receives mean rainfall of below 800 mm per annum from November to about mid-December, due to its low altitudes that range between 400 to 900 meters above sea level (Shitumbanuma et al., 2016). It has an average growing season of 80 to 120 days (Umar, 2012). The soil type in this region is loam to clay on the valley floor, while on the escarpments it has coarse to fine textured loamy shallow soils. Thus, the region supports the growth of short-duration crop varieties such as sesame, sorghum, groundnut, bean, sweet potato, cassava, rice, cotton and millet (Green Climate Fund, 2018). Beans grown in these areas should be of fast maturity between 80 and 120 days. The zone has a high potential for irrigated agriculture especially for horticultural crops. Extensive cattle production can be practiced, though, due to low altitude, the region is prone to tsetse fly infestation.

In the cool semi-arid zone, rainfall ranges between 800 and 1000 mm per annum. The growing season is between 100 to 140 days (Shitumbanuma et al., 2016). The most common soils in this region are red to brown clay, to loam. These soils are moderately to strongly leached (Chikowo, 2019). The region supports the production of a variety of food and cash crops. Food crops include maize, vegetables and groundnut. The zone is also suitable for livestock production and beef, dairy and poultry production are practiced (Moonga & Moonga, 2018). Other crops supported, particularly in sandy soils, include rice, cashew nut, timber and vegetables.

The wettest areas (cool and warm sub-humid zones) receive rainfall of between 1,000 mm and 1,500 mm per annum between October to mid-December. They have the longest growing season that ranges from 120 to 150 days (Shitumbanuma et al., 2016). With Copperbelt Province excluded, there is massive leaching of bases in high rainfall areas, thus, hydrogen and aluminium ions are accumulated in the soils (Mweetwa et al., 2016). The soils leached are acidic in nature and thus need the application of agricultural lime and use of manure and organic matter for soil improvement. With perennial streams, the region has the potential to use the waters for small-scale irrigated agriculture. Dominant crops include cassava, bean, millets and maize. Other crops such as sorghum, beans, groundnut, coffee, sugarcane, rice and pineapple can be grown. Besides, fisheries resource management and aquaculture can be practiced to offer income opportunities for the population and for development (Green Climate Fund, 2018).

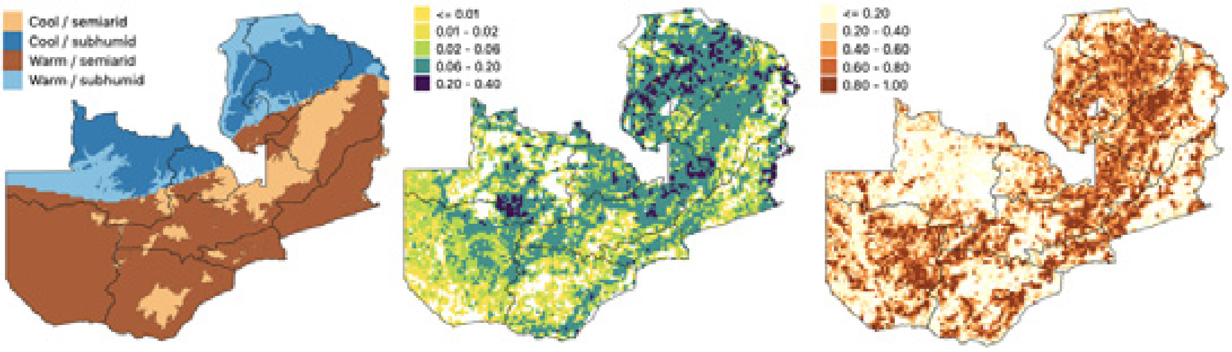


Figure 21: Agroecological zones of Zambia (left), areas cropped (centre), and areas with pastures (right). Data for the left panel were taken from FAO/IIASA (2002), and for the centre and right panels from Ramankutty et al. (2008)

Most of Zambia's territory grows either crops or rears livestock (Figure 21), with crops distributed mainly across the wetter and cooler areas, whereas the pasture areas are distributed mainly across the drier warm areas. The main staple crop is maize, though many other crops including sorghum, cowpea, rice, wheat, cotton and groundnut are also grown (Arslan et al., 2015; Jain, 2007; Rippke et al., 2016). Given the extent of variation in agroecological conditions, and the importance of agriculture, Zambian agriculture is exposed to a variety of climate hazards, which create substantial risks for its farming population (Mubaya et al., 2012; Stern and Cooper, 2011). This is especially so in areas where adaptive capacity is low due to lack of or limited access to financial, health, technical advisory and education services.

Here, we assess vulnerability for crops and livestock in Zambia, using a numerical analysis that explicitly accounts for the level of exposure, sensitivity and adaptive capacity across the entire territory. The analysis uses the vulnerability framework proposed by the IPCC (Adger, 2006; IPCC, 2014; O'Brien et al., 2007), which defines vulnerability as "*the degree to which a system is susceptible to injury, damage or harm*". Vulnerability encompasses three dimensions, namely, exposure, sensitivity and adaptive capacity. Exposure is the amount of climate variation to which a system is subjected; sensitivity is the degree to which the system is affected; and adaptive capacity is the ability to adjust, cope or benefit from the expected climate variations. We implemented the analysis by selecting a series of country-relevant indicators for each of the dimensions of vulnerability and then aggregating them to determine vulnerability for each value chain and district in Zambia.

The specific application of the vulnerability framework we use here is fully described by Parker et al. (2019), whereby vulnerability is calculated using crop-specific sensitivities, exposure to natural hazards and a series of indicators of adaptive capacity (Eq. 1).

$$Overall\ vulnerability = \sum_{i=1}^{n} \frac{1}{2}\left(\left(\frac{1}{2}\left(\frac{Growing\ area_i}{Total\ area} * S_i + E_i\right)\right) - AC\right)$$

[Equation 1]

Where *i* is each value chain; *Growing area* refers to the extent of suitable area for the crop *i*; *Total area* is the total area for all value chains; S_i is the sensitivity of the value chain *i*; E_i is the exposure of each value chain; and *AC* is the adaptive capacity. For livestock species, the ratio of growing to total area is not used in the calculation.

3.2 Sensitivity of value chains to climate change

Sensitivity was defined for crops using suitability, whereas for livestock using the Temperature-humidity Index (THI). Crop suitability measures the extent to which the climatic conditions at particular sites allow farmers to grow a given crop (Rippke et al., 2016; Taba-Morales et al., 2020). The THI helps determine the extent to which a particular livestock species is experiencing heat stress conditions likely to reduce productivity in a particular area. To calculate sensitivity, the following analyses were conducted:

- **Crop suitability analysis.** We calculated changes in crop suitability using the Maxent suitability model for all five crops of interest (groundnut, soybean, bean, cowpea and rice). Maxent modelling was performed using available crop presence data and publicly available gridded climate data for the present and future (2030, 2050), for two Representative Concentration Pathways (RCPs): RCP 4.5 and RCP 8.5. The RCPs try to capture these future trends and make predictions of how concentrations of greenhouse gases in the atmosphere will change in the future as a result of human activity. RCP 4.5 is an intermediate emissions pathways scenario, whereas RCP 8.5 is a high-end scenario, consistent with the highest greenhouse gas emissions.

  Crop presence data were gathered from agricultural census, and public databases including GBIF (http://www.gbif.org) and Genesys (http://www.genesys-pgr.org). Current climate data were gathered from WorldClim (Hijmans et al., 2005), whereas future climate was downloaded from CCAFS-Climate (Navarro-Racines et al., 2020). The future climate data were from five representative Global Climate Models.

- **Livestock heat stress analysis.** We used daily gridded data from both current and future (2021-2050) periods to assess thermal heat stress conditions using a temperature-humidity index (THI). This index is based on temperature and relative humidity parameters and is considered a suitable indicator for assessing the level of heat stress on animals caused by weather conditions. THI was calculated using various equations for specific livestock species i.e. cattle (National Research Council, 1971), sheep and goat (LPHSI, 1990), and poultry (LPHSI, 1990). The THI was classified into four categories: none, mild, moderate, and severe. The sensitivity of livestock to climate change was assessed by analyzing changes in the frequency of severe thermal heat stress (THI) events, which is when livestock productivity starts to be affected by heat conditions. We computed the difference between the current and future periods.

Once future projected changes in crop suitability and livestock heat stress were calculated, we reclassified them into a scale from –1 (no sensitivity) to 1 (high sensitivity). Areas that do not grow the crop or have projected changes in the range –5 to +5 percentage are assigned a value of zero for the sensitivity indicator. Livestock analyses were conducted for all districts.

Figure 22 shows the sensitivity of all crops and livestock species analysed for 2030 under RCP 4.5. All crops experience some degree of sensitivity, with rice and cowpea being the most sensitive crops in this particular scenario and period. Groundnut is the least sensitive crop. As seen in Figure 22, these crop-specific impacts result in an overall decrease in areas virtually throughout the entire country.

Crops **Livestock**

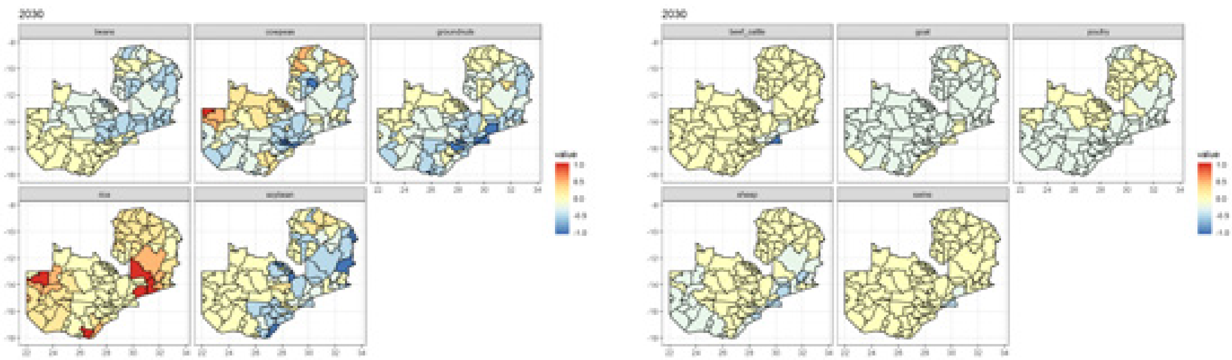


Figure 22: Sensitivity of the ten value chains analysed to climate change under RCP 4.5for 2030

Negative impacts of climate change occur in the north and north-west of the country, towards the semi-humid areas, and hence these areas show the greatest sensitivity across crops. Similar results are seen for livestock, although with generally less sensitivity as compared to crops. We note that pigs and cattle are the species that experience the greatest increase in severe heat stress days, and hence the greatest sensitivity.

Results for other scenarios and periods are shown in Supplementary Figures S1–S3. In general, there is consistency with respect to RCP 4.5 (2030), though with generally less sensitivity for crops under RCP 8.5, likely because of projected precipitation increases in the wet season (IPCC, 2014; Knutti and Sedláček, 2012). Temperature stress for livestock, on the other hand, is more prominent for RCP 8.5, because of more drastic temperature increases.

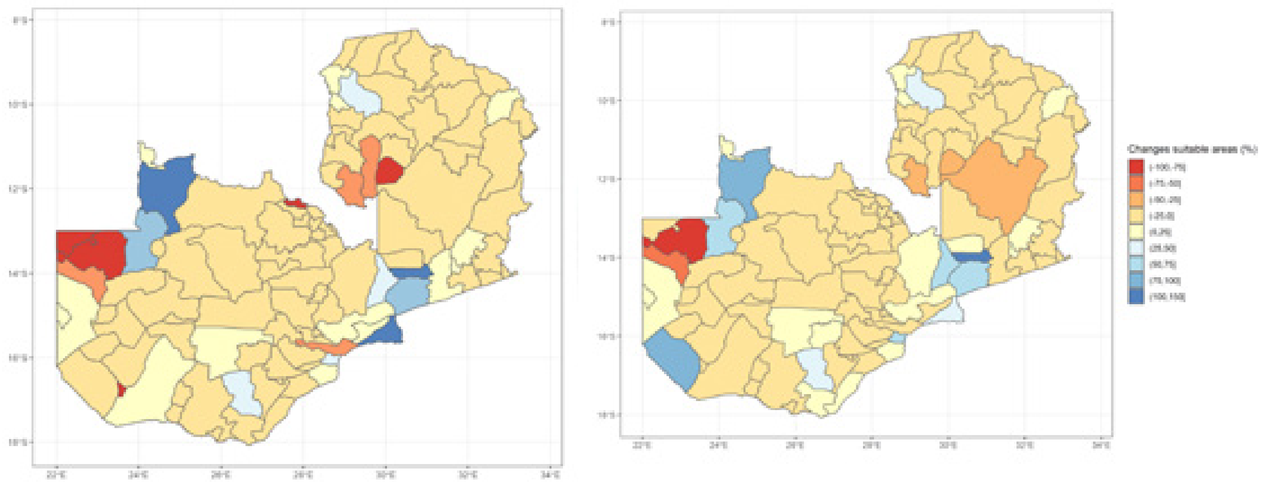


Figure 23: Projected changes in suitable land area for RCP 4.5 (left) and RCP 8.5 (right) by 2030, for the five crop-based value chains analysed

Figure 23 shows the projected changes in suitable land area by 2030 in Zambia. Negative changes of climate change are seen with overall at least a 25 per cent reduction in suitable land for both RCP 4.5 and under RCP 8.5 in all the regions of Zambia.

3.3 Exposure to natural hazards

A wide range of hazards affect agriculture in Zambia. Agriculture is primarily rainfed, and highly exposed to climate variability and change. The last three decades have been characterized by large interannual variability and frequent droughts (Arslan et al., 2015). These trends are projected to continue into the future (Thurlow et al., 2012). Long-term observations indicate that Zambia's territory has also been warming in the last few decades (Mulenga et al., 2017). For instance, Jain (2007) reports that, for the main growing season (November to April), an increase in the November-December mean temperature and a decrease in the January-February mean rainfall (likely relating to drought levels) have negative impacts on net farm revenue. At the same time, farmers have perceived less predictable rains, later rainy season onsets and more frequent dry spells (Mulenga et al., 2017). Concomitantly, land degradation is a major concern across sub-Saharan Africa, with major impacts on crop and livestock productivity throughout the region (Nkonya et al., 2016). Land degradation is tightly related to burning of biomass on the soil surface as part of the standard management practices that many farmers employ throughout Africa[1]. In assessing vulnerability, it is important to consider crop and livestock exposure to these hazards. We thus mapped natural hazards, as shown in Table 1.

Table 1: Key natural hazards for Zambia

Hazard	Reference(s) that justify inclusion	Data link
Drought	Thurlow et al. (2012) Arslan et al. (2015) Mulenga et al. (2017)	https://bit.ly/2pgeN0p
Soil erosion	Nkonya et al. (2016)	https://bit.ly/2JBU0eC
Flooding	Mubaya et al. (2012) Manhique et al. (2015) Mulenga et al. (2017)	https://bit.ly/34kl9ux
Fires	Phillips (2012) Govender et al. (2006)	https://go.nasa.gov/3200nPc

Each of these were normalized on a scale from 0 to 1, and then used into Equation 1 for each district of Zambia. Figure 24 shows the spatial distribution of the four natural hazards considered here. Aridity is the hazard that most affects Zambia. Exposure to arid conditions is particularly high towards the south, and is lowest in the north-western districts. Firesin the period 2001–2018, are a widespread problem, but of moderate intensity. Erosion is a much-localized issue towards the very south of the country.

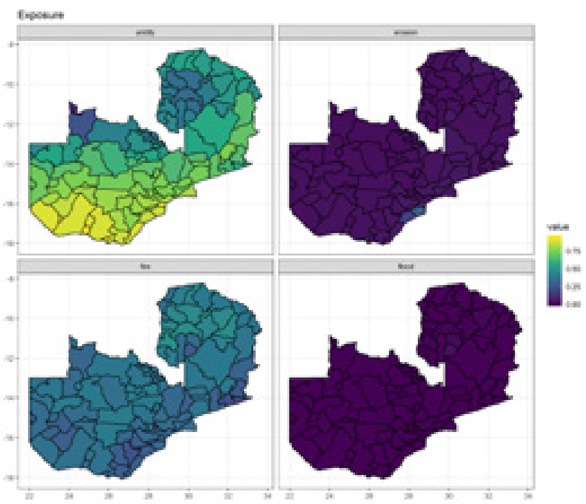


Figure 24: Spatial distribution of natural hazards across Zambia

[1] See NASA's analysis for the 2005 season at https://earthobservatory.nasa.gov/images/5800/2005-fire-patterns-across-africa

3.4 Adaptive capacity across the Zambian territory

Adaptive capacity refers to the ability of a system to adjust to changes in climate, to moderate potential damages, to take advantage of opportunities or to cope with the consequences (IPCC, 2014). Perez et al. (2019) recently conducted a systematic literature review on variables typically used to assess adaptive capacity. Here we gathered geospatial data on as many of those variables as possible and incorporated them on the analysis. We focused our attention on high-resolution datasets. The variables included in the adaptive capacity analysis are listed in Table 2. All adaptive capacity variables were normalized so that 0 indicates no adaptive capacity and 1 indicates absolute adaptive capacity.

Table 2: Adaptive capacity variables used in the vulnerability assessment for Zambia

Variable	Description
Travel time	Travel time (in hours) to major cities is used as a measure of accessibility to markets
Poverty index	Poverty is originally the poverty headcount ratio; that is, the number of people living under $1.25 per day, adjusted to 2005 PPP.
Wasting	Prevalence of wasting measured as the percentage of children under 5 years of age with low weight for height
Underweight	Prevalence of underweight measured as the percentage of children under 5 years of age that have low weight for age
Stunting	Prevalence of stunting measured as the percentage of children under 5 years of age that have low height for age
Education	The “education index” represents the potential of a population to access information and knowledge in a certain area in 2010. The index results from a combination of mainly three dominant variables, namely, “adult literacy”, “primary gross enrolment rate” and “prevalence of HIV”.
Institutional capital	Institutional capital index in 2010. The “institutional capital index” relates to the management means that determine the potential adaptive capacity degree. It is the combination of three underlying indexes: the “governance index”, “conflictuality index” and the “environmental management index”.
Access to water	Distance to the nearest river or water body is used to represent access to irrigation and household consumption water.
Health care	Distance to health care facilities reported in Maina et al. (2019)
Crop diversification	Count of the total number of crops that are growing in a particular area. Crop distribution areas taken from MapSPAM (You et al., 2017)/

In general, all indicators of adaptive capacity varied substantially across Zambia (Figure 25). There was also significant variation between adaptive capacity indicators for any given district. For instance, districts were generally subjected to relatively high rates of poverty, but were also highly diverse in terms of crops, and had relatively good access to hospitals and markets. Rates of stunting in children were generally high in the north of the country and decreased towards the south. Rates of stunting (low height for age) were generally greater than the rates of wasting (low weight for height) and underweight (low weight for age). Access to water was also relatively limited in most districts, as was the capacity for and availability of education.

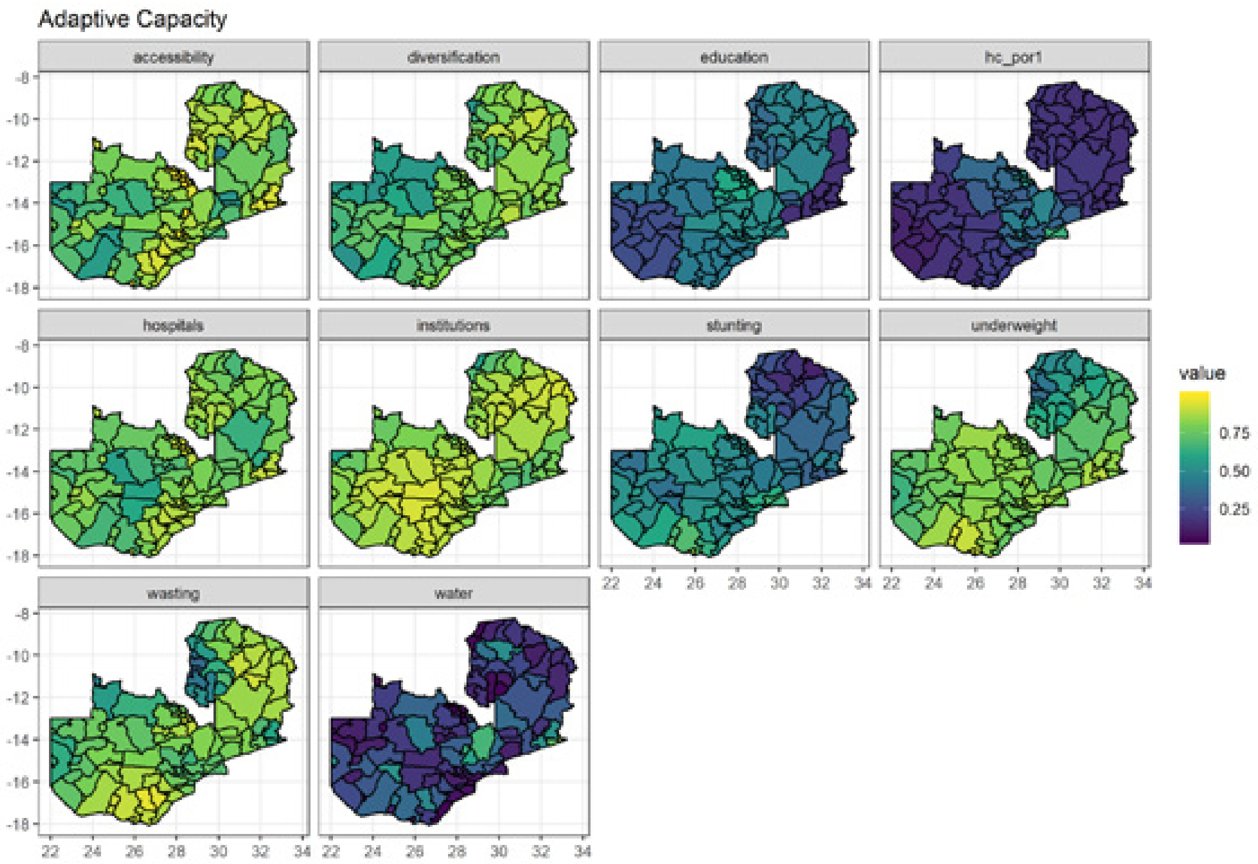


Figure 25: Spatial distribution of adaptive capacity indicators for Zambia. A value of zero indicates no adaptive capacity, and a value of 1 indicates absolute adaptive capacity

The analysis highlights several areas of work for the Zambian Government and society in terms of improving adaptive capacity in the country. Most notably, a reduction in the prevalence of stunting in rural areas, likely to be achieved through sustainable agricultural intensification and enhanced resilience (Arslan et al., 2015; Thurlow et al., 2012), improvements in the capacity of education institutions and an overall reduction in the incidence of poverty across the country.

3.5 Vulnerability of the Zambian agricultural sector to climate change

Using all of the indicators for sensitivity, exposure and adaptive capacity, we finally computed the vulnerability of the Zambian agricultural sector to climate change. Analyses focused on 2030 and 2050, and used two emissions scenarios, namely, RCP 8.5 (business as usual) and RCP 4.5 (partial implementation of Paris Agreement). We assessed vulnerability for the whole sector, separately for crops and livestock, and separately for each value chain. Our findings suggest that the overall crop and livestock vulnerability in 2030 is greatest towards the western and northern districts, and in specific pockets elsewhere (Figure 26). Conversely, vulnerability is lowest towards the centre and southeast of the country. By 2050, unless adaptive capacity is enhanced, and adaptation strategies are implemented throughout the country, climate change will exacerbate vulnerability even further (Supplementary Figure S4).

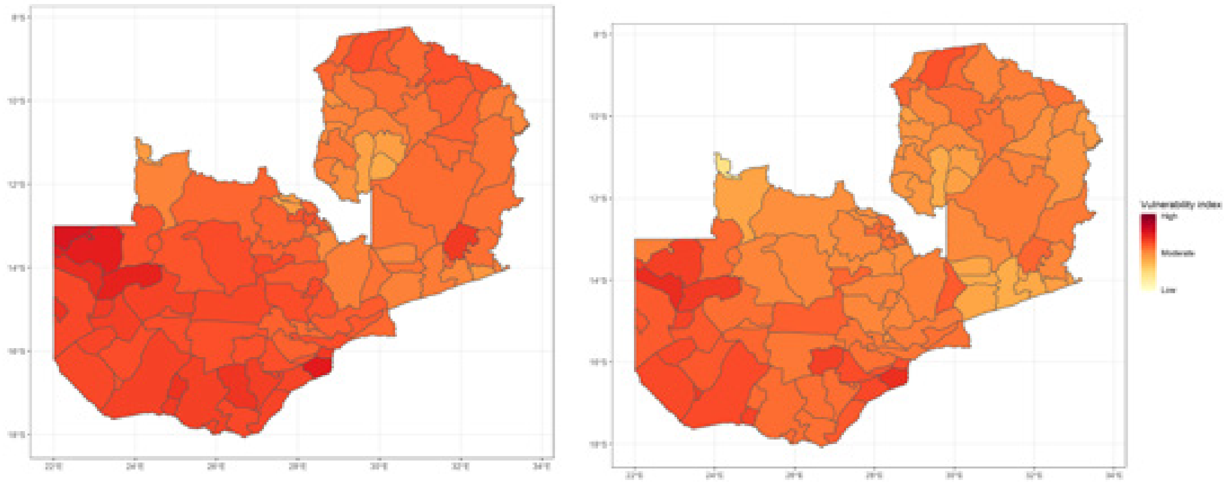


Figure 26: Overall vulnerability of Zambian agriculture to climate change by 2030 for RCP 4.5 (left) and RCP 8.5 (right). Supplementary Figure S4 shows results for the 2050s

In the areas of greatest vulnerability, we note a systematic reduction in the suitability of most of the crops analysed, as well as a mild increase in the frequency of severe heat stress days for livestock. We also note that these areas experience high poverty rates, stunting, and limited access to water. When looking at overall vulnerability across agroecological zones, several findings become apparent. First, that vulnerability of livestock production is greater than that of crops. Secondly, crop vulnerability is relatively uniform across agroecological zones, whereas for livestock it is clear that the warm semi-arid zone is the most vulnerable, followed by the warm sub-humid zone (Table 3). This is due to a greater likelihood of heat stress both historically and in the future.

Table 3: Average vulnerability index per agroecological zone for crops and livestock

Value chain	Period	RCP	Cool / semi-arid	Warm / semi-arid	Cool / sub humid	Warm / sub humid
Crops	2030s	RCP4.5	0.26	0.30	0.25	0.29
		RCP8.5	0.21	0.22	0.23	0.27
	2050s	RCP4.5	0.25	0.30	0.25	0.29
		RCP8.5	0.18	0.19	0.23	0.25
Livestock	2030s	RCP4.5	0.70	0.63	0.87	0.71
		RCP8.5	0.70	0.63	0.87	0.65
	2050s	RCP4.5	0.64	0.57	0.80	0.58
		RCP8.5	0.64	0.57	0.74	0.46

Results for crop and livestock systems separately indicate that livestock is most vulnerable in southern Zambia (drier areas), whereas crops are most vulnerable towards the west and north-west of the country (Supplementary Figure S5). When analysing the contribution of individual value chains to overall vulnerability, we note significant differences in the geographic vulnerability for the different value chains (Figure 27). For instance, bean production is most vulnerable in the south of the country, whereas rice and cowpea production are most vulnerable towards the north-west Zambia. The vulnerability of livestock production was more geographically consistent across livestock species.

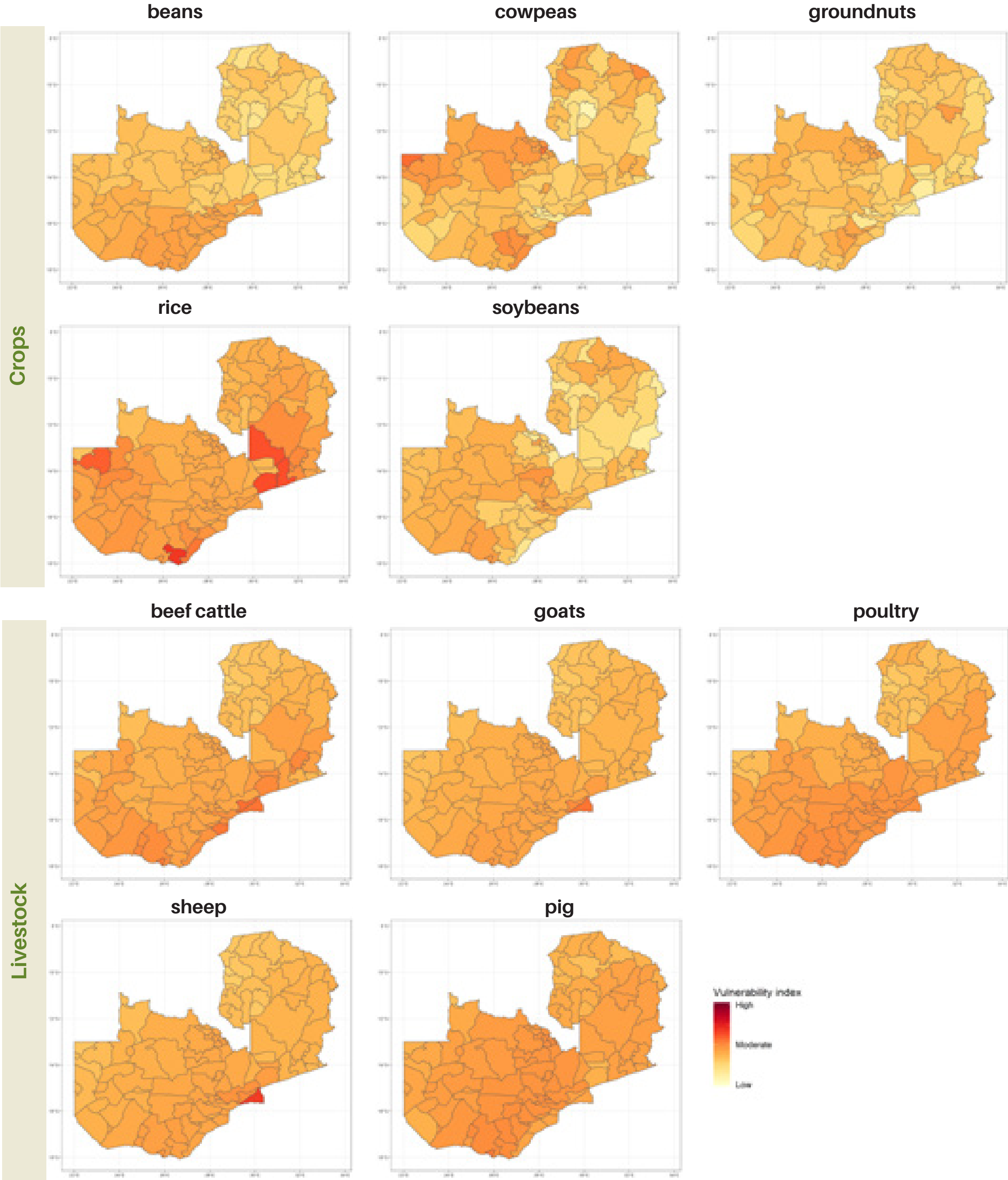


Figure 27: Contribution of different agricultural value chains to overall climate change vulnerability by 2030 for RCP 4.5 Supplementary Figures S6–S8 show results for RCP 4.5 by 2050s and for RCP 8.5 by 2030s and 2050s

Conclusions for Chapter 3

We applied a vulnerability framework that integrates Zambia's exposure to natural hazards, the sensitivity of its crop and livestock production systems to climate change, and the adaptive capacity of the farming population. Based on the findings presented here, we conclude that the Zambian government needs to invest significantly in enhancing adaptive capacity of the farming population, especially in relation to poverty rates, nutrition and access to education, in order to tackle climate change vulnerability. Particular attention must be paid to livestock systems in warm zones due to their sensitivity to heat stress and its potential impact on meat and milk productivity. Similarly, priority should be given to addressing crop vulnerability with emphasis in western Zambia. Addressing crop vulnerability will require a tailored crop-specific approach that enhances adaptive capacity and resilience locally. Strategies such as improved seeds, improved agronomic management, improved infrastructure, and climate risk reduction strategies such as climate information services and insurance.

Chapter 4: Modelling the implication of current and future climate on pests and diseases

Chapter authors: *Wilson Nguru and Caroline Mwongera*

Key messages

- Warm average temperatures and high relative humidity are climatic conditions that favour the prevalence of pests and diseases in Zambia
- For the 2030s, i.e. the period between 2021 and 2040, both RCP 4.5 and 8.5 scenarios indicate an increase in the distribution and infestation of pests and diseases in Zambia
- For the 2050s i.e. 2041 to 2060, the results predict a reduction in distribution and infestations of pests and diseases in comparison to 2030s. Under RCP 4.5, prevalence reduces because of the underlying technologies adapted to reduce emissions, whereas for RCP 8.5 climatic conditions become unfavourable for the pests and diseases.
- Adoption of management practices aimed at lowering greenhouse gas emissions and carbon capture, such as use of clean energy, forestry, agroforestry and bio pesticides will be beneficial as a long-term response in mitigating climate change, thereby creating unfavourable environmental conditions that inhibit pests and diseases.

4.1 Introduction

We investigated the impact of climate change on important pests and diseases for the selected value chains in Zambia. To determine the most important pest and disease affecting production for each value chain, we gathered information from literature review, which included websites, reports, journals and online newspapers. Optimum environmental conditions for the development of the selected pests and diseases were also evaluated from literature (Table 4).

Table 4: Common pests and diseases for the selected value chains, and their optimum temperature, rainfall and relative humidity conditions

Value chain	Pest or disease	Common name	Scientific name	Optimum Temperature	Optimum Rainfall	Optimum Relative humidity range (%)	Source
Rice	Pest	African rice gall midge	*Orseolia oryzivora*	26-30° C	Frequent rain or mist. Above 800 mm per annum	82-88	(Nwilene et al., 2006; Pathak and Khan, 1994)
	Disease	Rice blast	*Magnaporthe grisea*	24-28° C	High rainfall of up to 9.1 mm at a period of 2 rainy days at 141 days after sowing	56.7-80.4	(Dubey, 2003; Katsantonis et al., 2017; Ghini et al., 2011; Mahmood, 2017; Ghini & Bevitori, 2014)

Value chain	Pest or disease	Common name	Scientific name	Optimum Temperature	Optimum Rainfall	Optimum Relative humidity range (%)	Source
Bean	Pest	Legume pod borer	Maruca vitrata	19.5-29.3° C	Above 800 mm per annum	40-93	(Adati et al., 2004; Traorea1 et al., 2013)
	Disease	Bean blight	Xanthomonas axonopodis pv. Phaseoli	28-32° C	800-2000 mm per annum	85-95	(EPPO/CABI, 1986; He and Munkvold, 2012; Mahuku et al., 2006)
Groundnuts	Pest	Groundnut aphid	Aphis craccivora	24-28.5° C	below 1000 mm per annum	Above 65	(Javed et al., 2014; Amici et al., 2016; Mayeux, 1984)
	Disease	Groundnut rosette disease	Groundnut rosette disease	24-28.5° C	below 1000 mm per annum	Above 65	(CABI, 2015; Naidu et al., 1999)
	Disease	Cercospora leaf spot of groundnuts	Cercospora arachidicola	22.5-30.9° C	1.1-21.4 mm and 2-21 consecutive rain days in a season	75.2-99.9	(CABI, 2015; Dubey, 2005)
Cowpea	Pest	Bean flower thrips	Megalurothrips sjostedti	23–29 ° C	0.4 mm/ month	Below 10	("Infonet Biovision Home.," 2018; Lewis, 1997)
	Disease	Anthracnose of cowpea	Colletotrichum destructivum	22-30° C	8-36 mm and 1-3 consecutive rain days	63-96	(Cabi, 2015; Kaur et al., 2016)
Soybean	Pest	Cotton bollworm	Helicoverpa armigera	25-30° C	Little or no rain fall	45-55	(CABI, 2016; Kriticos et al., 2015; Weston and Desurmont, 2008)
	Disease	Stem and pod rot	Athelia rolfsii	24–30 °C	Warm and rainy	Above 90	(Ferrin, 2015; Mersha et al., 2019)

We evaluated the optimum environmental conditions for all the above pests and diseases and categorized two groups of similar or almost similar ranges of temperature, precipitation and relative humidity (Table 5).

Table 5: Environmental parameters used in the modelling of suitability for important pests and diseases affecting the selected value chains

	Environmental conditions	Pests	Diseases
Group 1 Warm; high rainfall and medium to high humidity conditions	• Temperature 20^{o} C to 30^{o} C, rainfall between 800 mm and 2000 mm and relative humidity between 40 and 99 per cent	• African rice gall midge • Legume pod borer • Bean flower thrips	• Rice blast • Bean blight • leaf spot of groundnuts • Anthracnose of cowpea • Soybean stem and pod rot
Group 2 Warm; low rainfall conditions and medium relative humidity conditions	• Temperature ranging between 20^{o} C and 30^{o} C, rainfall less than 1000 mm and relative humidity between 45and 65 per cent	• Groundnut aphid • Cotton bollworm	• Groundnut rosette disease

The pest and disease suitability modelling was conducted using the Targeting tools (https://targetingtools.ciat.cgiar.org/). It evaluates if there are adequate climatic conditions within the growing season that would favour the pest and disease. In other words, it calculates climatic suitability of the resulting interaction between rainfall, temperature and relative humidity.

Data for current climatic suitability (1981-2015) was obtained from Worldclim (Hijmans et al., 2005) for annual temperature and annual precipitation. Relative humidity was calculated using the method first developed by the Numerical Terradynamic Simulation Group at the University of Montana (www.ntsg.umt.edu) in their MTCLIM model as proposed by Wesolowski et al. (2015) and Eccel (2012). Below are the equations.

We start by calculating dew point temperature, T_d

$$T_d = T_{min} - k\,(T_{day} - T_{min}),$$

Where, k is a calibration coefficient (here k =1), T_{min} is the daily minimum temperature and is the estimated diurnal temperature.

$$T_{day} = 0.45*(T_{max} - T_{mean}) + T_{mean}$$

Where: T_{max} is the daily maximum temperature and T_{mean} is the daily mean temperature. Dew point (T_d) and temperature (T) are converted to relative humidity, using

$$RH = 100 * \exp((1.7625*T_d)/(243.04+T_d)) / \exp((1.7625*T_d)/243.04+T))$$

Data for future climate was obtained from the CCAFS climate portal (http:www.ccafs-climate.org) for two periods (2030s and 2050s), and for two scenarios (RCP 4.5 and RCP 8.5). The future climate data were obtained from five representative Global Climate Models and was downloaded from Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), and France's National Centre for Meteorological Research CNRM-CM3,. Averages were calculated for minimum, maximum temperatures and precipitation, and used to calculate relative humidity for the two scenarios at 5 km resolution.

4.2 Suitability of pests and diseases in Group 1

The pests in this group include the African rice gall midge and the Legume pod borer, while the diseases are Rice blast, Bean blight, Cercospora leaf spot of groundnuts, Anthracnose of cowpea and Stem and pod rot.

a. Current climate suitability for pests and diseases in Group 1

Currently, the pests and diseases in Group 1 are climatically more prevalent in the Luapula, Northern, Muchinga, Eastern, Central, Lusaka Provinces, and parts of the eastern parts of the Southern Province (Figure 28). Very high prevalence is observed in Muchinga, Northern, Luapula and Eastern Provinces. The provinces to the west of Zambia show less pest prevalence probably due low precipitation and low relative humidity.

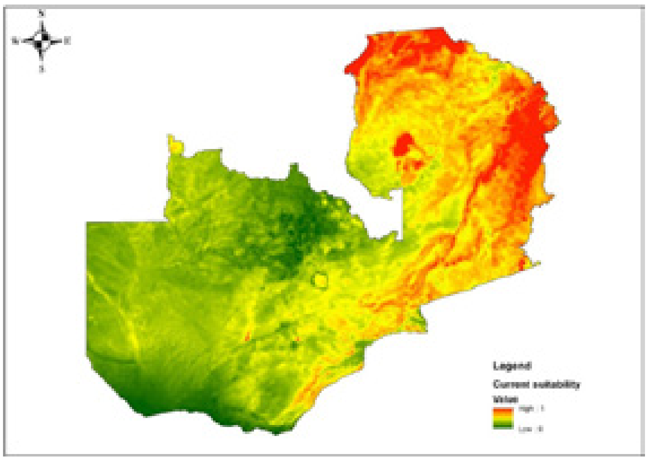


Figure 28: Current climate suitability for pests and diseases in Group 1 in Zambia (1981-2015), on a scale of low to high

b. Projected climate suitability for pests and diseases in Group 1 for the 2030s

RCP 4.5 (Figure 29) shows a higher prevalence of pests and diseases compared to the current prevalence but at a reduced rate compared to RCP 8.5 (Figure 30). The future prevalence for the 2030s for RCP 8.5 (Figure 30) shows an increased prevalence from the current climatic conditions with high prevalence in all areas except the western and northwestern provinces. This could be attributed to increased rainfall, temperatures and relative humidity. There is only a slight difference in pest and disease prevalence between RCP 4.5 and 8.5 during this period, with slightly increased infestation in the northwestern provinces for RCP 8.5. This is because the effects of the employment of technologies and strategies for reducing GHGE are assumed to be taking effect.

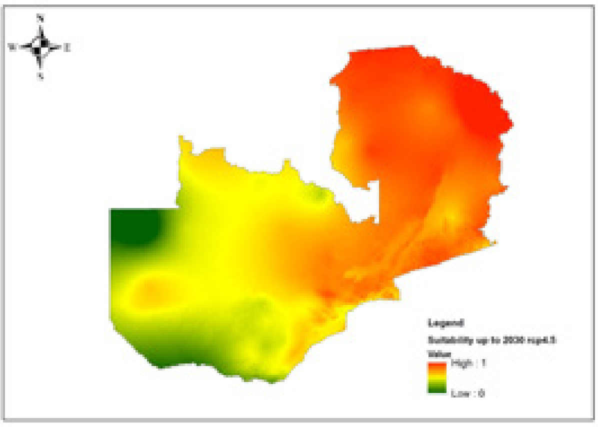


Figure 29: Projected future climate suitability for pests and diseases in Group 1 in Zambia for the 2030s under RCP 4.5, on a scale of low to high

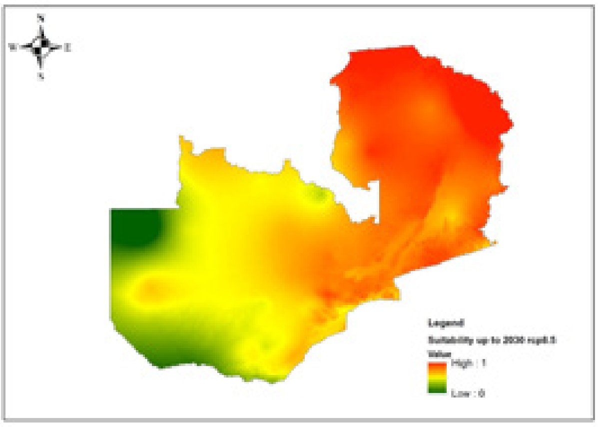


Figure 30: Projected future climate suitability for pests and diseases in Group 1 in Zambia for the 2030s under RCP 8.5, on a scale of low to high

c. Projected climate suitability for pests and diseases in Group 1 for the 2050s

Under projected climate suitability for pests and disease modelled for the 2050s, RCP 4.5 (Figure 31), shows a similar trend to RCP 8.5 (Figure 32). This exhibits a decreased infestation compared to the 2030s. During this period relative humidity continues to decrease towards the east of the country. This creates less favourable environmental conditions for the development of pests and diseases. Under RCP 4.5, decreased infestation in comparison with the 2030s is as a result of the effects of the GHGE reduction technologies and strategies taking effect.

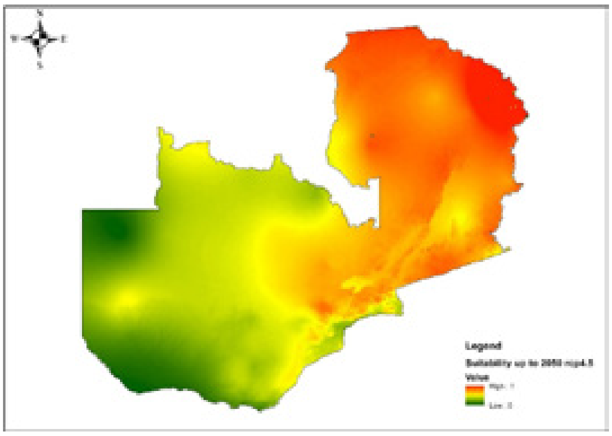


Figure 31: Projected future climate suitability for pests and diseases in Group 1 in Zambia for the 2050s under RCP 4.5, on a scale of low to high

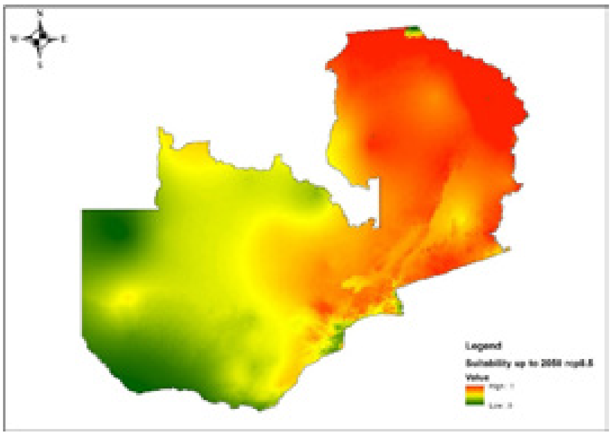


Figure 32: Projected future climate suitability for pests and diseases in Group 1 in Zambia for the 2050s under RCP 8.5, on a scale of low to high

4.3 Current climate suitability of pests and diseases in Group 2

The pests modelled in Group 2 are groundnut aphid and cotton bollworm, while the disease modellled is the groundnut rosette disease. Groundnut aphid is the vector for groundnut rosette disease.

a. Current climate suitability for pests and diseases in Group 2

Under current climate conditions, the pests and disease modelled in Group 2 are more prevalent in the Eastern Province, as well as the eastern parts of Muchinga Province and parts of the Northern Province neighbouring Congo (Figure 33). The provinces to the west and some in the north of Zambia show less pest and disease prevalence. Low prevalence to the west is probably due to low relative humidity while that to the north of the country it is due to high rainfall, which leads to the death of small sized pests and aphids, similar to the trend observed for diseases in Group 1.

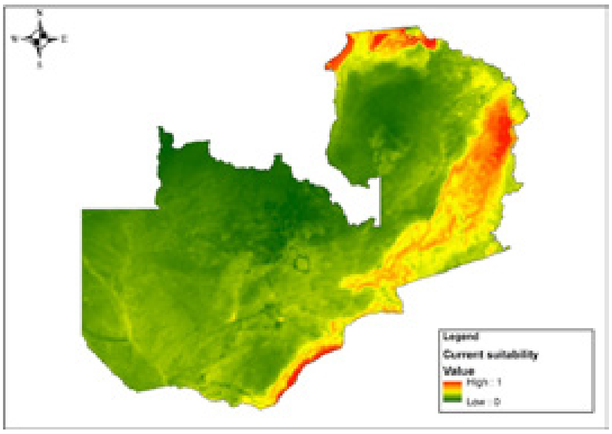


Figure 33: Current climate suitability for pests and diseases in Group 1 in Zambia (1981-2015), on a scale of low to high

b. Projected climate suitability for pests and diseases in Group 2 for the 2030s

Under projected climate change, it is noticeable that the climate suitability for groundnut aphid, groundnut rosette disease and cotton bollworm have significant suitability compared to the current suitability. A highly noticeable change is observed in both RCP 4.5 (Figure 34), and the pessimistic RCP 8.5 (Figure 35) scenario.

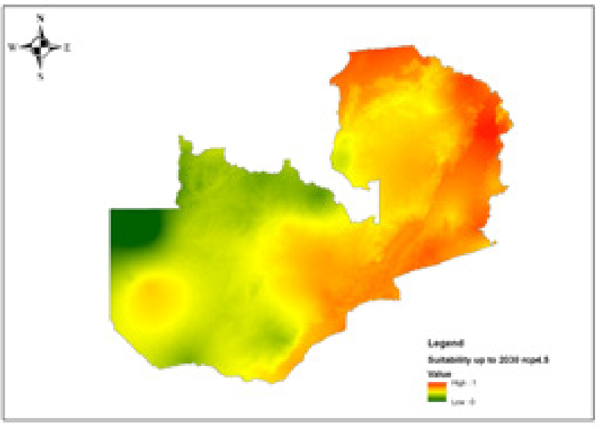


Figure 34: Projected future climate suitability for pests and diseases in Group 2 in Zambia for the 2030s under RCP 4.5, on a scale of low to high

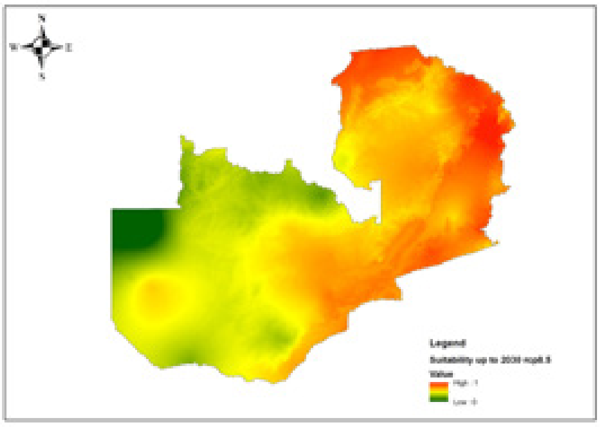


Figure 35: Projected future climate suitability for pests and diseases in Group 2 in Zambia for the 2030s under RCP 8.5, on a scale of low to high

c. Projected climate suitability for pests and diseases in Group 2 for the 2050s

A noticeable decrease in suitability for both RCP 4.5 (Figure 36) and RCP 8.5 (Figure 37) is observed for the 2050s compared to the 2030s. However, future climatic suitability for the two pests and disease modelled under Group 2, will be higher compared to the current suitability. This may translate to new opportunities for groundnut and cotton production.

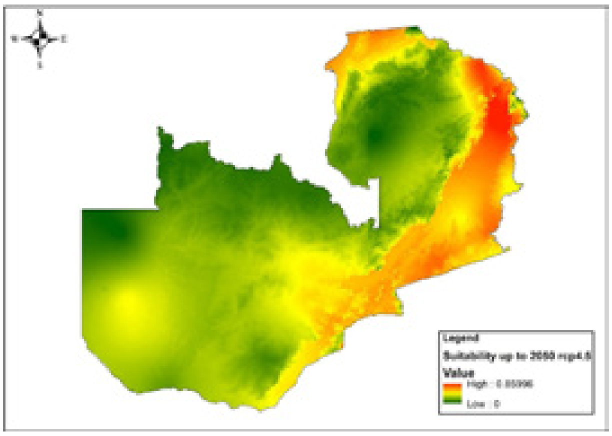


Figure 36: Projected future climate suitability for pests and diseases in Group 2 in Zambia for the 2050s under RCP 4.5, on a scale of low to high

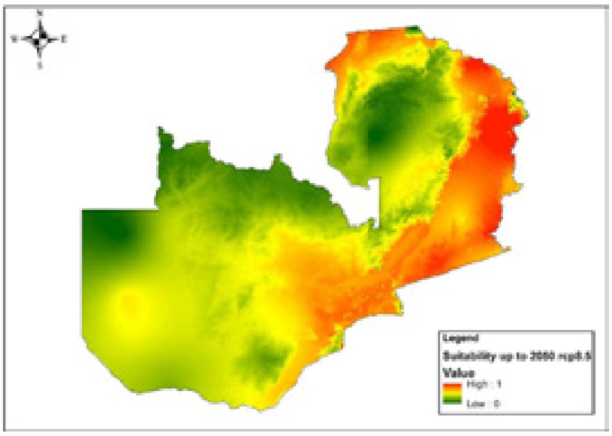


Figure 37: Projected future climate suitability for pests and diseases in Group 1 in Zambia for the 2050s under RCP 8.5, on a scale of low to high

Conclusions for Chapter 4

In Zambia, climate change will result in increased distribution of pests and diseases in the period between 2021 and 2039 because climate conditions will be more conducive. Consequently, plant health problems are anticipated to be of a greater significance. In the 2050s, there will be a decline in prevalence compared to 2030s. Most insect pests are poikilothermic, their body temperatures change with that of the environment, and therefore, almost all insects will be affected by changes in temperatures, with every degree rise in global temperature resulting in a shorter insect life cycle (Biber-Freudenberger et al., 2016). The shorter life cycle will result in increased populations of pests leading to increased crop destruction. General predictions show that an increase in temperatures will lead to the species shifting their geographical ranges to higher elevation where the species-specific climate requirements essential for their growth, survival and reproduction will be available (Kambrekar et al., 2016). Therefore, areas that are currently not favourable to these pests will become favourable, leading to the introduction of pests into areas where they are currently not present. During the periods of heavy rainfall, small pests may be reduced as they are washed away from crops (Pathak et al., 2012; Pareek et al., 2017). Heavy rainfall coupled with warm weather creates a higher relative humidity leading to increased infestation by most pests and the development of diseases such as rust and blight (Groenen, 2018).

Chapter 5: Vulnerability to climate change for selected value chains across the E-SAPP beneficiary spectrum

Chapter authors: Caroline Mwongera and Ivy Kinyua

Key messages

- Drought spells is the most significant climatic hazard for all the selected value chains
- Moisture stress is the second most significant hazard for legumes and small livestock
- Inadequate climate-smart knowledge and skills, which is exacerbated by inadequate extension services, and limited political will are the main factors that are likely to hinder effective implementation of climate adaptation actions
- Community values, attitudes, beliefs and practices contribute to inequalities, social exclusion and discrimination based on gender, age or social status.
- Scaling off-farm services such as index-based insurance, early warning systems, disease surveillance, credit and financing is required to enhance climate adaptation

5.1 Introduction

Consultations were carried out in a two-day workshop with actors representing the three commodity groups. The purpose of the workshop was to evaluate climate-related risks and vulnerabilities across the E-SAPP beneficiary spectrum and prioritize appropriate adaptation options. Twenty-five experts representing (institutions, both public and private) project partners, value chain actors and key sector actors (climate change, environment, natural resource management, youth, gender, and sustainable development) attended the workshop.

Specific workshop objectives and activities included: presenting and discussing initial climate analysis (historic and future trends) for Zambia, identifying important climate hazards and key risks for the selected value-chain commodity groups, assessing the climate vulnerabilities across the E-SAPP beneficiary spectrum (Figure 38) and identifying potential adaptation actions in the selected commodity groups. To achieve these objectives, we used an approach focusing on the value stages, i.e. input supply, on-farm production, harvesting, storage, processing, and product marketing.

5.2 Characteristics of the E-SAPP beneficiary spectrum

SMALLHOLDER FARMERS

	CATEGORY A Strategic linkages of graduating subsistence farmers to markets	CATEGORY B Enhancing Agro-Micro, Small and Medium Enterprises (MSME)	CATEGORY C Facilitating Pro-Smallholder Market-Pull Agribusiness Partnerships
Typology	**Subsistence farmers**- production is mainly for household consumption	**Economically active farmers** - production is for household consumption and surplus is sold to local markets	**Commercial farmers** - production is mainly for selling to local markets
Main characteristics	• Viable to commercialize their food • Low literacy levels • Low levels of knowledge • Low productivity • High dependency ratio	• High access to knowledge -through meetings, public and private extension • High productivity • High education levels	• Aggregators • High literacy levels • High levels of knowledge • Very High productivity
Farm size	< 1ha	5 - 20ha	> 20ha
Farming system	Mixed systems (crop and small livestock)	Mixed systems (crop and livestock e.g cattle)	Oil crops(sunflower), cotton
Resources	• Low input use • No mechanization • No credit access-lack assets for collateral	• Some mechanization • Medium input use • Village banking, micro finance, re-invest on the farm • Are in farmer groups, cooperatives	• High mechanization • High technology • Have irrigation systems • Loans from commercial banks • Are in farmers unions • Linkages to external markets
Average income	< 1600 Kwacha/Year	Multiple sources of income(on and off farm sources) agro dealers, groceries	High value crops
Challenges	• Provide off farm labor to other farms • Cultural norms dictate gender roles e.g. land owned by men, women are expected to farm • Socio-cultural influence on gender roles, asset ownership, value chain involvement	• Biophysical factors - mainly natural hazards	• Government regulatory frameworks that hinder selling to markets (import and export) • Economic issues such as exchange rates/interest rates limits borrowing • External markets competitions

Figure 38: Characteristics of the E-SAPP beneficiary spectrum

5.3 Identification of key climate hazards for the selected value chains

Stakeholders identified nine key climate hazards: drought spells, heat stress, floods, reduced crop cycle, erosion risk, moisture stress, fire, winds, and pests and diseases as the most problematic for agricultural production in Zambia (Figure 39). In separate commodity value chain groups (legumes, rice, small livestock), participants ranked the climate hazards from 1 to 9, representing most to lowest significance, respectively. The most significant climatic hazard in the three commodity groups was identified as drought spells (Figure 39). This was attributed to the frequency in occurrence and the associated risks of precipitation changes that interfere with start and the length of the growing season thus affecting crucial crop development stages. Additionally, drought spells result in low production and sometimes total crop failure that increases food insecurity and poverty in the country. Irrigation infrastructure development is limited in the three value chain groups, which further limits adaptation to drought spells.

Moisture stress was selected as the second most significant hazard for legumes and small livestock due to its contribution to soil-water deficits that affect plant functions consequently affecting productivity. For rice, flooding is the second most significant climate hazard because of the extensive damage caused by too much water, submerging the rice fields (Figure 39).

Climate Hazard Rank

Most significant hazards for each commodity group

1(most significant) to 9 (least significant)

	Legumes	Rice	Small livestock
Drought spells	1	1	1
Heat stress	7	3	3
Floods	5	2	6
Reduced crop cycle	4	5	4
Erosion risk	6	7	8
Moisture stress	2	4	2
Fire	9	8	9
Winds	8	9	7
Pest and diseases	3	6	5

Figure 39: Climate hazards selected as the most problematic for the three commodity groups, with scores of 1 to 9 representing the most to lowest significance, respectively

1. Legumes (beans, groundnuts, cowpeas, soybeans)

Drought spells have a major impact on legume production (Figure 40). In particular, drought affects the supply of seeds for the subsequent season causing an increase in seed prices. This consequently affects the quantity and quality of the harvested grain. Smallholder farmers, particularly in category A, followed by those in category B are the most affected. This is because these farmers depend on their own resources and lack crop insurance to offset crop losses. This leads to a chain reaction where legume yields reduce, thus reducing volumes for storage, processing and marketing. Market prices increase because of the high demand, but low supply of the grains. While this affects the traders and retailers moderately, farmers' household incomes decrease affecting subsequent growing seasons.

Moisture stress has a moderate effect on the supply of legume inputs such as seed and fertilizers. Similar to drought, moisture stress affects the quality and quantity of seed for planting which affects the level of production (Figure 40). Small-scale farmers, particularly subsistence farmers under Category A of the E-SAPP beneficiary spectrum are especially affected because they depend on legumes for both household food security and incomes. Poor production leads to low quantities for storage and processing, hence low volumes for trading in the markets. This increases the costs of postharvest processes and increases the market prices due to poor supply.

LEGUMES

Drought Spells

		Consequence 1	Consequence 2	Consequence 3	Consequence 4
Input Supply	Consequence description	Reduced availability of seed in the next season	Increased seed price	Reduced quality of seed	Reduced quantity of chemicals/fertilisers used
	Severity of the consequence	MAJOR	MAJOR	MODERATE	MAJOR
	Who is impacted?	Small scale farmers (young and old)	Large and small scale farmers	Small scale farmers	Agro dealers and input suppliers
On - Farm production	Consequence description	Reduced production	Seed loss	Low use of agrochemicals	Reduced productivity
	Severity of the consequence	MAJOR	MAJOR	MINOR	MAJOR
	Who is impacted?	Small scale farmers without irrigation	Small scale farmers	Small scale traders	Small scale farmers
Post- Harvest	Consequence description	Reduced quality of produce	Reduced volumes to process	Reduced aggregation	Low volumes for packaging and storage
	Severity of the consequence	MODERATE	MODERATE	MODERATE	MODERATE
	Who is impacted?	Processors and women mostly	Processors and women mostly	Farmer groups/traders	Farmers/cooperatives
Market	Consequence description	Low tradeable volumes	High commodity prices	Reduced incomes	Low transportation activities
	Severity of the consequence	MODERATE	MODERATE	MINOR	MINOR
	Who is impacted?	Traders, processors, retailers	Consumers	Traders and small scale farmers	Traders

Moisture stress

		Consequence 1	Consequence 2	Consequence 3	Consequence 4
Input Supply	Consequence description	Reduced availability of seed for next season	Increased seed price	Reduced quality of seed	Reduced quantity of chemicals/fertilisers used
	Severity of the consequence	MODERATE	MODERATE	MODERATE	MINOR
	Who is impacted?	Small scale farmers and mostly men	Large and small scale farmers (mostly men)	Small scale farmers	Agro dealers
On - Farm production	Consequence description	Reduced production	Reduced productivity	Moisture stress at land preparation, difficult to till land	
	Severity of the consequence	MODERATE	MODERATE	MODERATE	
	Who is impacted?	Small scale farmers without irrigation	Small scale farmers	Small scale farmers, mostly women	
Post- Harvest	Consequence description	Reduced quantity to process	Reduced quality of produce		
	Severity of the consequence	MODERATE	MODERATE		
	Who is impacted?	Processors and women mostly	Processors and women mostly		
Market	Consequence description	Low tradeable volumes	High commodity prices		
	Severity of the consequence	MODERATE	MODERATE		
	Who is impacted?	Traders who are mainly men and youth (small scale)	Women who are purchasing legumes for the households		

Figure 40: Effects of drought spells and moisture stress on the legume commodity group

2. Rice

The impact of a drought spell on rice production is severe because the crop has very high water requirements (Figure 41). Due to its sensitivity to drought spells, the rice crop wilts significantly reducing yields. More importantly, it leads to food insecurity for the smallholder farming communities. Smallholder farmers depend on the crop for food security. Reduced rice quantities and quality lead to low prices for rice, which significantly decreases household incomes. Similarly, floods severely affect rice production. Too much water washes away inputs e.g. seeds and fertilizers used in the rice field. Crops are submerged in water resulting in low production, ultimately causing acute food shortages. Incidences of pests and diseases increase during floods also affect the yields. Low production translates into economic losses for smallholder farming households who depend on rice production for their incomes. Besides reducing volumes for processing, floods can also make it physically challenging to access storage facilities and market centres contributing to post-harvest losses.

RICE

Drought Spells

Stage		Consequence 1	Consequence 2	Consequence 3	Consequence 4
Input Supply	Consequence description	Low input demand	Low availability of quality inputs	High loan default rates	
	Severity of the consequence	SEVERE	SEVERE	MAJOR	
	Who is impacted?	Men	Men	Men	
On - Farm production	Consequence description	Low yield/production	Poor crop stand	Crop wilting	Food insecurity
	Severity of the consequence	SEVERE	SEVERE	SEVERE	SEVERE
	Who is impacted?	Men	Men	Men	Men,women and youth
Post- Harvest	Consequence description	Grain quality poor	Low yields/production		
	Severity of the consequence	SEVERE	SEVERE		
	Who is impacted?	Women	Men,women and youth		
Market	Consequence description	Low pricing	Low profitability	Increases poverty	
	Severity of the consequence	SEVERE	SEVERE	MAJOR	
	Who is impacted?	Men	Men, women and youth	Men, women and youth	

Floods

Stage		Consequence 1	Consequence 2	Consequence 3	Consequence 4
Input Supply	Consequence description	Low access to inputs	Low uptake of inputs by farmers	Inputs will be washed away	
	Severity of the consequence	SEVERE	SEVERE	SEVERE	
	Who is impacted?	Men	Men, women and youth	Men, women and youth	
On - Farm production	Consequence description	Crops will be submerged in water	Poor crop stand	Low yield/production	Food insecurity
	Severity of the consequence	SEVERE	SEVERE	SEVERE	SEVERE
	Who is impacted?	Men, women and youth	Men, women and youth	Men, women and youth	Men, women and youth
Post- Harvest	Consequence description	Difficult to access storage facilities	Post harvest losses	Increased incidences of pests and diseases	Increased moisture content
	Severity of the consequence	SEVERE	MAJOR	MODERATE	SEVERE
	Who is impacted?	Women	Men, women and youth	Men, women and youth	Women
Market	Consequence description	Difficulties to access markets	Poor quality products	Low profitability	Increases poverty
	Severity of the consequence	SEVERE	SEVERE	MAJOR	MAJOR
	Who is impacted?	Men	Men, women and youth	Men, women and youth	Men, women and youth

Figure 41: Effects of drought spells and floods on the rice value chain

3. Small livestock (local poultry, sheep, goats, pig)

Small livestock production is severely affected by drought spells (Figure 42). Apart from the reduced availability of pasture and water, there is increased pests and disease incidences. This affects input supply and the demand for food supplementation and pesticides for disease management increases. These consequences disproportionately affect the men more, as they are more involved in animal husbandry tasks. Due to reduced precipitation associated with drought spells, hydro-powered processing plants are severely affected. This affects timely processing of livestock products and proper postharvest handling reducing packaging, supply and quality of products delivered to the markets.

Moisture stress has a major effect on pasture and water availability, thus requiring supplementation for livestock production (Figure 42). This leads to poor nutrition and reduced animal performance. This moderately contributes to post-harvest losses because of poor quality of meat, milk, eggs, wool and reduced market prices. Men and women play important roles in the management of small livestock hence both are affected, but differently at each value chain stage.

SMALL LIVESTOCK

Drought Spells

Stage		Consequence 1	Consequence 2	Consequence 3
Input Supply	Consequence description	Limit production of raw materials for feed	High price of feed due to low supply	High loan default rates
	Severity of the consequence	SEVERE	SEVERE	SEVERE
	Who is impacted?	Men	Men	
On - Farm production	Consequence description	Reduced availability of pasture and water	Livestock breeding performance declines	Increased incidences of disease
	Severity of the consequence	SEVERE	SEVERE	SEVERE
	Who is impacted?	Men and women	Men and women	Men and women
Post- Harvest	Consequence description	Production is affected which reduces processing	Impacts hydro electricity supply affecting processing	
	Severity of the consequence	SEVERE	SEVERE	
	Who is impacted?	Men and women	Men and women	
Market	Consequence description	Drought supply and quality of meat	Packaging affected by powercuts	
	Severity of the consequence	MAJOR	MODERATE	
	Who is impacted?	Men and women	Men and women	

Moisture stress

Stage		Consequence 1	Consequence 2	Consequence 3
Input Supply	Consequence description	Reduces availability of pasture and water	Quality of raw materials used in the manufacture of stock feed	
	Severity of the consequence	MAJOR	MODERATE	
	Who is impacted?	Men and women	Men and women	
On - Farm production	Consequence description	Pasture reduced	Pasture less nutritious	
	Severity of the consequence	MODERATE	MAJOR	
	Who is impacted?	Men and women	Men and women	
Post- Harvest	Consequence description	Reduces quantity of both pasture and meat	Post harvest losses	
	Severity of the consequence	MODERATE	MODERATE	
	Who is impacted?	Men and women	Men and women	
Market	Consequence description	Lower prices of meat due to compromised quality		
	Severity of the consequence	MODERATE		
	Who is impacted?	Men		

Figure 42: Effects of drought spells and moisture stress on the small livestock commodity group

5.4 Underlying vulnerability factors for E-SAPP beneficiaries

Many of the smallholder farmers lack the capacity to anticipate or respond to climate change risks due to institutional, political, economic, socio cultural, geographical or biophysical factors. Inadequate farmer extension services contribute to farmers' lack of crucial climate adaptation knowledge and practical skills. Poverty exacerbates the challenges, as farmers have limited access to resources.

Community values, attitudes, beliefs and practices on gender roles, asset ownership and value chain involvement contribute to inequalities, social exclusion and discrimination based on gender, age or social status. For instance, even though women dominate general production of small livestock, men are assumed to take control over resources and decision-making. This hinders the active participation of women and youth in small livestock production, as they do not have equity in access to incomes. Land ownership, especially because of customary tenure system remains to the adoption of longer-term climate-smart practices. The geographical location of production areas also expose some farmers to natural hazards e.g. low-lying areas are prone to flooding.

5.5 Promising adaptation options

1. Legumes (beans, groundnuts, cowpeas, soybeans)

Many of the ongoing adaptive strategies used by farmers focus on productivity. For instance, promoting adoption of improved (high yielding, disease and drought tolerant varieties), quality seed and crop varieties, conservation agriculture (minimum tillage, crop rotation and intercropping, mulching) and soil management practices like liming, and afforestation. Other practices include crop diversification and value addition to increase incomes (Figure 43).

Proposed adaptation option are broader, focusing on all the value chain stages. These include introduction of affordable mechanization services, climate information services, agro-sector advisories, weather forecasting and index based weather insurance (Figure 43). In addition, stakeholders recognize the importance for capacity building through organizing trainings and fora for increasing farmers' knowledge and skills on climate-smart agriculture practices. There is also a need to strengthen ongoing adaptation options such as value addition, conservation agriculture practices and the use of drought tolerant varieties.

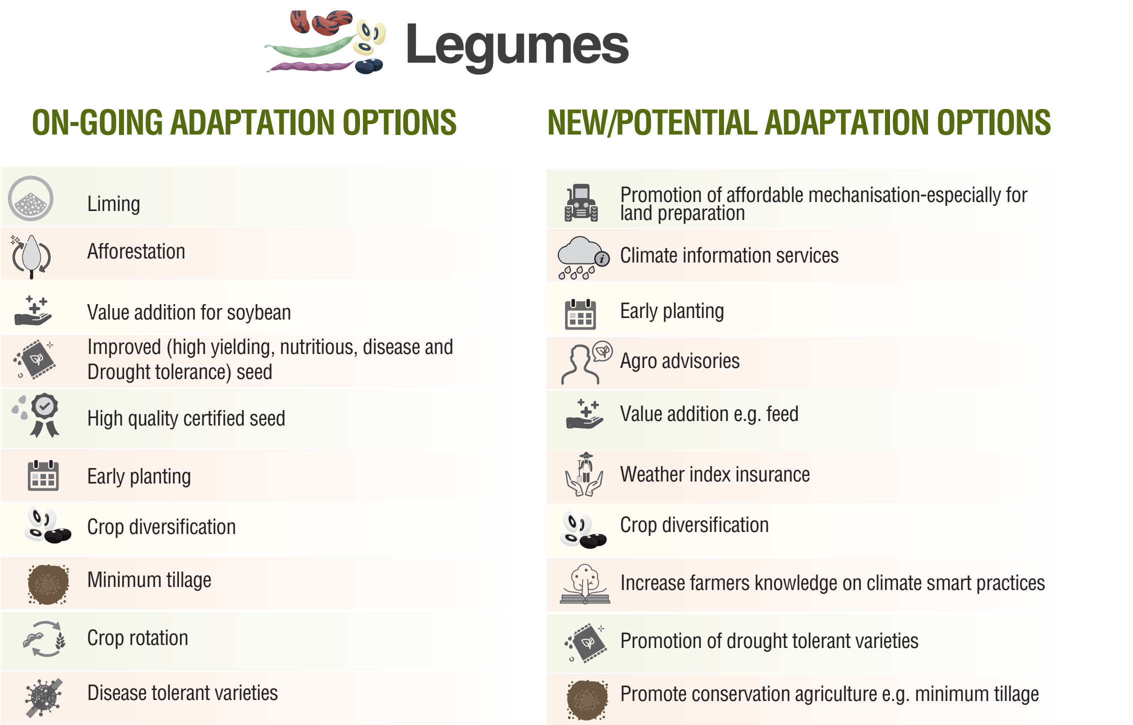


Figure 43: Ongoing and potential adaptation to drought spells and moisture stress in the legume commodity group

2. Rice

Rice farmers employ various adaptation options for instance the use of water efficient technologies including efficient irrigation systems, crop diversification, conservation agriculture, intensification through agroforestry and horticulture, tolerant varieties, contour ridging and index based weather insurance (Figure 44). Many of these efforts focus towards increasing productivity and adaptation to climate vulnerability.

To enhance rice production and adaptation, scaling of ongoing adaptation options such as water use efficient technologies, and water harvesting. Integrated farming and climate information services are needed. Farmer training on climate-smart skills and practices remains a gap. Additionally, there is need to increase adoption of new technologies such as the system of rice intensification, potholing and alternate wetting and drying. Other proposed promising adaptation options include the use of green energy technologies (Figure 44).

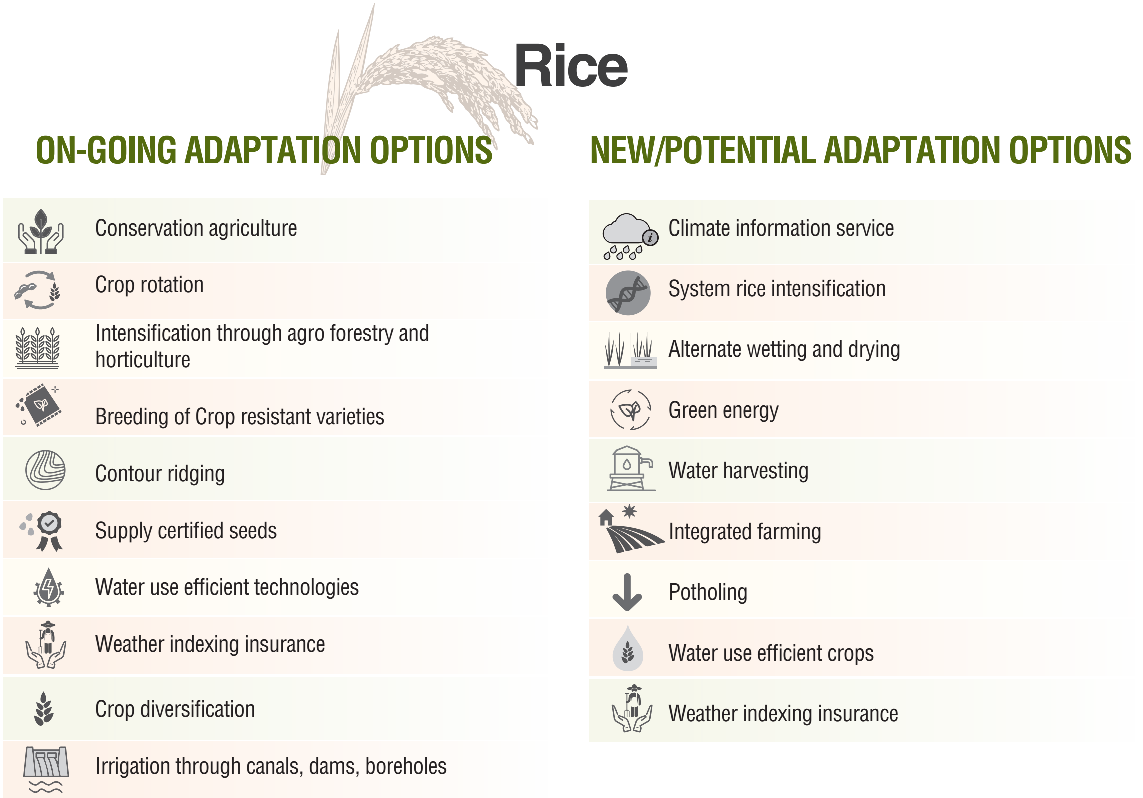


Figure 44: Ongoing and potential adaptation to drought spells and floods in the Zambian rice value chain

3. Small livestock (poultry, goats, sheep and pigs)

Current adaptation option in livestock production include those targeted towards increasing production, adaptation and mitigation of greenhouse gases. These include bio digesters, drilling small water boreholes for water provision, climate tolerant livestock breeds, tolerant pasture varieties, water smart practices e.g. efficient irrigation technologies (Figure 45). Capacity building for livestock farmers is also required in this commodity group.

Disease management is ongoing through construction of dip tanks and proper housing to ensure proper sanitation and ventilation. To facilitate change in behaviour and attitudes on gender roles in livestock production, stakeholders are mainstreaming gender into the project designs and implementation.

Improving access to livestock insurance services is likely to enhance resilience to climate shocks. Similarly, climate information services e.g. early warning, disease surveillance systems is needed. Farmers should practice livestock diversification or mixed farming with crops and the use of climate tolerant breeds, and pasture. Other proposed options include feed and water conservation, afforestation and use of renewable and sustainable energy options (Figure 45). Given the increasing call for engagement of young men and women in small livestock, stakeholders encourage investment in youth led solutions.

Figure 45: Ongoing and potential adaptation to drought spells and moisture stress in the small livestock commodity group

5.6 Policies and strategies to support adaptation to climate change

A. National policy on climate change (NPCC)

According to GoZ (2016b), the national policy on climate change envisions a prosperous and climate resilient economy by 2030.

The guiding principles include sustainable climate change response under which all climate change actions will need to be environmentally sustainable and contribute positively to national economic growth and social development objectives. Also, there will be a need for compliance with international obligations in accordance with Multilateral Environmental Agreements (MEAs) on climate change. Resilience building has been identified as an integral part of the development process, and the collectiveness and inclusiveness in climate change response measures undertaken in the country. The policy also looks at the consultative approach and multi-stakeholder involvement including ecosystem integrity. The policy also looks at complementarity of adaptation, Disaster Risk Reduction (DRR) and mitigation. The NPCC seeks to increase financing of climate-resilient programs by 25 per cent.

B. The Seventh National Development Plan, 2017-2021 (7NDP)

7NDP is a planning document that outlines Zambia government's desired developmental outcomes as well as the accompanying strategies and programmes (GoZ, 2017). It addresses adaptation and mitigation strategies to minimize effects of climate change on the agriculture sector. It promotes adoption of agricultural and climate smart and organic techniques, for example, conservation farming, crop rotation, minimal use of chemical fertilizer and creating public awareness on effects of climate change. The plan has put in place strategies and programmes to aid communities to adapt to its effects through climate proofing their livelihoods, production and assets. Strategies include rainwater harvesting and catchment protection, promotion of local and trans-boundary aquifer management and promotion of inter-basin/catchment water transfer schemes.

C. Zambia strengthening climate resilience project (PPCR Phase II)

PPCR Phase II is a project designed to support the pillar of Zambia's National Climate Change Program by ensuring that the country makes climate change a core part of its economic development. (GOZ, 2019). It aims at strengthening Zambia's institutional framework for climate resilience while improving the adaptive capacity of vulnerable communities in targeted areas. The PPCR comprises a National Project Implementation Unit (NPIU) whose mandate is to coordinate project activities. The PPCR is being piloted in 28 districts in Western, Southern, Central, and Lusaka Provinces.

D. Zambia National Strategy to Reduce Emissions from Deforestation and Forest Degradation (Redd+)

This is a government of Zambia document submitted to the United Nations Framework Convention on Climate Change (UNFCCC) (Patrick, Misael, & Jochen, 2015). The objectives of this strategy include:

- Manage and protect threatened and unsustainably managed national and local forests by 2030
- Manage and monitor selected high value forests in open areas by 2030
- Timber concession areas have management plans that are enforced and monitored with the full participation of local communities by 2030.
- Good agricultural practices that mitigate carbon emissions adopted by 2030
- Production of wood fuel (charcoal & firewood) regulated by 2030
- Appropriate and affordable alternative energy sources adopted by 2020
- Protected areas legislated as "no-go areas" for mining and infrastructure development by 2020

Conclusions for Chapter 5

- Off farm services such as index-based insurance, early warning systems, disease surveillance, credit and financing are still very limited for the three value-chain commodity groups.
- Category A and B beneficiaries are more vulnerable to climate change due to limited insurance and financial services.
- Supporting farmers in category A to access farmer associations and cooperatives to catalyse the provision of inputs, climate smart technologies and skills, and marketing services can accelerate their graduation to agribusiness and out of poverty. Farmer organization can facilitate the provision of bundled services for this category of E-SAPP beneficiaries.
- For beneficiaries in category B, limited adaptation options at the post-harvest and marketing, in comparison to production is hindering gains from the value chain. Studies have highlighted that about 60 per cent of value chain benefits occur post-harvest. It is therefore crucial that post-harvest climate adaptation is a priority in order to unlock more benefits for value chain actors.
- Stakeholders highlight that lack of political will is the greatest challenge to promoting effective implementation of adaptation across all value chains. Policies are particularly, a great challenge to facilitating smallholder market linkages and participation for the E-SAPP beneficiaries under category C.
- Zambia has developed various policies and strategy, which can provide an enabling policy environment and synergies to support climate adaptation for the E-SAPP programme beneficiaries.

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Supplementary information

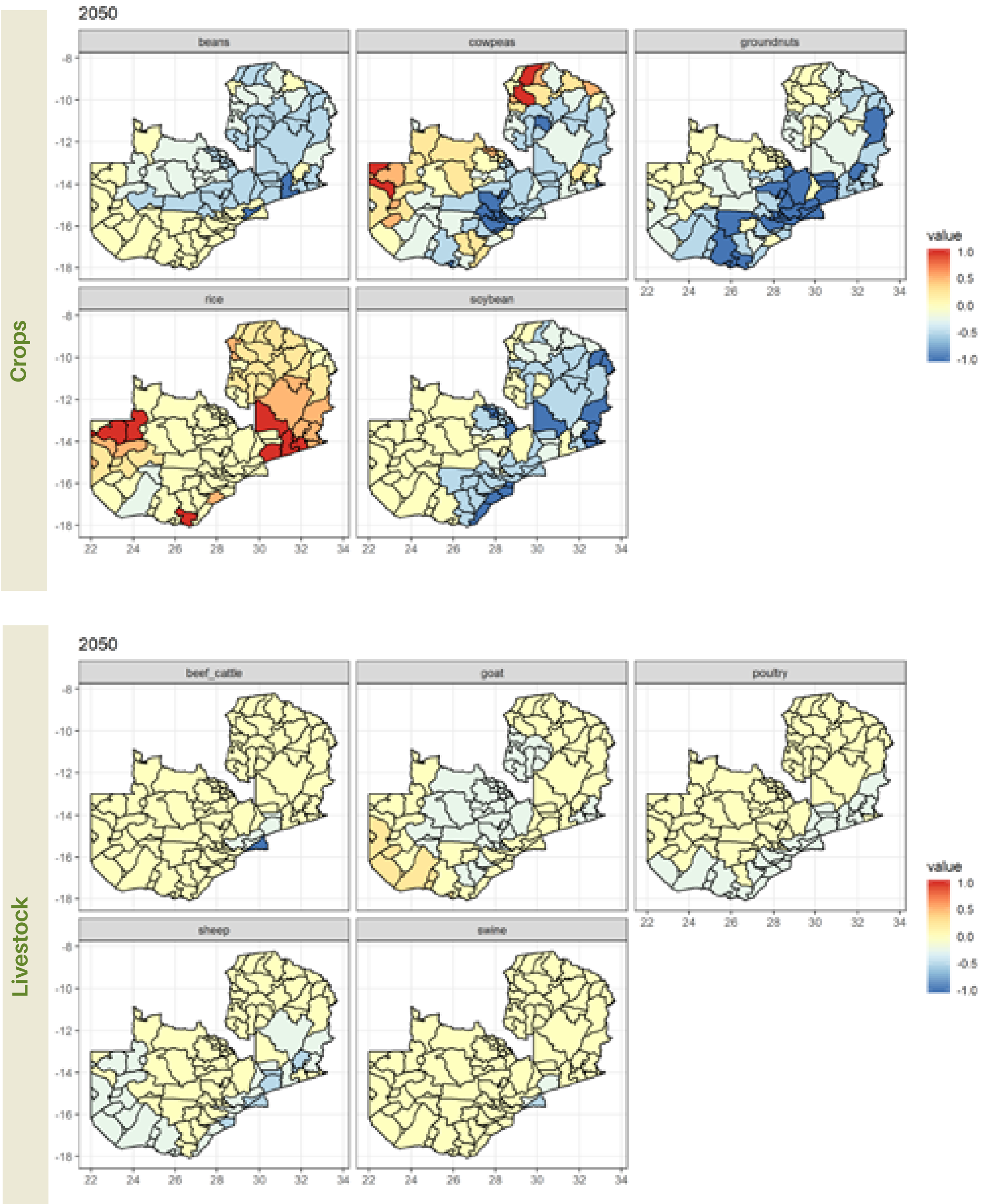


Figure S 1: Sensitivity of the ten value chains analysed here to climate change by the 2050s for scenario RCP 4.5

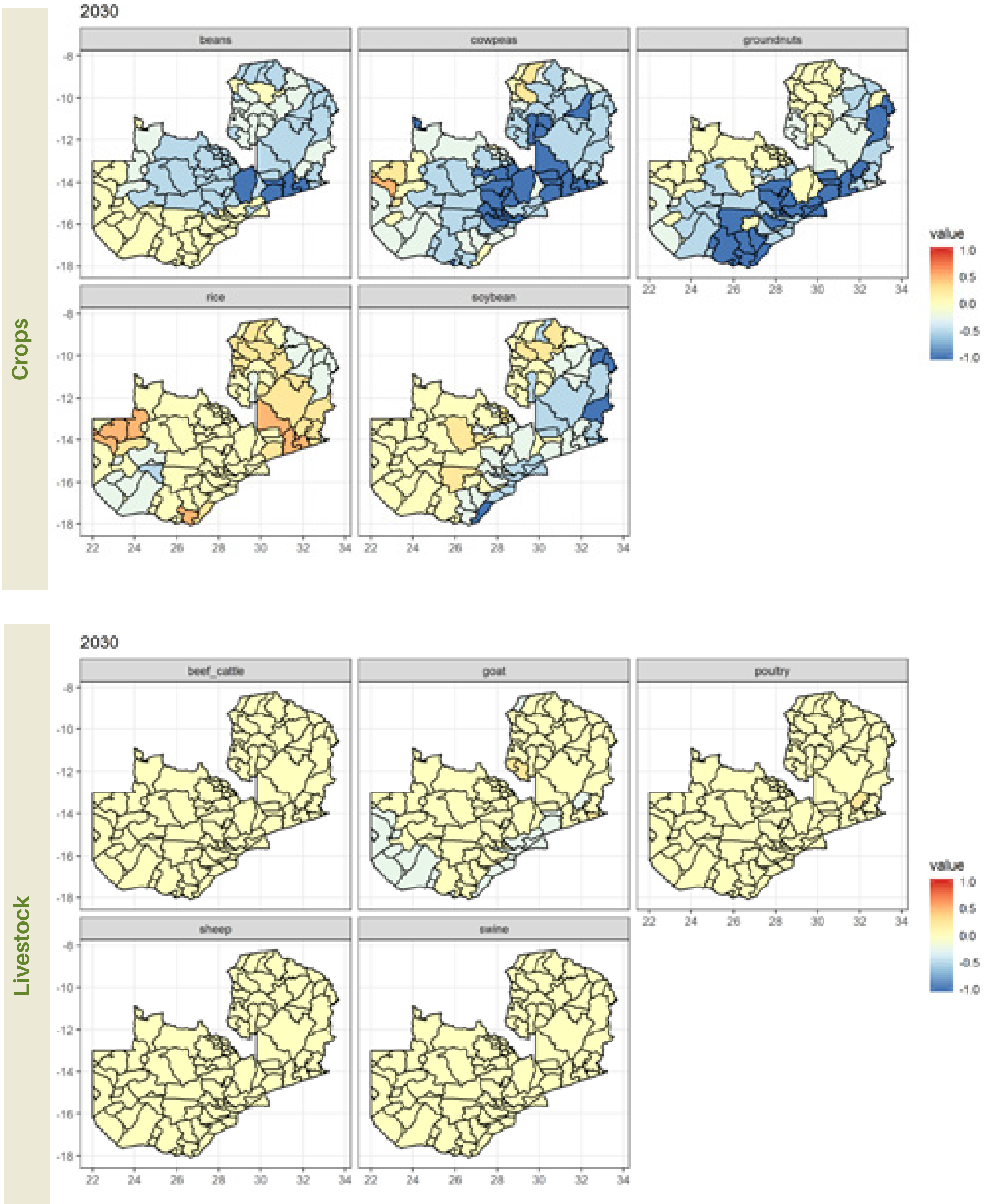


Figure S 2: Sensitivity of the ten value chains analysed here to climate change by the 2030s for scenario RCP 8.5

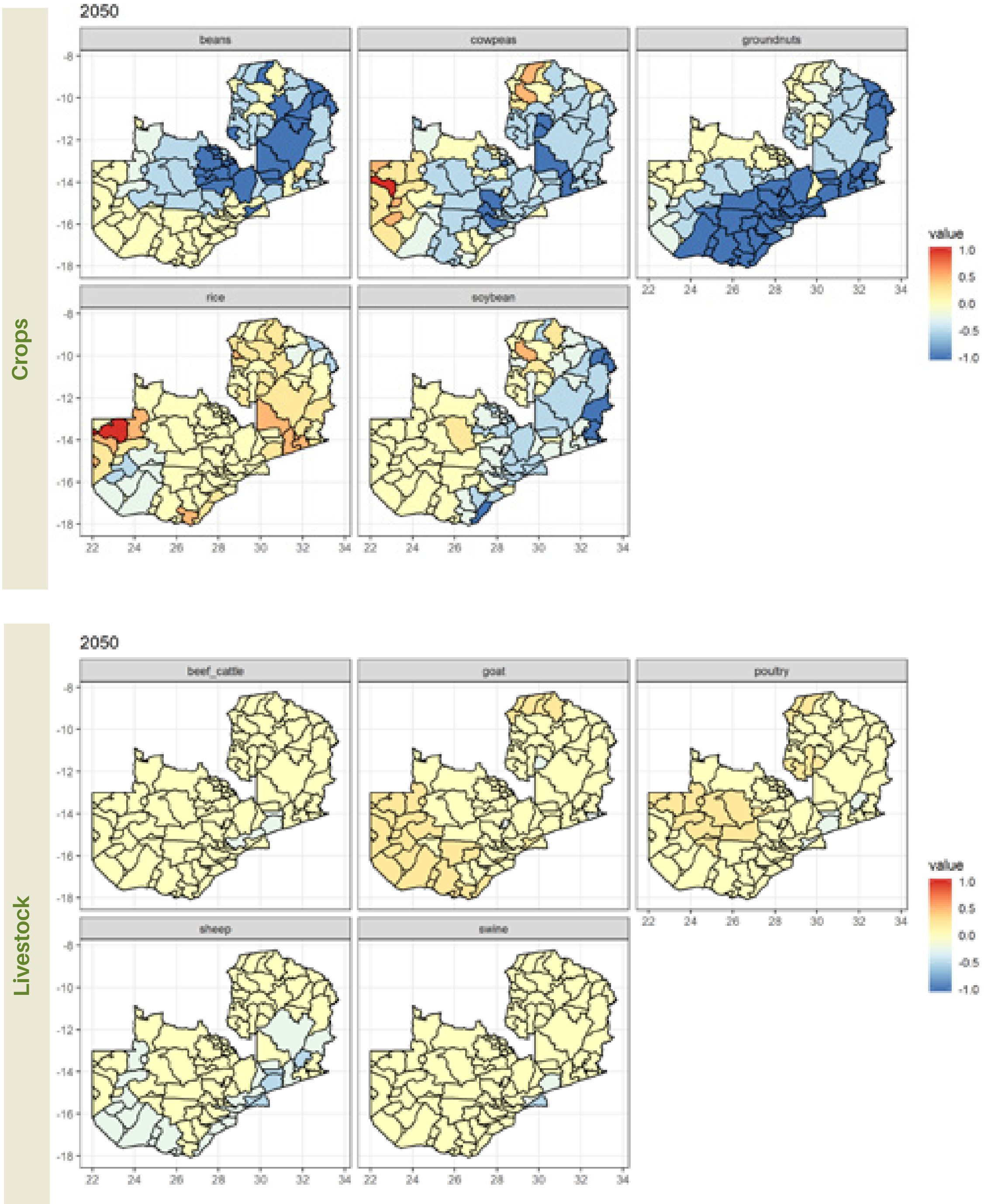
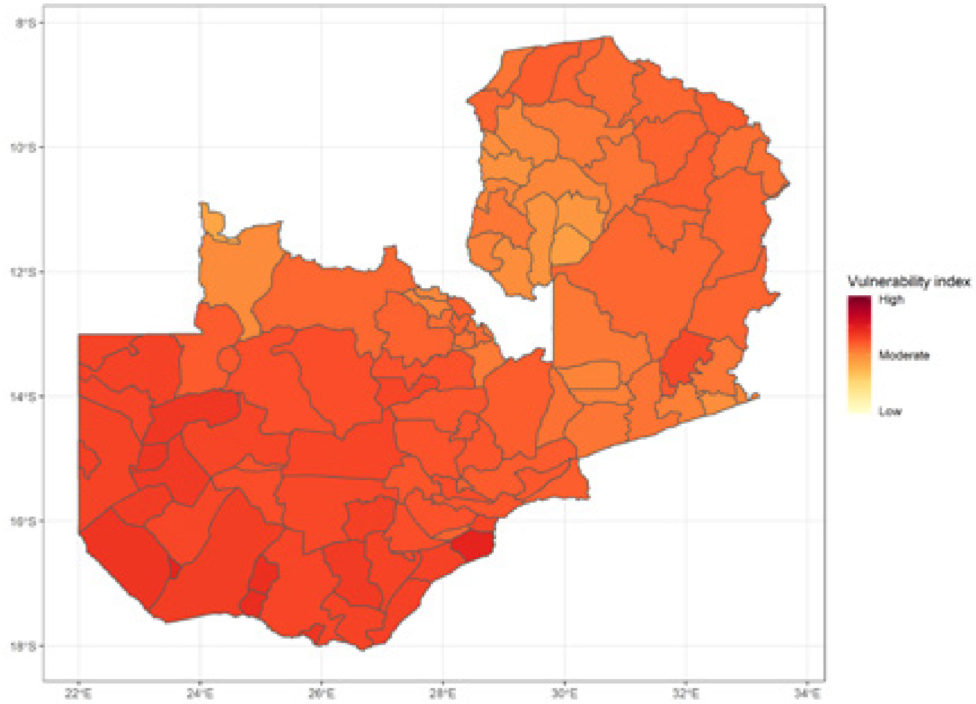


Figure S 3: Sensitivity of the ten value chains analyzed here to climate change by 2050s for scenario RCP 8.5



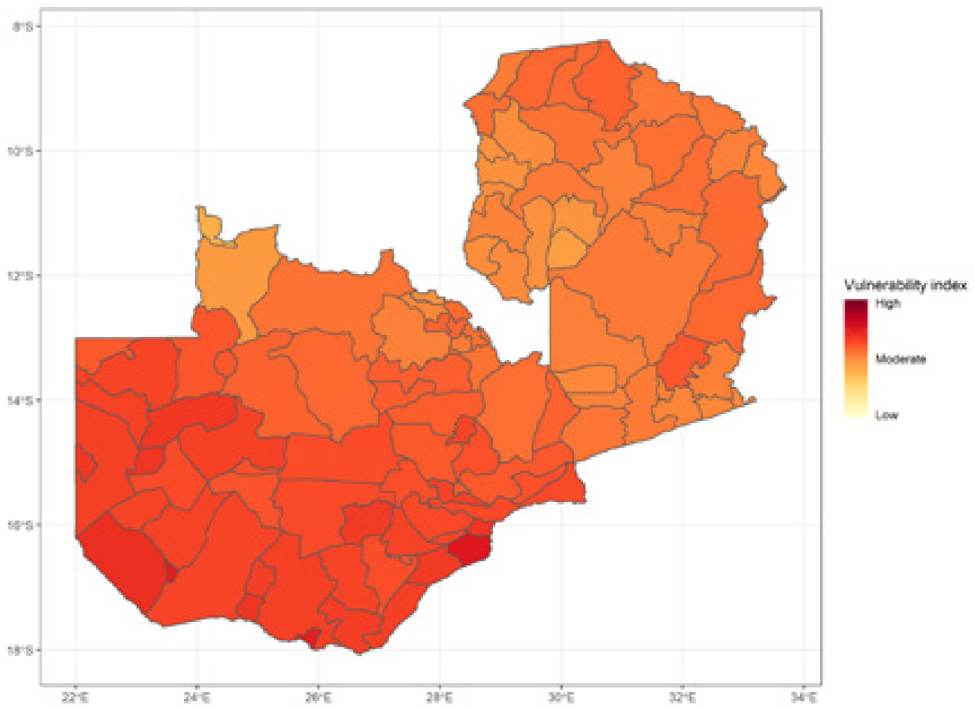


Figure S 4: Overall vulnerability of Zambian agriculture to climate change by 2050 for RCP 4.5 (top) and RCP 8.5 (bottom)

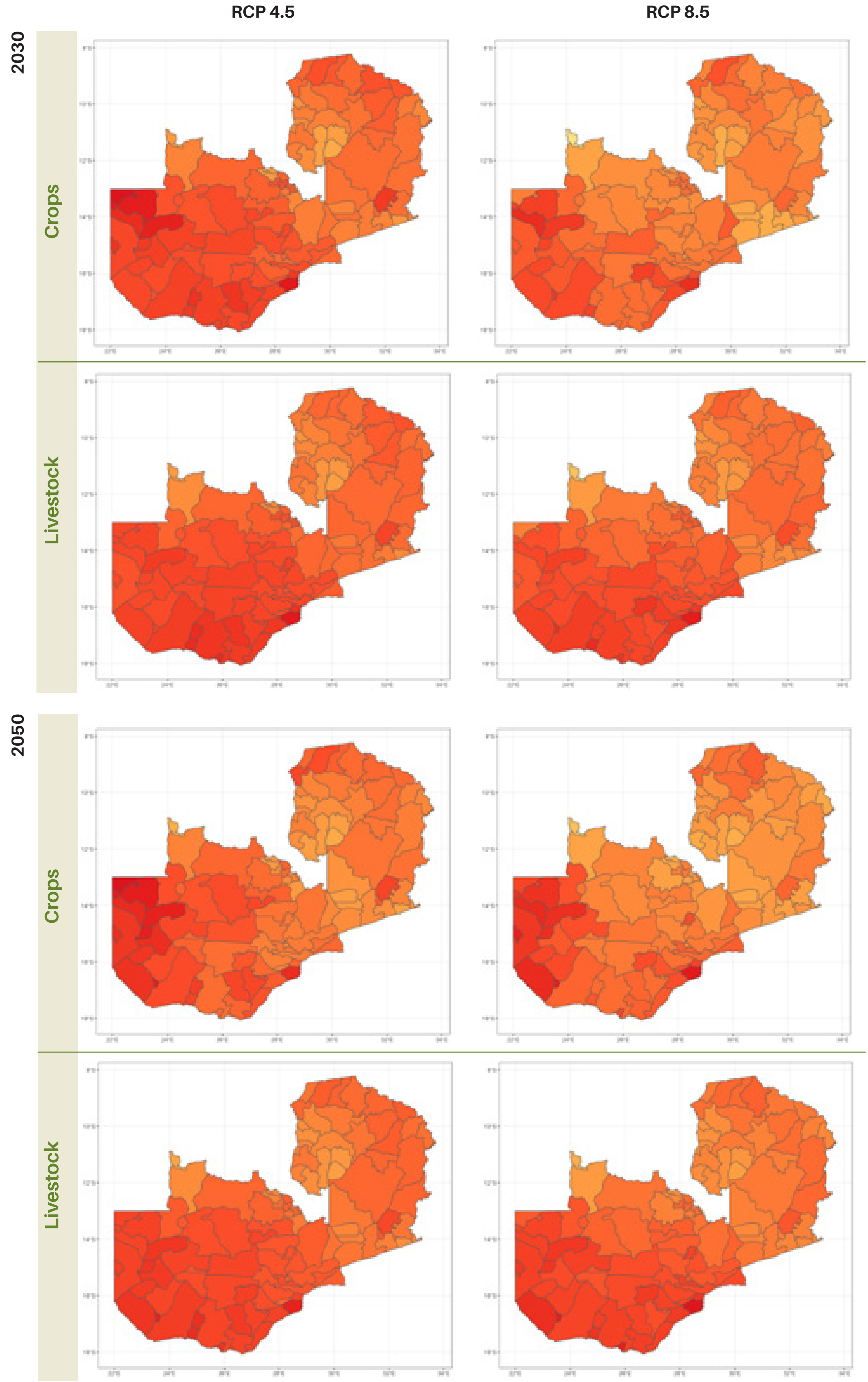


Figure S 5: Vulnerability of Zambian crop and livestock systems to climate change

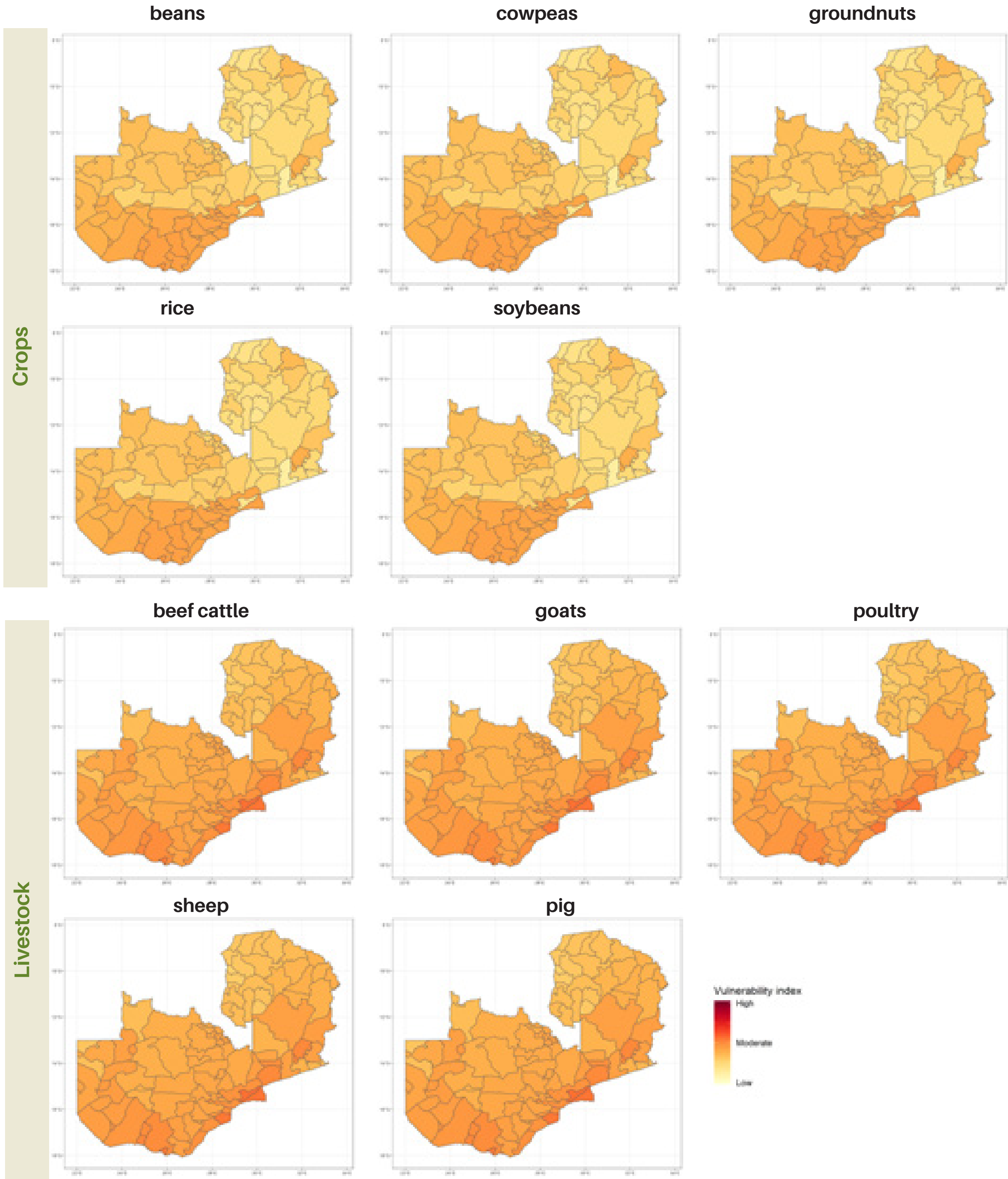


Figure S 6: Contribution of individual Zambian agricultural value chains to overall vulnerability to climate change by 2050 for RCP 4.5

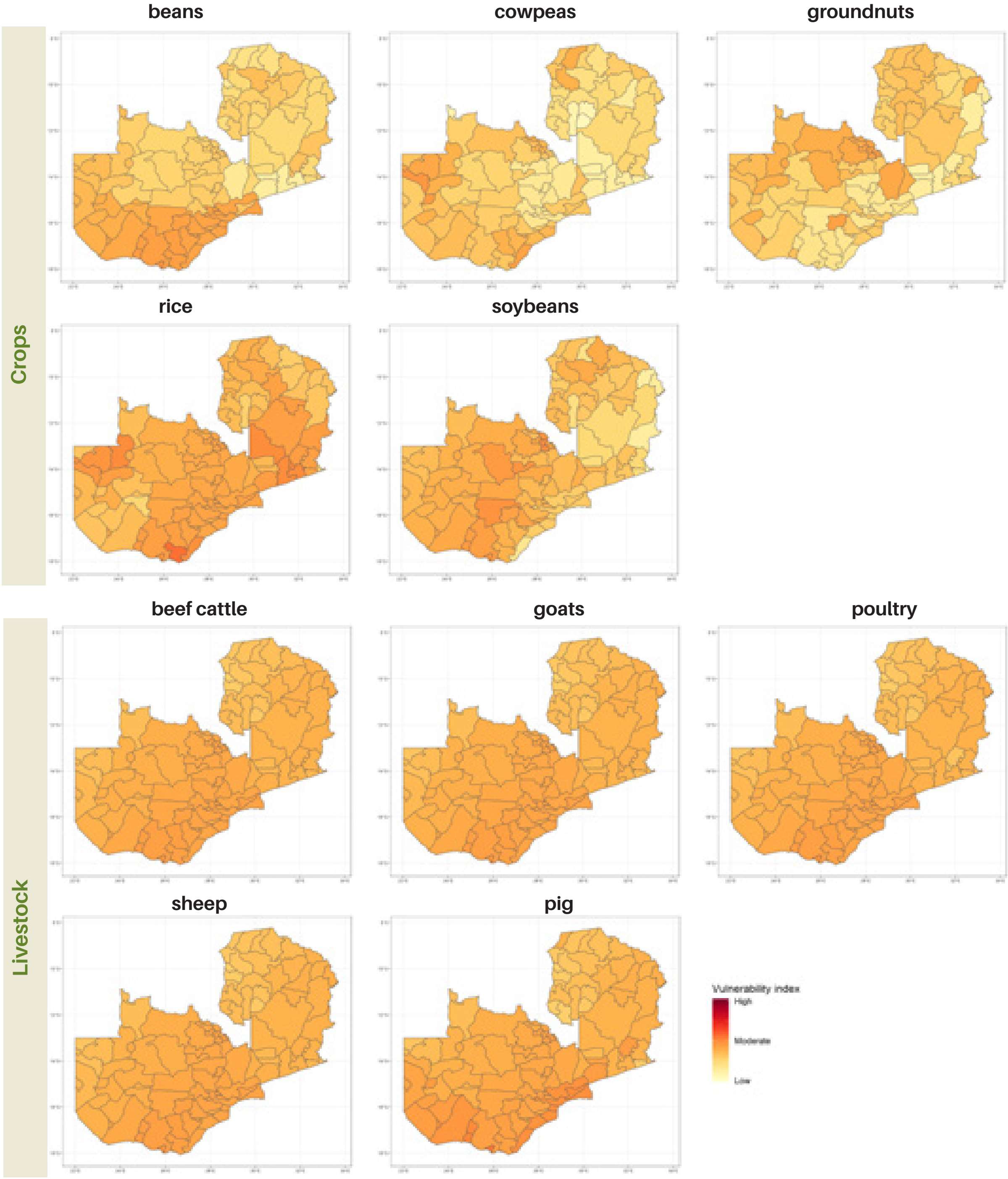


Figure S 7: Contribution of individual Zambian agricultural value chains to overall vulnerability to climate change by 2030 for RCP 8.5

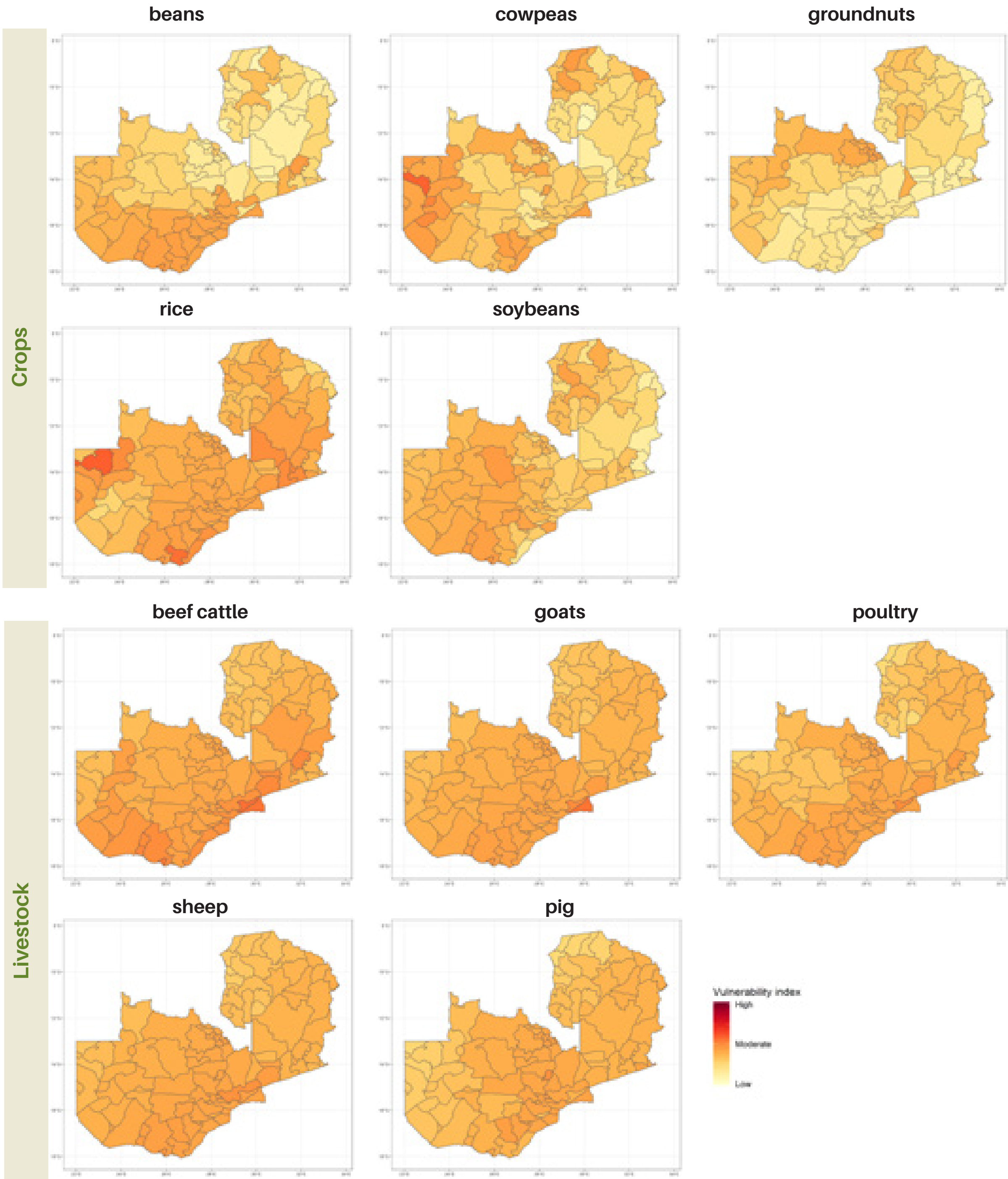


Figure S 8: Contribution of individual Zambian agricultural value chains to overall vulnerability to climate change by 2050 for RCP 8.5

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