Analysis of Projected Climate Change and Livelihoods

— A Pilot Study —

in the Botswana Open Access Livestock

and the Mozambique Coastal Zambezia

Livelihood Zones

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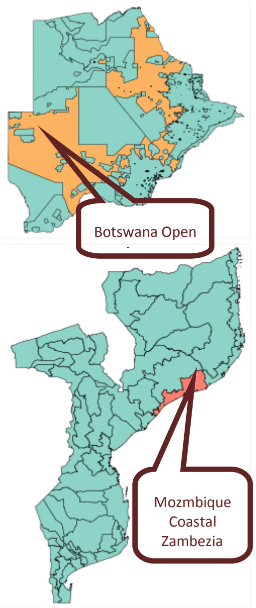
Executive Summary

Study rationale. The Regional Vulnerability Assessment and Analysis (RVAA) Programme has gradually developed a livelihoods-based vulnerability assessment system, with a number of member states undertaking baseline profiles and analyses of livelihoods that project outcomes for a single year. However, they do not necessarily allow for a projection over a long period, such as twenty or more years, which is needed for studying the livelihood impacts of climate change. Climate change, as an added stressor on livelihood systems, is understood to be more unpredictable with extreme occurrences of hazards (such as droughts and floods).

The SADC RVAA Programme has initiated a pilot study intended to test hypotheses of being able to analyse livelihood impacts based on a selection of projected climate scenarios into the future. This pilot study aimed at testing out a process of combining long-term downscaled climate projections with livelihoods data. This facilitated an analysis on whether changes in climate and climate variability will lead to periodic losses that households are unable to recover from in time for the next climate hazard—leading to impoverishment and heightened vulnerability. The pilot undertook to create a measure of the sensitivity of livelihood systems to climate change.

Livelihoods. The livelihoods system used in this analysis works by establishing a quantified baseline of how households can transform their assets into income—both cash and in kind, but which is expressed either in currency or in calorie terms—and how that income is used to meet their needs. These needs are ranked as survival, livelihoods protection or discretionary. Livelihoods are grouped geographically into Livelihood Zones[1] and the two areas selected for this study are the Botswana Open Access Livestock and the Mozambique Coastal Zambezia livelihood zones.

Figure 1: Livelihood Zones Locations



Issues. This work is a pilot and the aim is to see if the modelling and analysis is possible and then, if it is, to discover the key issues and concerns with it making it more reliable. This analysis is seen as useful to enhancing future contingency and mitigation planning. The weakest link in the analysis in this pilot is in many ways the climate-production relationships. With livestock, there needs to be a reliable rainfall, temperature and carbon simulator for the pasture found in the central Kalahari of Botswana. This can to be used to estimate reliable holding capacities and that needs to be integrated with the herd dynamic models. With crops, better use needs to be made of CliCrop or a simulator such as APSIM to predict yields based on monthly climate projections, so that water logging and dry spells can also be factored in. These models need to be extended to a greater variety of crops, including rice, coconut, millet and various legumes. More work needs to be done with modern population data sets, to explore the limits for expansion of the extent of farming, both in Mozambique and in Botswana. For example, ground water may present a constraint on human settlement in Botswana, limiting grazing land expansion, while arable land may also be limited in Mozambique. Population factors may be a greater factor in livelihood failure than climate (although climate variations could still act as trigger events for disaster). To some extent, economic shocks (such as staple price rises) are possible to predict for a given climate and large-scale (national or regional) production scenario—this would require some economic expertise and analysis.

Conclusion. The study found that in the Open Access Livestock livelihood zone in Botswana, which has a fragile ecology and is already water-stressed, climate change will impact enormously on productive potential and livelihoods. A net rainfall decrease will slash cattle production and income (and most likely force a switch to some other means of livelihood), while a net increase will substantially boost income. In

[1] Livelihood zones are geographical areas where people share similar patterns of livelihood

the Coastal Zambezia livelihood zone in Mozambique, changes in rainfall, temperature and carbon-dioxide will produce limited changes to household income. This is because of their reliance on fishing as well as their inability—due to poverty—to take advantage of the possible increases in rainfall that this area could experience as a result of climate change. Factors such as increased flooding from rivers or from storm surges, damage from cyclones and saline intrusion are other threats from the changing climate in this part of Mozambique.

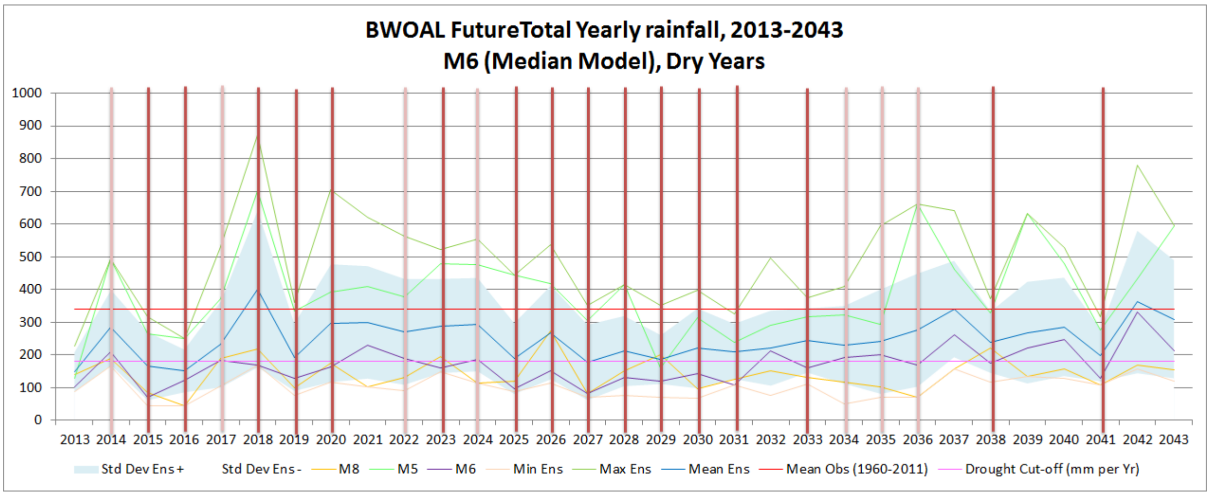
The analysis resulting from this pilot is evidence that livelihood and climate information can be combined using the methods developed in this study. However, this is dependent on data availability. Livelihood baselines are essential and climate projections can be validated if there is at least one weather station with good data records in the area of study. The linking of climate and livelihoods analysis hinges on reliable models of productions systems (such as climate/livestock or climate/crop production systems). It is crucial that rigorous models of the relationships between the livelihood asset being analysed and the components of climate (i.e. rainfall, temperature, etc.) are established. The outputs produced by these models must also be tested and validated as a means of verifying their robustness. This is aided by access to a set of multi-disciplinary expertise that can be consulted to interpret the results produced by the models, checking the accuracy, representativeness and completeness.

The phenomenon and impacts of climate change are wide-ranging and highly complex. Further value can be added by including analysis on such factors as economic consequences (what are future potential relative price trends resulting from climate stress?), population growth and dynamics (are resources bounded by population pressure rather than climate stress?) and access to services.

Summary of Results and Outcomes - Analysis of projected climate change and livelihoods

Climate scenarios. The approach taken was one of using a number of climate scenarios based on Global Circulation Models (GCMs), attempting to investigate the long-term consequences of these different scenario's on households' income and assets. Within the database used, there is a total of eleven Global Circulation Models. The four scenarios selected for this analysis included the second wettest model, the second driest model and the median model for each livelihood zone as well as an averaged combination of all eleven of the Global Circulation Models (referred to as a GCM Ensemble). Figure 2 below graphs the models used against a Drought Cut-off (shown by the straight pink line) and a line representing the mean observed total annual rainfall in the Botswana Open Access Livestock livelihood zone (shown by the straight red line, estimated using historical rainfall for this particular area).

Figure 2: Botswana Dry Years, Median Model



Data Source: From Tshane weather station, accessed via CSAG Climate Information Portal, http://cip.csag.uct.ac.za

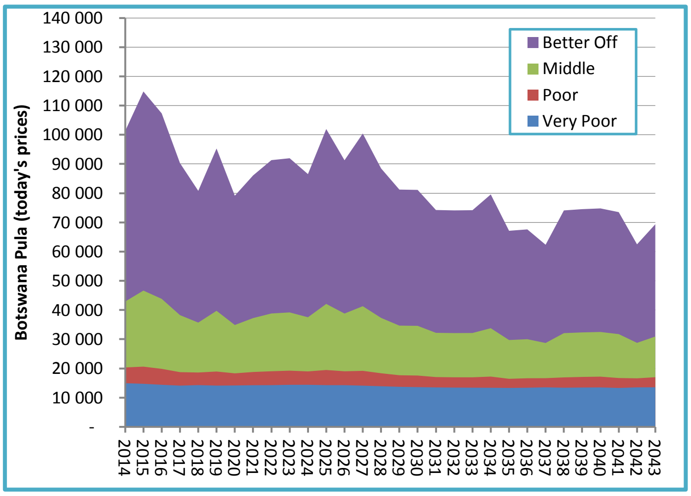
In the Botswana livelihood zone, a drought year is characterised as having a total annual rainfall less than 180mm. The graph below provides an analysis whereby dry (or drought) years are identified in the

Botswana Open Access Livestock livelihood zone under a scenario where the total annual rainfall for the median model (the jagged purple line – M6) falls below the Drought Cut-off line. Darker shaded vertical red bars depict drought years. These years are classified as drought years as the line for the median model [M6] for this specific area in Botswana is below the drought cut-off line. The lighter shaded vertical red bars depict years where there is a relatively dry year experienced (in terms of the projected total annual rainfall) but where the level of total annual rainfall (of the model being analysed) does not per se fall below the drought cut-off rainfall limit.

As can be seen in the figure above, it is crucial to have observed weather data that is accessed from historical data records. A central finding from the pilot is that the methods for combining climate and livelihoods information is highly dependent of being able to access data for observed weather as well as for projected climate for a particular site. Observed weather figures (rainfall, temperature, etc.) provide benchmarks that allow for a comparison against projected climate data. By creating these benchmarks or cut-offs, one is able to get a sense of potentially how different climate may be in the future in comparison to averages of what has been observed in the past. Thus the feasibility of a particular site is reliant on the presence of a weather station with observed weather and projected climate data, as well as having a livelihoods baseline.

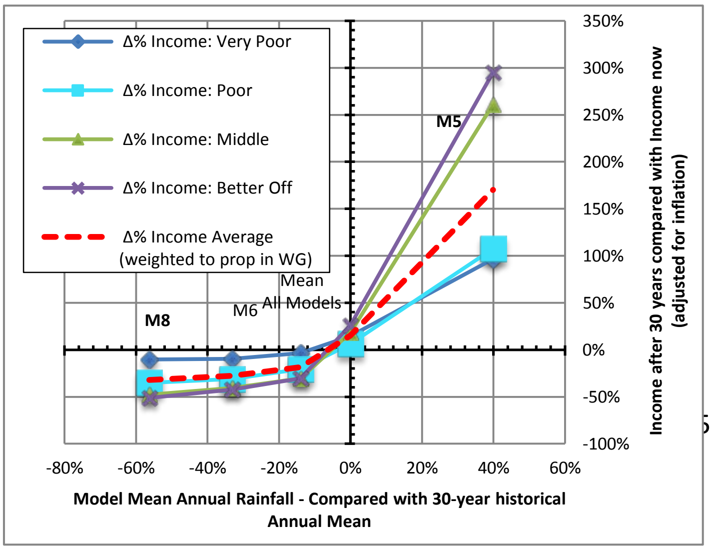
Climate to livelihoods. The study investigated the relationships between climate and productive components in each livelihood system. With livestock as the main productive activity in Botswana, the complexity of the key relationship between climate and livestock productivity was analysed based on herd dynamics and livestock productivity against rainfall (for forage and water for animals). The team found that death rates and overall herd numbers correlated somewhat with rainfall but not birth rates. The team were unable to find useful literature on the effects of temperature, although it is understood that it will impact on both pasture and animal condition directly. The rainfall outcomes from the climate models were then applied to the livestock herd dynamics models. In the cropping area in Mozambique, rainfall to yield, temperature to yield and carbon dioxide to yield models were applied on a yearly basis to determine the potential outcome for households. In all analyses it was assumed that there is sufficient land to accommodate expanding populations or additional population growth would be absorbed outside of the livelihood zone, meaning that population would not necessarily be a significant constraint. Further, it was assumed that prudent economic and policy management would enable the continuation of existing government social protection programmes, without severe price shocks or loss of employment opportunities or market access. In reality, it is rare for a country to go thirty years without some sort of economic shock and this could undermine households' livelihoods more substantially than just climate factors.

Figure 3: Time series of income for the mean of all climate models in Botswana Open Access Livestock livelihood zone



Livelihood Outcomes. The study found that in Botswana, for climate scenarios that range from the driest to the median in rainfall, livestock production collapsed for the drier climate models and scenarios, resulting in substantially lower incomes that taper off (less than 50% of baseline) in the last decade.

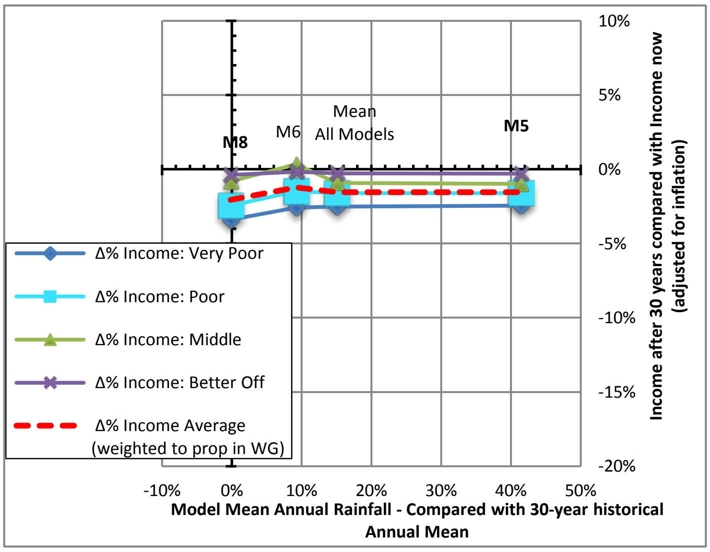
Figure 4: Livelihood to climate sensitivity for Botswana Open Access Livestock livelihood zone



In these climate scenarios households will be forced to move away from cattle husbandry as their primary activity, perhaps switching to more resilient livestock species. When using the mean of all climate scenarios the annual household income oscillates, with a steady decline, as shown in Figure 3. However, for the second-wettest scenario, the average income increases substantially over the period, by 170%.

In the Coastal Zambezia livelihood zone of Mozambique the climate models are more generous in their rainfall projections. However, since the livelihoods here depend on fishing and capital expenditure, with low productivity of crop farming, the impact of the extra rainfall is limited. Using better climate to crop performance models such as CliCrop and APSIM can help determine a wider range of risks (especially risks in distribution of rainfall—as opposed to just the total—like waterlogging).

Figure 5: Livelihood to climate sensitivity for Mozambique Coastal Zambezia livelihood zone



As can be seen by the curves in Figure 4 and Figure 5, Botswana Open Access Livestock liveliood zone has a high sensitivity to climate change, while the flat shape of the lines for Mozambique show that sensitivity of Mozambique is lower (income unchanged across the scenarios). However, there are a number of other climate-related factors that could affect this part of Mozambique, such as rising sea levels, coastal surges from increased cyclone frequency and intensity and increased flooding. These could lead to other impacts such as saline intrusion on the farmland.

Background

The Regional Vulnerability Assessment and Analysis (RVAA) Programme is part of the Southern African Development Community Food, Agriculture and Natural Resources (SADC-FANR) Directorate, implementing the Regional Vulnerability and Assessment Committee's (RVAC's) five-year strategic plan. The main focus of this plan is on strengthening national and regional vulnerability assessment and analysis (VAA) systems through institutional support, training and capacity building.

The RVAA Programme is assisting SADC-FANR in fulfilling its mandate of tracking and monitoring progress of member states' commitments to the Dar-es-Salaam Declaration, by working with institutions that are engaged throughout the region and in different sectors linked to vulnerability, food insecurity, and poverty. These institutions include SADC projects and programmes, National Vulnerability Assessment Committees (NVACs), academic institutions, donor-funded projects and programmes, and research institutions.

The RVAA Programme has gradually developed a livelihoods-based vulnerability assessment system, with baseline profiles and spread sheets for analyses of livelihoods units over a single consumption year, for many parts of the region and in a number of member states.

Climate change is one of many influences on development and is an additional stress factor on livelihoods. Globally, over the last thirty to forty years, temperatures have risen, there have been increases in the duration of dry spells and seasons without sufficient rains, increases in the proportion of heavy rainfall events, and increases in the frequency of climate disasters.

The impacts that may result due to a changing and variable climate include (but are not limited to) declining crop yields, declining crop production (Easterling et al., 2007) and declining availability of water for humans and livestock, for example. When crop and livestock production fails because of drought, floods, pests or diseases, both poverty and hunger increase (Chapman et al., 2012). Climate change is likely to place increasing strain on agricultural growth (Jones & Thornton, 2003) thus rendering poverty and hunger reduction targets elusive as population numbers rise. In their publication entitled "The potential impacts of climate change on maize production in Africa and Latin America in 2055", Jones and Thornton (2003) provide an example in which it was found that aggregate yields of maize in smallholder rain-fed systems in Africa and Latin America are likely to show a decrease of 10% by 2055.

However, responding to climate change presents trade-offs that need to be considered. Decisions on managing climate change are complicated by the high level of uncertainty that characterises the dynamics of it in the region. We may observe emergent climate trends but are unable to know with certainty the future change (how many degrees warmer 'an area' will get) or the rate of change (how long it will take for average temperatures to rise). Thus, whilst climate change models may project more frequent extreme weather events (e.g. droughts, storms, floods) models themselves cannot tell us with any certainty when, where or with what intensity these events will occur. Hence, it is one thing to know that climate change is occurring and to know that it will continue to occur in the foreseeable future, but it is quite another to put numbers and estimates to what that future change may look like in detail.

The SADC RVAA Programme has initiated a pilot study intended to test hypotheses of different climate scenarios and to measure sensitivity of livelihood systems to climate variability. The approach taken avoids making accurate predictions into the future and instead creates a number of scenarios, for which it might be possible to examine livelihood impacts. These scenarios would be grounded in existing forecasts and climate models so that they are reasonably realistic. The practical policy implications of this study will be knowledge of:

1. The populations in the selected areas that are most sensitive to climate change;
2. The types of information required to measure livelihoods adaptation to climate change;
3. Options for making livelihoods more resilient to climate change (adaptation).

The analyses being done by member states and National Vulnerability Assessment Committees (NVACs) at present are limited to periods of a single year. Hence, they are actually short-term analyses based on weather changes and weather events. What is also required are longer-term analyses based on climate changes and climate events. To obtain an impact on livelihoods resulting from changed climate variability, longer periods of multiple years need to be covered. This pilot study synthesises an analysis over a future thirty-year period based on a number of agreed scenarios, thereby defining sensitivity to climate events, not the future climate events themselves.

This pilot is envisaged to inform future work on livelihoods and climate change analyses that will hopefully be possible throughout the region where livelihoods data exist. As such this pilot study highlights issues on data requirements, analysis needs, personnel, resources and the feasibility of combining the methodologies for livelihoods analysis and future climate scenario development.

The activities within this study undertook to marry the existing knowledge of livelihoods and climate and convert this into information that is useful for decision-makers in determining appropriate policy and programming for climate change adaptation.

The Objectives of the Study

To main purpose of the pilot study was to gain an understanding of the impact of climate change on livelihoods. This assignment aimed to obtain a measure of sensitivity of two livelihoods zones to climate variability using a series of analyses based on scenarios. The following results have lead to the achievement of this goal:

a. Compilation of data, information and information system prerequisites for undertaking a meaningful climate change analysis;
b. Creation of problem specifications from each of the scenarios and running these repeatedly at the intervals specified so as to observe whether households are able to recover between hazard events or not.
c. Quantification and comparison of two livelihood zones' sensitivity to climate change and analysis of possible resilience of the livelihoods in these two livelihood zones' to climate change.

The Study

Livelihoods and Climate

This pilot study aimed at testing out a process of combining livelihoods and climate models and information to analyse the impact of climate change on poor households in Southern Africa. The approach taken was one of using a number of climate scenarios based on Global Circulation Models (GCMs), attempting to investigate the long-term consequences to households' income and assets.

Livelihoods are necessarily complicated as households have different ways of making a living; not only are each of these ways affected differently by each type of shock or hazard, the constraints and threats to livelihoods can vary considerably. Ideally, an analyst would seek out each and every household to understand the details and nuances of each pattern of livelihood but this is impractical. Hence, some kind of aggregation is called for and, to keep samples as small as possible, households are grouped according to two key determinants: geography and household resources (household assets).

Geography describes the climate, soils, vegetation, human settlement and access to markets in different areas and this is important because where someone lives determines to a large extent the options they have for making a living. Areas with a reasonable degree of spatial commonality are grouped into ***livelihood zones***—these can also be described as geographical areas where people have similar patterns of livelihood or similar ways in which they make a living.

Within each livelihood zone, the wealth and access to resources that different households have will affect their livelihoods. The approach often taken is to combine households with similar asset levels into ***wealth groups***—these are groups of households that are defined by the communities themselves, according to local definitions of wealth.

The aim of this pilot is to combine the effects of long-term downscaled climate projections with livelihoods data; in particular to study whether the changes in climate variability will lead to periodic losses that households are unable to recover from in time for the next climate hazard. This does, of course, assume that other possible stressors on livelihoods (such as economic factors like pricing and market access) do not worsen further. A significant factor for livelihoods and vulnerability is population growth, especially when the main resources (usually land and grazing) upon which economic activities are wholly dependent, are limited. This will be discussed in subsequent sections. It is also important to investigate the impact of climate change on different livelihood types in different countries, which have different degrees of government intervention taking place in their localities. For this reason the study team chose two rural livelihood zones, one livestock farming based and one crop farming based, in two very different countries, Botswana and Mozambique.

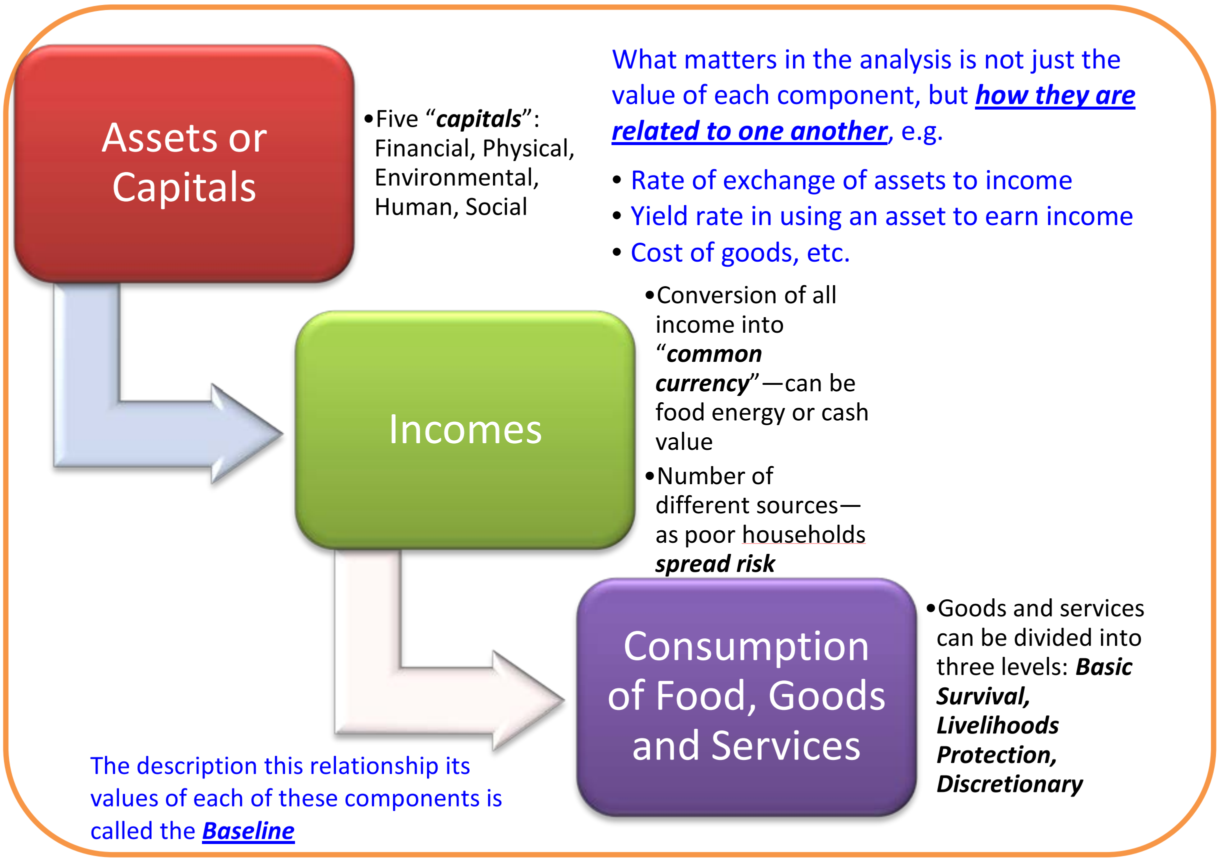
The livestock-based livelihood zone in Botswana is called the Botswana Open Access Livestock (BWOAL) livelihood zone. It consists of a large geographical area that is often called the "central Kalahari" and which spans the central part of the country from the west to the north-east, including much of Ghanzi District, northern half of Kgalagadi District, northern half of Southern District, the western parts of Kweneng District, northern half of Central District, eastern edge of Ngamiland District and the south of Chobe District. The map of Botswana in Appendix II on page 36 shows the location of the zone.

The crop-based livelihood zone in Mozambique is called the Mozambique Coastal Zambezia (MZZ14) livelihood zone. It is an area in the coastal plain surrounding Quelimane in Zambezia Province, located in the coastal districts comprising the whole of Pebane, approximately half of Maganja da Costa, approximately half of Namacurra, about a quarter of Nicoadala and the whole of Inhassunge. Nearby, to the south-west, is the massive Zambezi River delta but this is another livelihood zone, the Zambezi delta. The map of Mozambique in Appendix III on page 37 shows the location of the zone.

The livelihoods approach uses a model that quantifies the assets, income and expenditure in a ***reference*** or ***baseline*** year, the concept of which is shown in Figure 1. More importantly, the model seeks to quantify and describe the ***links and relationships*** between assets, income and expenditure.

The livelihood system consists of assets, which may be categorised into the five "capitals": financial, physical, environmental, human and social. These five assets are combined in various forms to bring in "income"—which may be cash (e.g. through the sale of a cash crop) or "in-kind" (e.g. food that is grown and consumed directly). The higher the productivity of the household, the greater the income they obtain for a given capital investment. For the ease of understanding of the results, income is usually converted into a "common currency"—a unit that enables all sources to be compared and added together. The usual "common currencies" that are used in analysis are monetary equivalents or food energy equivalents. Monetary equivalents are useful as they translate directly into budgetary costs when summed over the population; food energy equivalents are useful because they are directly linked to a basic need and are not subject to changes over time, such as the effect of inflation on cash values. Income can be spent on the consumption of goods and services and, in this study, these are divided into three levels: Survival, Livelihoods Protection and Discretionary.

Figure 6 – Livelihoods analysis principles



Survival expenditure is very minimal and basic. It is about staying alive temporarily—a short period of up to a year—and nothing else. It comprises minimum food energy, some basic oil, protein foods and mineral-rich foods such as a vegetable or two, the means for preparing those foods and keeping warm and dry (without investments in new shelter or clothing). Survival expenditure is a function of very basic human needs and therefore forms a threshold that is the same for all households, regardless of wealth. It's a threshold that is useful for ***prioritising emergency responses*** when resources are constrained, but it is of little value to programming for poverty alleviation, poverty reduction and building resilience.

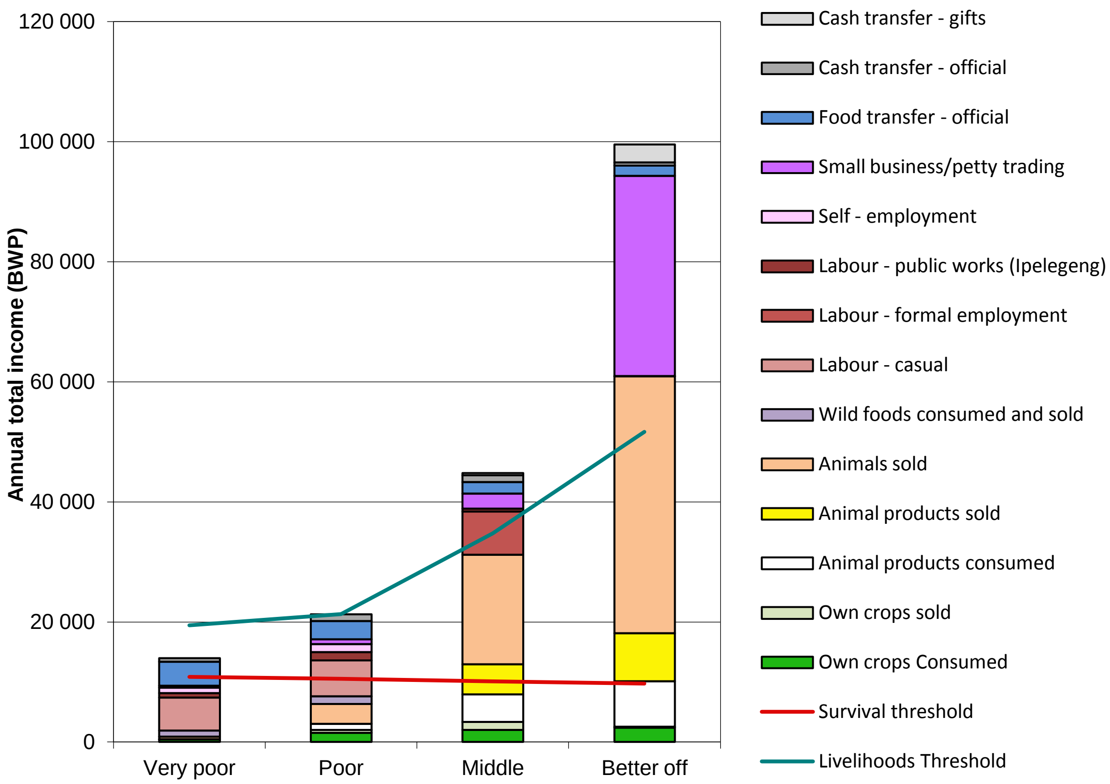
Livelihoods protection expenditure goes further and includes a larger range of expenditures that enable households to maintain their assets. Increased dietary diversity and expenditures on basic services (health and education) are considered—these all maintain "human capital"—as are expenditures on veterinary drugs or fertiliser—which maintain "physical capital" of livestock and land—or expenditures on labour hire, *stokvels*[2] or even communications—which maintain "social capital". As capital and asset ownership increases with increasing wealth, so must the expenditure on maintaining them, therefore this expenditure forms a threshold that is not absolute and increases with wealth.

The last category of expenditure is called discretionary—this is the amount the household has for purchasing more assets, investing in new ventures (such as petty trading), accessing more services or for "luxury" expenditure such as entertainment. Under duress, households will first reduce their discretionary expenditure, then their livelihoods protection and finally, when they have no choice, their expenditure will be below their survival threshold.

The sources of income and the survival and livelihoods protection thresholds are shown below for Botswana Open Access Livestock in Figure 2 and for Mozambique Coastal Zambezia in Figure 3. Each bar in the graph represents a ***wealth group***, not a quartile. This means that the proportions of households in each wealth groups vary: for example, the 'better off' in Botswana are 15% of the population, while the 'very poor' are 35% of the population.

When a livelihood system is subject to hazards, the relationships between assets, income and expenditure are affected, and capitals such as land, livestock and human labour no longer produce the requisite income. The assets or capitals themselves may be lost or lose their value as well. Lost income equates to lost expenditure and, if purchase prices rise, decreased access to food, goods and services. The first expenditure to be forfeited is the discretionary, followed by the livelihoods protection and lastly, if incomes are reduced to dire levels, households will no longer be able to afford the survival expenditure.

Figure 7 – Income bars for each wealth group in the Botswana Open Access Livestock livelihood zone



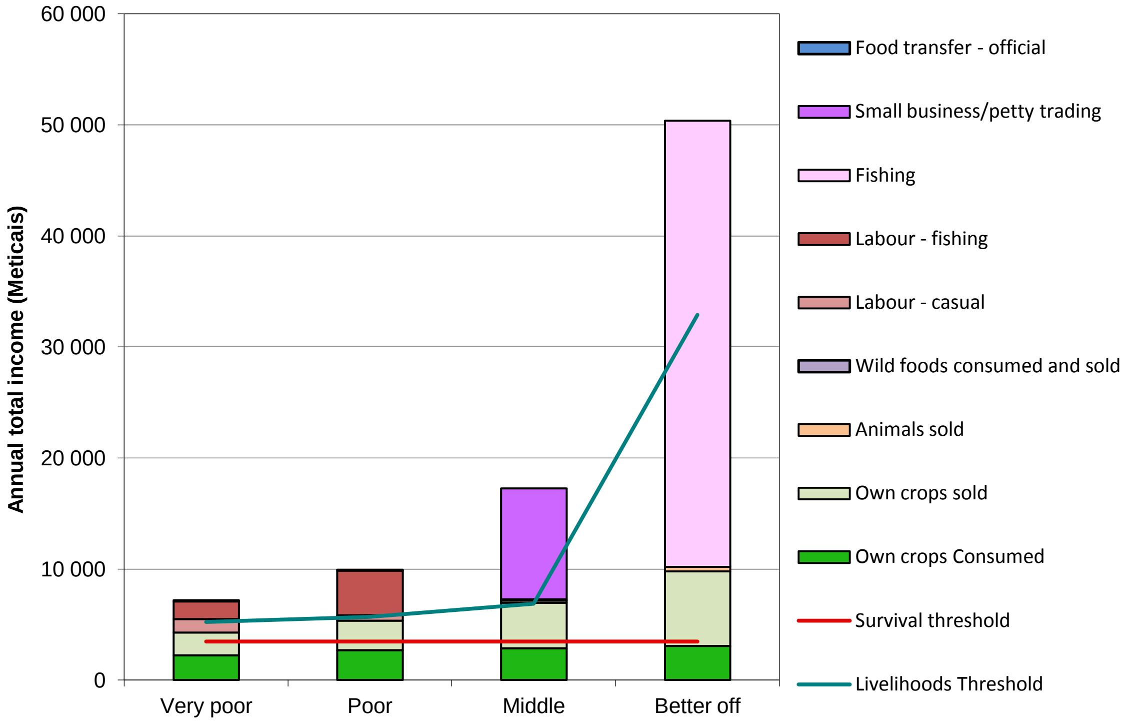
Source: Botswana Vulnerability Assessment Committee (BVAC)

Households usually respond to hazards or stress by switching their less-essential expenditure and then by increasing their income, either by engaging in alternative activities or by selling or exploiting their assets to the maximum potential. If their assets are sufficient they will meet their survival needs and possibly their livelihood protection needs through these strategies. However, they will pay the price by having their asset

[2] A *stokvel* is an informal savings group, were members contribute funds that can be lent in turn to individuals in need.

base considerably reduced and they will need to rebuild this over subsequent years. Their ability to rebuild this asset base in time for the next round of hazards determines whether they are in a cycle of increasing vulnerability or whether they can escape it.

Figure 8 – Income bars for each wealth group in the Mozambique Coastal Zambezia (*Litoral da Zambezia*) livelihood zone



Source: Mozambique Grupo de Análise de Vulnerabilidade (GAV), Secretariado Técnico de Segurança Alimentar e Nutricional (SETSAN)

The quantification of a hazard into data that can be mathematically linked to a livelihood baseline is called the ***problem specification***. Problem specifications are usually multi-dimensional (involving more than one (often several) variables at once and ephemeral[3]. The household's ability to respond by enlarging the contribution of a particular asset or income source is sometimes called the ***expandability***.

Methodology

Climate data: Data gathering and management

One weather station was chosen in each of the livelihood zones that were selected for this pilot. The Tshane station was used for the Botswana Open Access Livestock livelihood zone (BWOAL), which is situated in village of that name in the Kgalagadi District. For the Mozambique Coastal Zambezia livelihood zone (MZZ13), the Quelimane station was used. This station is located in the town of that name, which is in the Zambezia Province of Mozambique. These two stations are shown on the map in Figure 4 below.

For the purposes of this pilot, the data used from these weather stations include:

- Observed monthly rainfall figures
- Projected future rainfall figures for 11 Global Circulation Models (GCMs)

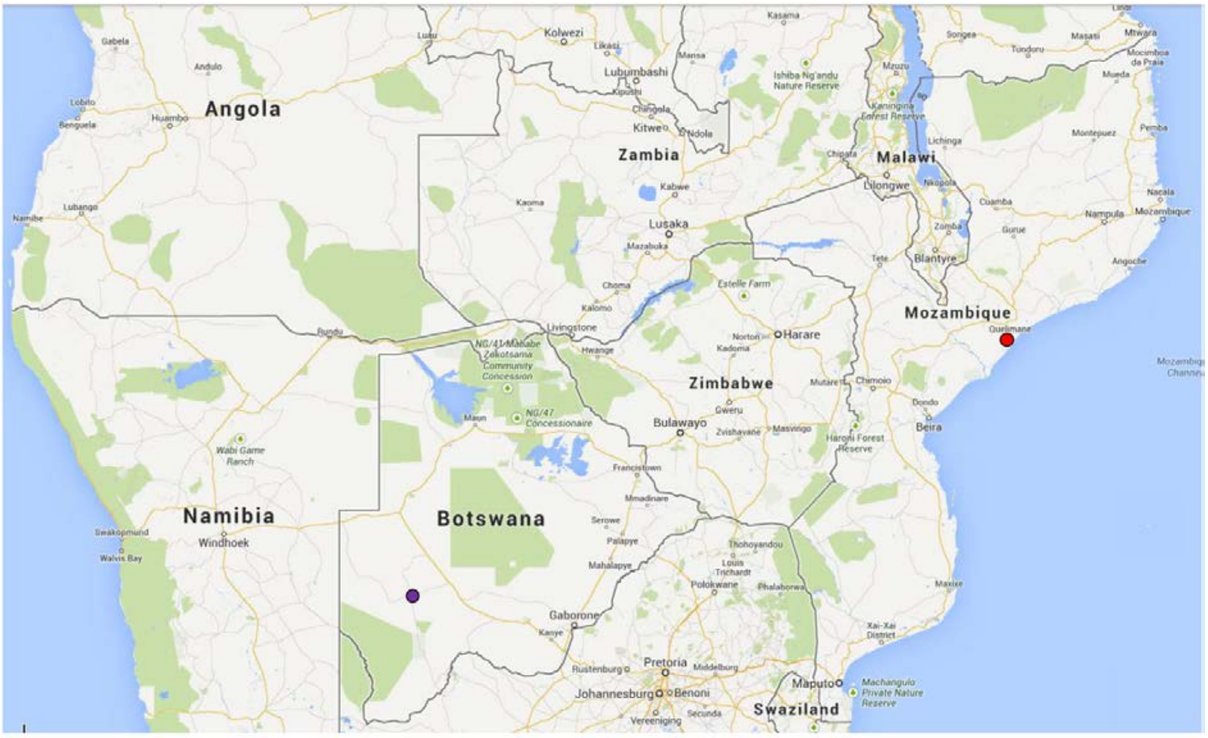
[3] For example, crops may fail, livestock production may be reduced, livestock sales prices may plummet and staple purchase prices may skyrocket simultaneously or within a very short time period from one another. These effects will always vary from year to another and so they will not be permanent.

Observed monthly rainfall figures

In analysing the observed monthly rainfall for these 2 stations, the aim was to access at least a 30-year period of historical rainfall figures. If more than 30 years of historical rainfall data could be accessed, these additional years of data were also integrated into the analysis.

In the case of the observed monthly rainfall figures for the Botswana livelihood zone (Botswana Open Access Livestock - BWOAL), observed monthly rainfall figures from the Tshane station were accessed for the period **1960-2011**[4]. For the Mozambique livelihood zone (Quelimane – MZ13), observed monthly rainfall figures were for the period **1951-1981**. The difference in the time period is due to the availability of data that is provided from these different stations.

Figure 9 – Geographic locations of the weather stations



● Tshane Station, Botswana
● Quelimane Station, Mozambique

Source: Google Maps

It is important to point out that the different time periods do not impact on the analysis conducted in this pilot. This is for two reasons. Firstly the observed figures are used to identify total monthly and yearly rainfall figures. The main purpose of this information is to allow for the identification of weather events (such as drought) that have occurred in the past. Secondly, the study of each of the livelihood zones is independent from one another and so there is no need to make use of the exact time periods for each of the two sites.

With the observed data at hand, it was then possible to distinguish between the dry and wet seasons and to calculate average observed annual rainfall for each of the livelihood zones. This information could then be used to identify droughts and other climate events that occurred in the past.

Projected future rainfall figures for 11 Global Circulation Models (GCM)

To understand future climate, GCM data under the fifth phase of the Coupled Model Inter-comparison Project (CMIP5) was used in this pilot. In this pilot, the analysis of future climate was done for a 30 year

[4] Additional data was accessed for the Botswana livelihood zone due to data provide by the Department of Meteorological Services (DMS) in Botswana. The authors acknowledge and are grateful for the support provided by the Department of Meteorological Services (DMS) in Botswana.

period into the future. Therefore, data from the GCMs for the period **2013-2043** was used in the analysis conducted for this pilot.

To provide some background, the CMIP5 resulted from a meeting held in September 2008 that involved 20 climate modelling groups from around the world, the World Climate Research Programme's (WCRP) Working Group on Coupled Modelling (WGCM), and with input from the International Geosphere–Biosphere Programme's (IGBP) Analysis, Integration and Modelling of the Earth System (AIMES) project. These participants agreed to promote a new set of coordinated climate model experiments. These experiments comprise the fifth phase of the Coupled Model Inter-comparison Project (CMIP5) and build on the successes of earlier phases of CMIP (see Meehl et al. 2000, 2005). The WGCM's endorsement of CMIP5 followed a planning stage involving extensive community input (Meehl and Hibbard 2007; Hibbard et al. 2007) that led to a proposal to perform a suite of climate simulations that focus on major gaps in understanding of past and future climate changes.

The CMIP5 GCM data was accessed from the Climate Information Portal[5] (CIP), hosted by the Climate Systems Analysis Group (CSAG), at the University of Cape Town (UCT). CSAG is an internationally recognised institution involved in the production of downscaled climate models. There are eleven GCMs contained in the CSAG CMIP5 dataset and all eleven of these GCMs were available for each of the livelihood zones used in this pilot.

All eleven models are listed in Table I below. This presents the models name, the name of the modelling group that developed the model, the corresponding shortened naming system used for the purposes of the analysis for the pilot, and the time span (in years) of the projections for each of the models. It is important to note that the time period for nine of the GCMs run to **2100**, whilst the remaining two GCMs run to **2099**.

Table I – List of climate models used in this study

Model name	**Modelling Centre (or Group)**	**Name in Datasheet**	**Time Period of Data**
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	M1	2013-2100
CNRM-CM5	Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique	M2	2013-2100
CanESM2	Canadian Centre for Climate Modelling and Analysis	M3	2013-2100
FGOALS-s2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	M4	2013-2099
BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University	M5	2013-2100
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	M6	2013-2100
GFDL-ESM2G	NOAA Geophysical Fluid Dynamics Laboratory	M7	2013-2100
MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	M8	2013-2100
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory	M9	2013-2100

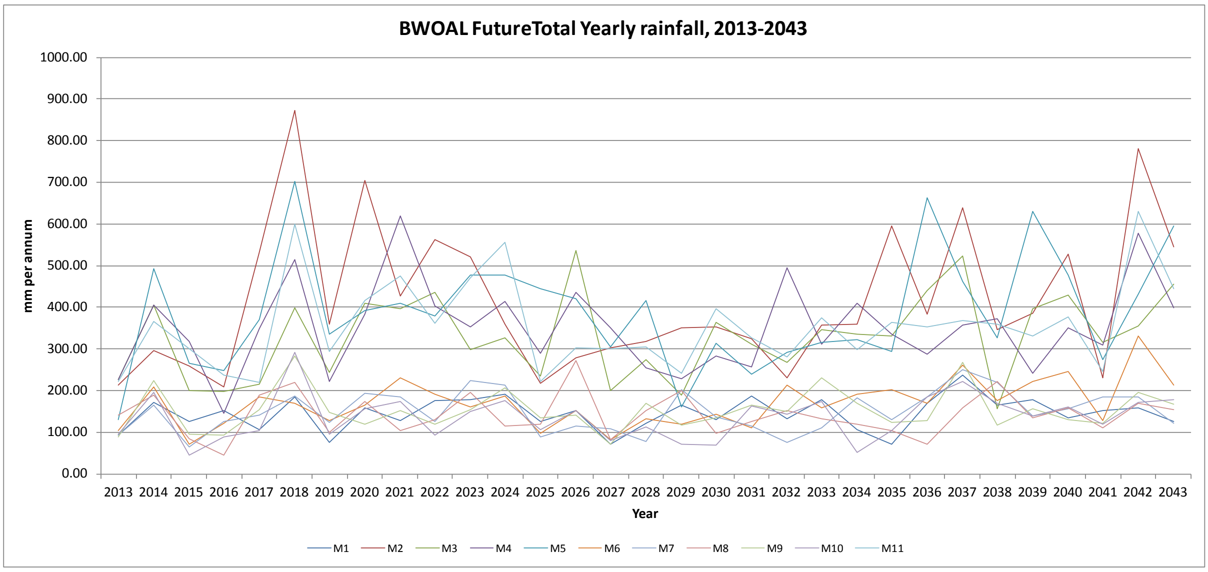
[5] CSAG Climate Information Portal - http://cip.csag.uct.ac.za/webclient/introduction

Model name	Modelling Centre (or Group)	Name in Datasheet	Time Period of Data
MRI-CGCM3	Meteorological Research Institute	M10	2013-2100
BCC-CSM1.1	Beijing Climate Centre, China Meteorological Administration	M11	2013-2099

A graph presenting the information for each GCM using data from the Tshane station (situated within the BWOAL livelihood zone) over the period 2013-2043 is provided below for illustrative purposes.

Figure 5 below shows that the different GCMs have varied projections of rainfall over the period 2013-2043. It is clear that there is little convergence of the various GCMs in terms of the projected climate into the future for the Tshane area. Engagement with experts that have made use of the GCM's and a review of the literature (Taylor et al., 2011) reveal that this can often be the case.

Figure 10 – Global Circulation Model (GCM) data from Tshane weather station



Data Source: From Tshane weather station, accessed via CSAG Climate Information Portal, http://cip.csag.uct.ac.za

As a means of attempting to get a clearer picture of what all of the models project on average for the different livelihood zones, an 'ensemble' of all eleven GCMs was produced (hereto referred to as the ensemble GCM). This was created by combining the data from all eleven models for each respective month of the year over the 30 year time frame (2013-2034) and then calculating an (i.e. one) average estimate for each month over the time period 2013-2034. This estimate then provides a sense of what future climate is doing by combining the outputs of all the models and producing an averaged output (i.e. the ensemble GCM). By creating an average estimate through combining the data from all of the models into one estimate, the aim is to factor in the data for the various models into one number.

Basic management of the data was undertaken in Microsoft Excel (i.e. summation of monthly figures to produced yearly figures, sorting of monthly figures to identify the 'dry season', etc.) and Excel functions were used to create descriptive statistics of the data sets. The descriptive statistics produced for each of the datasets include mean values, median values, maximum and minimum values, standard deviation[6] and coefficient of variation[7].

[6] A measure of how spread out numbers are, i.e. A measure of the dispersion of a set of data from its mean. The more spread apart the data (from the average (i.e. the mean)), the higher the deviation (i.e. the higher the standard deviation).

[7] The coefficient of variation represents the ratio of the standard deviation to the mean. This measure therefore provides a ratio that shows how far (or spread out) from the mean a particular value is. If the coefficient of variation value is high, this means that the observed values are not close to the mean. This means that there is a lot of variability (spread out away from the average value of the data).

As an example of the basic statistical analyses conducted, descriptive statistics using data of observed rainfall and projected rainfall (for the eleven GCM's and the ensemble GCM) from the Tshane station (BWOAL) are presented below (Table II, Table III and Table IV below).

Table II – Descriptive Statistics, Tshane weather station – Observed annual rainfall (mm) (1960-2011)

	Mean Obs (1960-2011)	Median Obs (1960-2011)	Max Obs (1960-2011)	Min Obs (1960-2011)	Std Dev Obs (1960-2011)
Tshane	339.9	339.2	728.5	110.0	136.5

Data Source: From Tshane weather station (Botswana), accessed via CSAG Climate Information Portal, http://cip.csag.uct.ac.za

Table III – Descriptive Statistics, Tshane weather station – GCM annual rainfall (mm) (2013 - 2043)

	Mean (2013-2043)	Median (2013-2043)	Max (2013-2043)	Min (2013-2043)	Std Dev (2013-2043)
M1	145.2	152.6	237.3	70.2	38.7
M2	414.1	358.7	873.5	207.5	172.6
M3	329.3	330.4	535.7	155.7	101.4
M4	351.6	349.9	620.0	146.2	105.2
M5	389.0	379.0	701.6	129.0	136.5
M6	169.8	169.1	330.6	70.0	56.7
M7	149.0	138.1	250.4	64.0	48.6
M8	142.4	135.1	272.7	45.0	49.8
M9	152.5	148.3	283.1	71.3	49.4
M10	136.4	142.1	291.4	45.1	53.8
M11	355.8	353.7	629.0	219.2	105.8

Data Source: From Tshane weather station (Botswana), accessed via CSAG Climate Information Portal, http://cip.csag.uct.ac.za

Table IV – Descriptive Statistics, Tshane weather station – Ensemble GCM annual rainfall (mm) (2013 - 2043)

	Mean	Median	Max	Min	Std Dev
GCM Ensemble	248.7	241.0	401.9	147.8	60.9

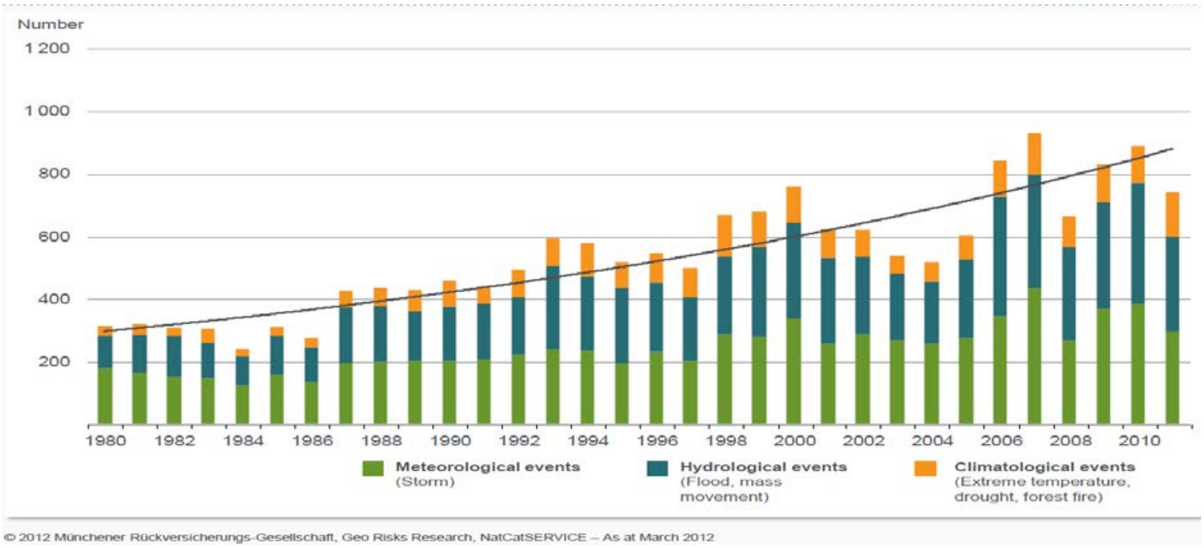
Data Source: From Tshane weather station (Botswana), accessed via CSAG Climate Information Portal, http://cip.csag.uct.ac.za

Future climate scenarios approach

In the context of a changing and variable climate, decision making related to the best approaches for building climate resilience can often become challenging. This is due, in part, to the high level of uncertainty that characterizes our understanding of the dynamics of regional climate change. One may observe emergent climate trends, but it is difficult to know with certainty the future change (how many millimetres wetter will an area get) or the rate of change (how long it will take for total annual rainfall to rise). So, whilst climate change models project more frequent extreme weather events (e.g. droughts, storms, floods) the models cannot tell us with any certainty when, where or with what intensity these events will occur. Similarly, because the environment is changing, historical patterns of extreme events are often no longer reliable guides of the future.

If one were to make the assumption that historical patterns of weather may provide a good indication of climate in the future, one is stating that future climate is similar to the historical patterns of observed weather. In essence this is making the statement that there is no (or only subdued) climate change in the future.

Figure 11 – Weather catastrophes worldwide (No. of events), 1980 – 2011



Source: MunichRe, 2011.

The challenge that climate change presents is that climate in the past is not likely to be a good predictor of climate in the future. There are already signs of increased intensity and frequency of disaster events when compared with historical occurrences of disasters. For instance, if we look at a global level, the number of disaster events has increased over the period 1980 to 2011 (MunichRe, 2011). This is depicted in Figure 6 above, produced by MunichRe Reinsurance company.

In light of the unpredictability of future climate, the approach taken for this pilot was to assess potential future scenarios of climate (as projected by the climate models) as opposed to identifying one model to base the analysis on. By looking at different scenarios, one is able to get a sense of the range of possible climate 'realities' that could result in the future. Scenarios therefore do not restrict the analysis to one potential 'outcome' or 'state' in the future.

A range of scenarios (i.e. 'Dry', 'Wet' and 'Median') were selected for the pilot. These scenarios were identified by ranking the various models according to the level of average (mean) total annual rainfall over the period 2013-2043. To avoid selecting the 'most wet' model and the 'most dry' model, the second wettest and the second driest model were selected to perform the analysis. This was done to avoid using the models/cases at the extremes. Table V and Table VI below show the ranking of the various climate models (according to mean annual rainfall, over the period 2013 - 2043) for the selected livelihood zones in Botswana and Mozambique, respectively.

Table V – Ranking of GCM's from Driest to Wettest Models, Tshane weather station (2013 – 2043)

	Mean	Median	Max	Min	Std Dev
M10	136.4	142.1	291.4	45.1	53.8
M8	142.4	135.1	272.7	45.0	49.8
M1	145.2	152.6	237.3	70.2	38.7
M7	149.0	138.1	250.4	64.0	48.6
M9	152.5	148.3	283.1	71.3	49.4
M6	169.8	169.1	330.6	70.0	56.7
M3	329.3	330.4	535.7	155.7	101.4
M4	351.6	349.9	620.0	146.2	105.2
M11	355.8	353.7	629.0	219.2	105.8
M5	389.0	379.0	701.6	129.0	136.5
M2	414.1	358.7	873.5	207.5	172.6

	Driest Model (by mean value)
	Median Model (by mean value)
	Wettest Model (by mean value)
	Selected Models for analysis

Data Source: From Tshane weather station (Botswana), accessed via CSAG Climate Information Portal, http://cip.csag.uct.ac.za

Table VI – Ranking of Global Circulation Models from Driest to Wettest Models, Quelimane weather station (2013 – 2043)

	Mean	Median	Max	Min	Std Dev
M1	1283.3	1241.5	2027.6	169.2	310.5
M8	1414.9	1433.5	2057.4	188.4	383.2
M11	1475.3	1452.6	2029.7	850.0	312.7
M3	1605.2	1588.2	2202.5	453.9	379.3
M10	1606.6	1592.7	2777.4	465.3	428.7
M4	1626.7	1637.2	2726.5	792.8	429.9
M5	1747.2	1716.3	2765.3	596.1	415.5
M2	1770.2	1724.0	2375.7	699.9	377.0
M6	1807.2	1831.2	2652.3	489.0	421.2
M9	1978.2	2038.5	2696.4	755.9	440.0
M7	1991.8	2034.2	2680.6	728.0	429.9

	Driest Model (by mean value)
	Median Model (by mean value)
	Wettest Model (by mean value)
	Selected Models for analysis

Data Source: From Quelimane weather station (Mozambique), accessed via CSAG Climate Information Portal, http://cip.csag.uct.ac.za

Data Analysis: Future climate scenario's

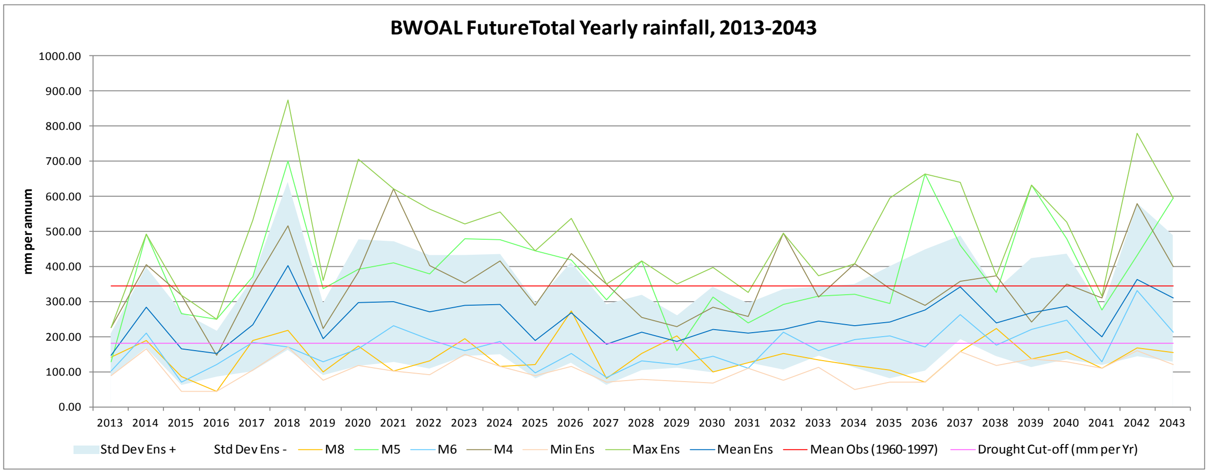
The figures of total annual rainfall (for the period 2013 -2043) were graphed for the selected wet, dry and median scenarios, allowing for a graphic representation of these different scenarios. An illustrative example is depicted in Figure 7 below.

In Figure 7, the bold red line depicts the observed average (mean) annual rainfall (over the period 1981-2011) in the BWOAL livelihood zone (in Botswana). This is presented as a straight line to represent the average annual rainfall conditions observed in the past (1981-2011) for this area of Botswana. A drought cut-off (the thin pink line) is also presented in Figure 7. This cut-off (set at 182mm of annual rainfall) was derived from a review of the literature relating to drought in Botswana and was also informed by consultations with an expert from the metrological services in Botswana.

The drought cut-off line provides a benchmark of when there could potentially be a drought year experienced in the future (according to the different scenarios). This allows for the identification of potential future climate shocks and gives an indication of whether there is a projection of increased frequency of climatic events in the future, depending on the scenario that is being assessed.

From Figure 7, one can see that if the 'dry scenario' (given by the MIROC-ESM-CHEM model [M8], or the yellow line on the graph) is considered for the BWOAL zone, total annual rainfall (for the period 2013 -2043) is projected to be substantial lower in this particular area of Botswana.

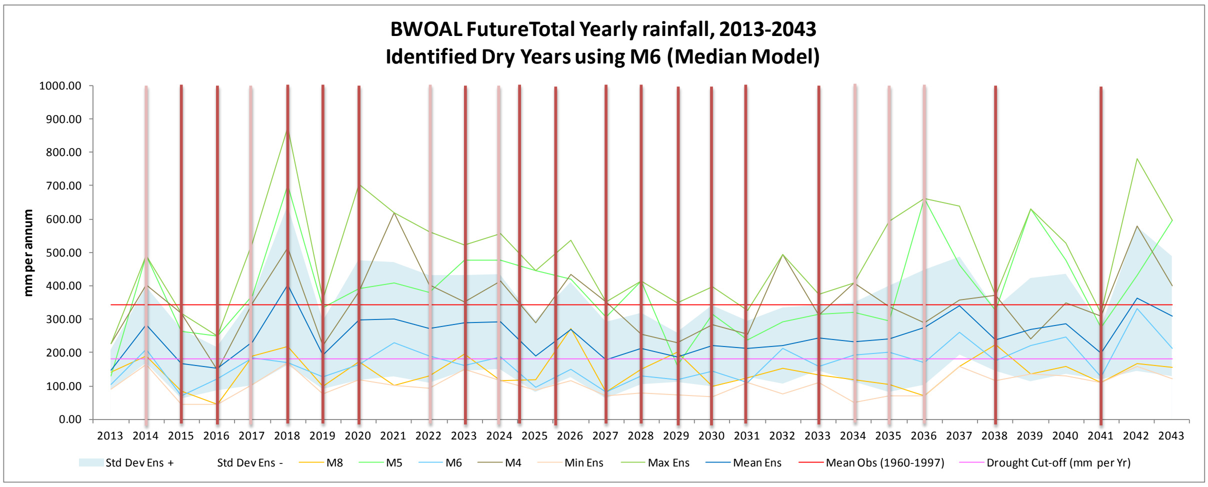
Figure 12 – Dry and wet Global Circulation Models against drought cut-off, Tshane weather station (2013 – 2043)



Data Source: From Tshane weather station (Botswana), accessed via CSAG Climate Information Portal, http://cip.csag.uct.ac.za

In Figure 8 below, a comparison of the selected median model [M6] (i.e. the model that ranks in the middle, in terms of it level of average total annual rainfall) to the drought cut-off is presented.

Figure 13 – Botswana: dry years, the median model



Data Source: From Tshane weather station (Botswana), accessed via CSAG Climate Information Portal, http://cip.csag.uct.ac.za

As can be seen in Figure 8 above, darker shaded vertical red bars are used to depict drought years. These years are classified as drought years as the line for the median model [M6] for this specific area in Botswana is below the drought cut-off line. The lighter shaded vertical red bars depict years where there is a relatively dry year experienced (in terms of the projected total annual rainfall) but where the level of total annual rainfall does not per se fall below the drought cut-off rainfall limit. These years are highlighted in the graph because although the level of rainfall may not fall strictly below the drought cut-off estimate, these are still relatively low levels of total annual rainfall.

Livelihoods Analysis

The livelihoods analysis model that has been applied by many member states in the SADC region is designed to provide forward-looking outcomes—but only for at most twelve months, or one consumption year[8]. The point of doing a climate change forecast is to look far further ahead into the future—thirty years at least—and to attempt to understand what might happen, given a set of conditions. What happens one year will inevitably have an effect on what happens the next, as a bad preceding year will decrease household assets and a good year will boost them. This leaves the household with a lower or higher starting point each year. Hence, each year's analysis will depend on the one that preceded it, meaning that what is needed is not just a ***single-year analysis*** for a theoretical year in the distant future, but rather a ***multi-year analysis*** for the entire period from the present to the desired end.

Livestock, particularly cattle, are the key productive resource for rural households in Botswana. Poor households derive much of their income from the casual labour that they undertake for wealthier households, while the wealthiest also own and manage a small business such as spaza shops[9], transport vehicles, and localised services. Income derived from government social protection programmes plays a significant role in rural Botswana, especially for the poorest.

In Mozambique, crop farming is the dominant productive activity. The most important crops are maize, cassava, sweet potatoes, groundnuts, rice and coconuts. The richest households do sometimes keep some cattle.

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[8] A *consumption year* is a time period from one main harvest until the next main harvest, that is, the period over which the proceeds from a main harvest have to be budgeted by the household.

[9] Small, semi-formal shops or kiosks often run from the back door or an extension onto the house. They mostly sell basic groceries, small household items such as batteries and cooking utensils, and toiletries.

Livestock

Of all the economic activities in the two livelihood systems under consideration in this pilot, livestock has by far the greatest knock-on effect from one year to the next. For example, if a household suffers the decimation of its herd in one year, the impact will be felt for many years to come, given the relatively slow rate of accumulation and restocking.

In order to understand this process, it is necessary to investigate two different aspects of the problem:

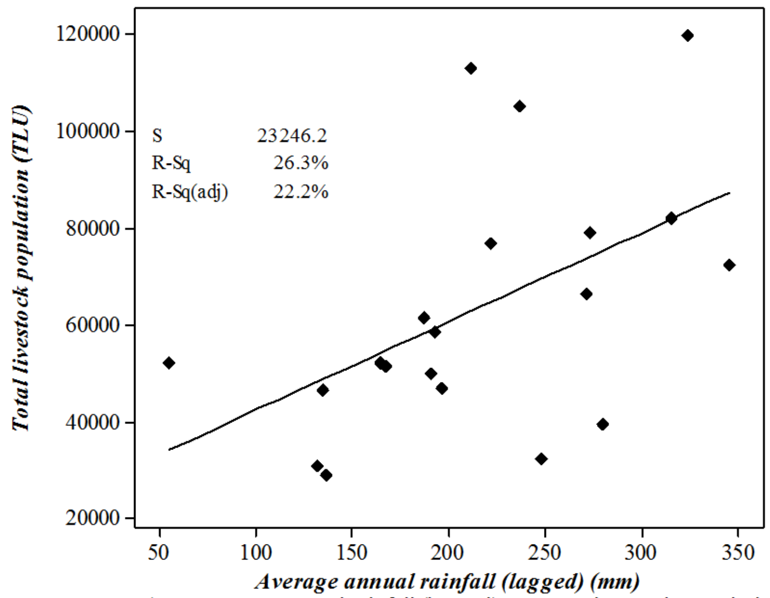
- The damage to the herd as a consequence of climate factors (the loss due to a climate hazard), and;
- The best rate at which the household can recover from the hazard, assuming the hazard condition has passed.

The effect on production by the loss of rainfall

The team reviewed a number of documents on the relationship between climate and livestock productivity. The key variables against rainfall that were considered are: herd size, livestock productivity—milk production and meat production, livestock birth rates—and therefore milking cow rate.

Kgosikoma[10] argued that although indices of the North Atlantic Oscillations (NAOs), the El Niño Southern Oscillations (ENSOs) and the Sea Surface Temperatures (SSTs) are poor predictors of livestock populations ($P>0.05$). Rainfall readings did however correlate with variability in cattle and goat populations, but not sheep ($P<0.05$). This is confirmed by previous studies (Desta and Coppock, 2002; McCane, 1987; Begzsuren et al., 2004). The relationships are explained by the loss of nutritional value in the rangelands for herbivores and limitations in movement by herders imposed under the government's Tribal Grazing Land Policy (TGLP).

Figure 14 – The relationship between rainfall in Kgalagadi District and Tropical Livestock Units (TLUs)



Y = 24152 + 183.0 X (X = average annual rainfall (lagged) mm, Y= Livestock population)

Source: Kgosikoma, *Effects of Climate Variability on Livestock Population Dynamics and Community Drought Management in Kgalagadi, Botswana*, Paper 1, May 2006

Kgosikoma noted a correlation between livestock numbers and rainfall as well as mortality rates and rainfall. There were no relationships between birth rates and rainfall nor was there a relationship between off-take and rainfall.

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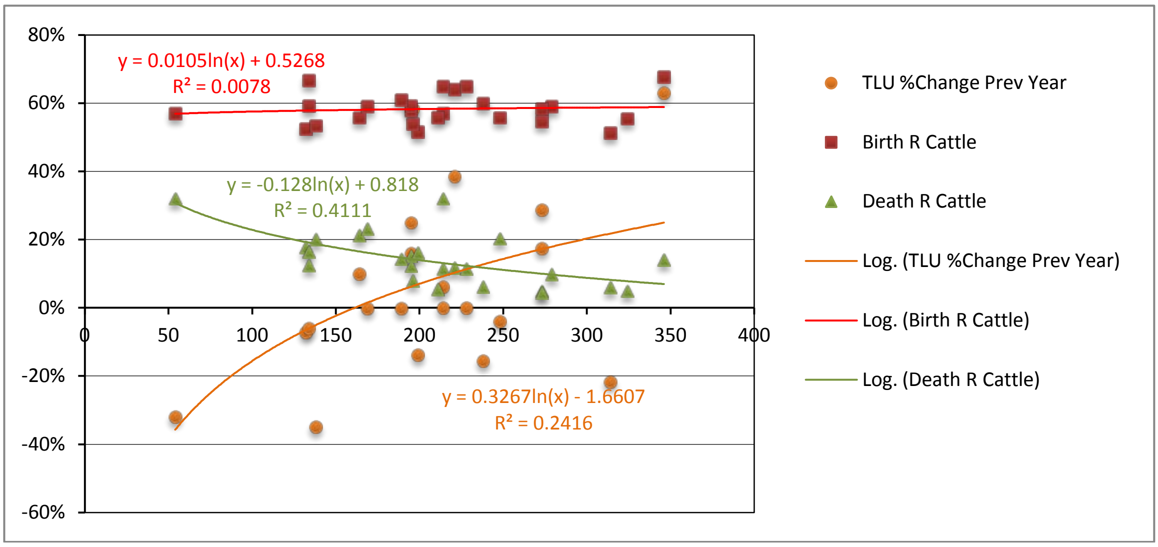
[10] Kgosikoma, *Effects of Climate Variability on Livestock Population Dynamics and Community Drought Management in Kgalagadi, Botswana*, Paper 1, May 2006

This pilot study also investigated relationships between livestock herds and rainfall, in an attempt to link herd sizes and productivity with climate. Due to time constraints the same analysis has not been done with temperature but it would be of value to also check this possible relationship.

Figure 10 shows the outcomes for the changes from the previous year in Tropical Livestock Units (TLUs) against annual rainfall and for cattle birth and death rates against annual rainfall. It can be seen that there is some sort of relationship for death rates and rainfall and for changes in herd sizes against rainfall, but there is little or no relationship between birth rates and rainfall—these are quite constant regardless of rainfall and the R-squared value is low. Logarithmic relationships appear to result in higher R-squared values than do linear relationships, suggesting that these might be more appropriate predictors. This makes some sense as one would expect death rates to rise exponentially during years of very low rainfall, while the change in herd size would become exponentially large and negative (i.e. there would be accelerating losses). Conversely, one might expect that eventually for very high rainfall, gains in livestock numbers or losses from mortality would become increasingly marginal.

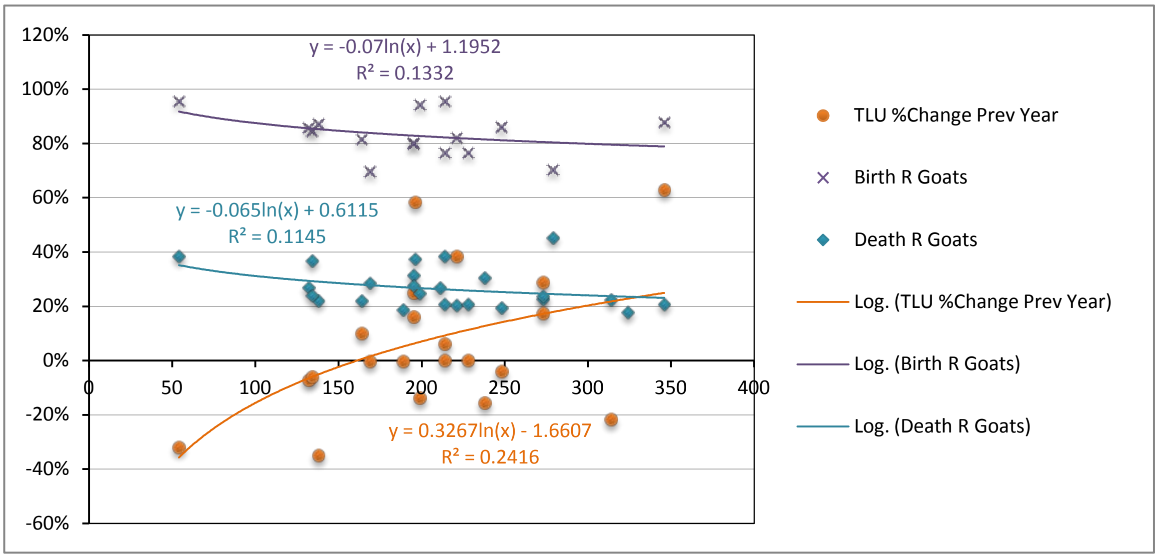
Similar results were obtained for goats although there was little correlation in death and birth rates—much less use than that obtain for cattle rates. This is shown below in Figure 11. Both birth and death rates show decreasing trends as the years get wetter.

Figure 15 – Percentage change in Tropical Livestock Units, cattle birth rates and cattle death rates against rainfall



Source of livestock data: Ministry of Agriculture and Livestock, Department of Meteorological Services

Figure 16 – Percentage change in Tropical Livestock Units, goat birth rates and goat death rates against rainfall



Source of livestock data: Ministry of Agriculture and Livestock, Department of Meteorological Services

The study team was unable to obtain sufficient data on sheep to do a meaningful analysis for that species.

The livelihoods approach used by SADC and its Vulnerability Assessment Committees (VACs) uses a herd dynamics model to understand herd composition—this is also very useful for predicting future herd growth or loss. The baselines, derived from exhaustive household interviews, provide a relationship ***in a typical or normal year***, between the key numbers in a given herd: the number of adult females, the number born, the off-take, the number died or lost and the number purchased. For example, in smaller herds the ratio of Herd Size : Adult Females : Number Sold is 4 : 2 : 1 but as the herd size gets bigger the percentages of adult females and off-take decreases somewhat. This is because the off-take decreases and an explanation for this is the cultural prestige associated with cattle ownership; when the owner has enough income from sales or slaughter to meet household needs, animals are kept rather than sold to deliberately build up the herd. Together with the purchase of additional stock, the herd size of 'better off' households will increase by 9% at the end of the year.

Table VII – Cattle herd dynamics in Botswana Open Access Livestock livelihood zone

	Poor		Middle		Better Off	
	Number	%age	Number	%age	Number	%age
Number at beginning of year	4	100%	30	100%	120	100%
Number adult females	2	50%	12	40%	45	38%
Number born	2	50%	8	27%	33	28%
Number sold or slaughtered	1	25%	6	20%	15	13%
Number died/lost	1	25%	2	7%	12	10%
Number bought	0	0%	0	0%	3	3%
Number at end of year	4	100%	30	100%	129	109%

Source: Botswana Vulnerability Assessment Committee (BVAC)

Table VIII – Goat herd dynamics in Botswana Open Access Livestock livelihood zone

	Very Poor		Poor		Middle		Better Off	
	Number	%age	Number	%age	Number	%age	Number	%age
Number at beginning of year	1	100%	10	100%	33	100%	80	100%
Number adult females	1	100%	6	60%	18	55%	43	54%
Number born	1.5	150%	8	80%	23	70%	56	70%
Number sold or slaughtered	1	100%	4	40%	11	33%	17	21%
Number died/lost	0.5	50%	3	30%	5	15%	10	13%
Number bought	0	0%	0	0	2	6%	3	4%
Number at end of year	1	100%	11	110%	42	127%	112	140%

Source: Botswana Vulnerability Assessment Committee (BVAC)

As shown in the graphs in Figure 10 and in Figure 11, a bad rainfall year will have the effect of increasing animal mortality, without changing birth rates, leading to a decrease in herd size. In the herd dynamics in Table VII and Table VIII this will manifest as an increase the numbers across the "Number died/lost" row and a decrease in the numbers across the "Number at end of year" row. This decrease in the resultant end of year herd size means that households will begin the next year with a smaller herd. If that next year has good rainfall then there will be some recovery, if it has poor rainfall then the household will suffer further losses.

Therefore, to obtain a problem specification for each future year for livestock production (milk production, livestock sales), the previous year's production has to be considered. The team did this by building up a table of each year's herd dynamics numbers, based on the impact of rainfall from each of the downscaled GCMs on the herd size of the 'middle' wealth group. Table IX to Table XII in Appendix III – Herd Dynamics Tables for the Climate Scenarios, show these herd dynamics models for the second direst rainfall model (Model 8), the median model (Model 6), the mean of all eleven models (mean ensemble) and the second-wettest model (Model 5).

In Table IX and Table X, the herd size at the end of each year very quickly drops off to one and two animals respectively, because of high death rates brought about by repeated droughts. In these scenarios, households may sell or slaughter fewer animals but in doing so they would lose income. In Table XI, the rate of attrition is reduced and the herd size falls more steadily. Finally, in Table XII there is a steady increase as the second-wettest model reduces death rates with fewer droughts and the herd builds up.

The numbers of animals in the sales and the births columns determine the 'problem specifications'—used to analyse income for a given year—for animal sales and for the numbers of milking animals, respectively. Milk yields are also determined by grazing and a separate calculation has been done for that.

A look at the baseline in Figure 2 shows that the 'very poor' and 'poor' households' main sources of income are casual labour and welfare grants. The main type of casual labour in this livelihood zone is herding. However, if the owners of the herds have lost their animals the opportunities for work will decrease—with the impact of this being likely to occur the following year. To account for this effect, the problem specification for the casual labour income source has been tied to the previous year's herd size.

Crops

Crop modelling, based on climate scenarios, is a scientific discipline on its own and rightly deserves much attention. For a given amount of rainfall over a season, crop performance may vary widely due to effects such as distribution of the rains, water-logging, insolation and so on. A good model would take all these factors into account in its prediction, and should be tested against previous years' data on climate and production. Owing to time constraints and the lack of expertise, the team did not apply these thorough models but if this application were to be taken to scale, these more precise models would be needed.

The team used very simple one-dimensional crop models to estimate future yields based on monthly and seasonal rainfall, and then applied a simple scaling factor to account for temperature rises and increased ozone and carbon dioxide levels. This is not ideal and much solid work has been and is being done using better models such as CliCrop or APSIM[11] to estimate future production, using finer-grained input variables such as dekadal or even daily rainfall and temperature predictions. This is because crop performance depends as much on the distribution of rainfall as it does on total rainfall itself; for example, a high total rainfall that is confined to a few scattered days will waterlog plants and drive down yields despite looking productive when viewed over a longer period. If this kind of analysis is to be taken further a key part of the work must be in identifying and using these better models with the correct parameters.

The livelihoods analysis used in this work presents its outcome as an income during a period called the "consumption year"—the period running from one harvest to the next. The income earned during a consumption year depends on the agricultural production resulting from the rainfall during ***the previous year***, so the problem specifications for crops are based on previous year's rainfall.

Population

Botswana enjoys the status of being abundantly endowed with certain mineral resources whilst also having a small population (2.025 million people[12]) that derives benefit from them; it is considered to be one of the most sparsely populated countries in the world with an average population density of 3.48 people per square kilometre. However, the exceedingly low rainfall and sandy soils not given to arability make the environment so sensitive that it limits the population it can support through traditional economic activities of basic cropping, livestock husbandry and ranching.

The last population census in 2011 showed that populations in rural areas have increased and for this livelihood zone the growth rate is approximately 4.5%. Part of the reason that this population rise has been sustained over the last twenty years is that households and their herds have expanded into new territories.

[11] Agricultural Production Simulator, a computer software package that can be used to predict yields and production based on a wide number of parameters.

[12] Statistics Botswana, Population and Housing Census 2011

However, this cannot go on indefinitely and there limits to further expansion. The main constraint is water availability and the proximity of water to forage. If water were more freely accessible there would be greater possibilities for expansion of herds.

Zambezia province in Mozambique is the second-most populated in the country, with 3.85 million people. The population leapt up in the late 1990s and early 2000s, this was the result of people returning to the area after the cessation of the civil war. For the analysis of this report it is assumed that the area can continue to support expansion with population growth until mid-century. This means that, barring new evidence, the land holdings will remain constrained more by labour capacity than by total land availability.

Understanding the limits for population expansion—and thus the corresponding livestock numbers and the size of farm holdings—is a study topic all of itself and is beyond the time frame of this pilot. There are a lot of dynamics to consider, such as rural-urban migration and possible new economic opportunities in or close to the rural areas.

The assumption here is that as populations grow, there will be adequate resources for expansion. Alternatively if the limit is reached, then rural population growth will be checked by outmigration to the towns and urban centres. Hence, households that lose animals will migrate to the towns and cities, leaving more space for the most successful famers, even in arduous environmental conditions.

Economic factors

Key variables to consider are price inflation and government policies with welfare and other transfers.

Presently, the Botswana Government provides a broad package of conditional and unconditional transfers to its citizens. The Mozambique Government does not, according to the livelihoods baselines, provide much in the way of predictable long-term transfers to households yet. However, this situation is changing and will continue to evolve in future.

For the sake of simplicity, the analysis in this report assumes the continuation of existing policies and programmes, and that these programmes are adjusted to match prevailing prices and economic conditions.

Monetary policy in both countries is quite strong and inflation is controlled through monetary policy, lying between 4% and 10% for Mozambique and 3% to 6% for Botswana.

The assumption made in this analysis is that the inflation rates in both countries will track equally for items of income as for items of expenditure; in other words, the modelling done in this work assumes the terms of trade for households remains the same over the entire 30-year period. In reality, of course, this is not likely to happen; there will be periods when purchase prices rise faster than incomes and others when incomes rise correspondingly as well. However, this study was conducted to investigate the feasibility and possible outcomes of the effects of climate change on livelihoods, not the effects of economic shifts. Suffice to say: economic changes can have drastic consequences that completely overshadow any climate-related change or shock, so economic policy and its consequences for variables such as prices, remains of prime importance to livelihoods analysis and the resilience of households' livelihoods.

Outcome

Botswana

The effects of climate change on Botswana's livelihoods are profound. Crops are an almost insignificant contributor to total income in this livelihood zone and so although reductions in rainfall will wipe out production, the impact is not severe enough to merit being an issue. Livestock production is quite different.

Figure 17 – Annual income time-line for the second-driest climate model (Model 8) in BWOAL

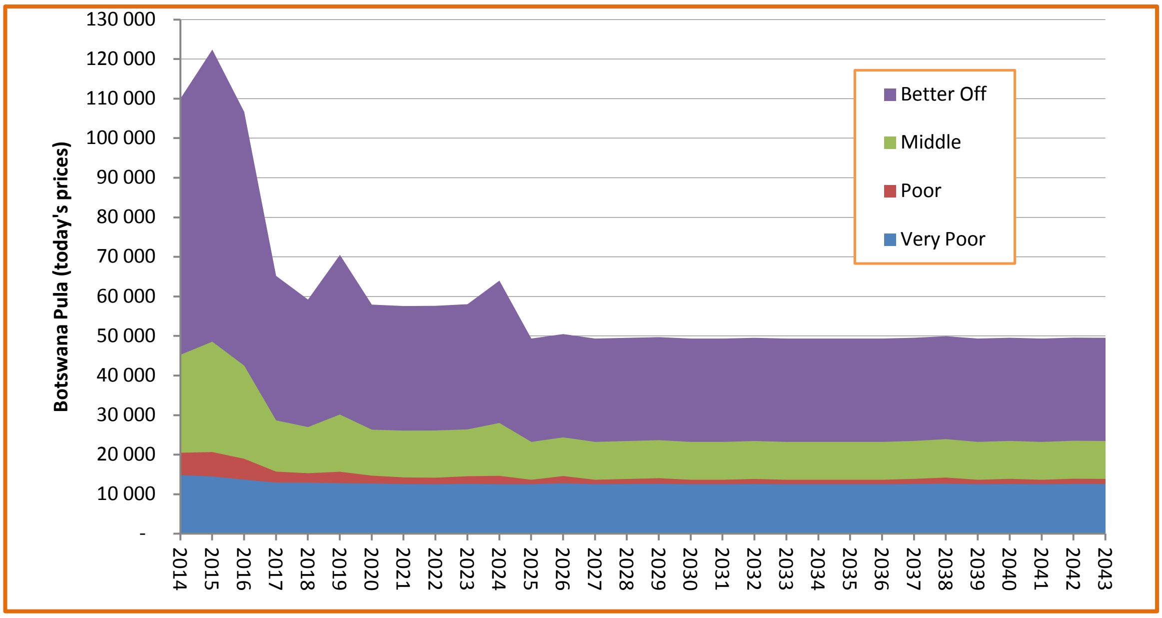
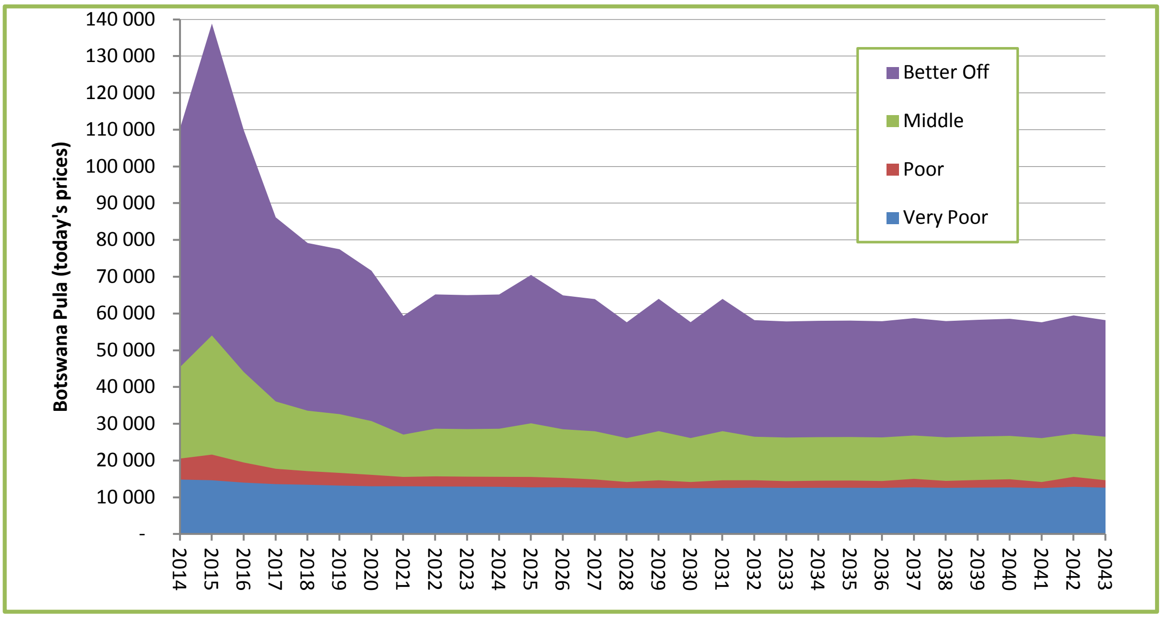


Figure 18 – Annual income time-line for the median climate model (Model 6) in BWOAL



The majority of scenarios and climate models forecast a decline in rainfall, with much variation from year to year. The sensitive nature of the environment and the economy's dependency on livestock, which in turn is dependent on rainfall, means that for the driest to the median scenarios, livestock production per household will decline rapidly, pushing down incomes with it. This decline will level off as households are forced to seek alternatives to their animals, primarily cattle at present, as a source of livelihood. The 'poor' and 'very poor' will experience a marginal drop but since their incomes are derived mostly from casual labour and government welfare, they will remain stable, albeit low with little or no prospect of improvement (or reduced dependency on government support).

Hence, for these drier—and possibly more likely—scenarios, livelihoods in the rural areas of this zone will require adaptation that include changes to the livestock species they keep, perhaps to small stock or even to game and a wider range of hardier animals, as well as proven rangeland and animal management strategies that allow grazing on more marginal land. This would enable ‘middle’ and ‘better off’ households to maintain something like their present level of income, while the ‘poor’ and ‘very poor’ could benefit from extra employment opportunities or perhaps by seeking out other options and activities such as trading or crafts.

Figure 19 – Annual income time-line for the mean of all climate models (mean ensemble models) in BWOAL

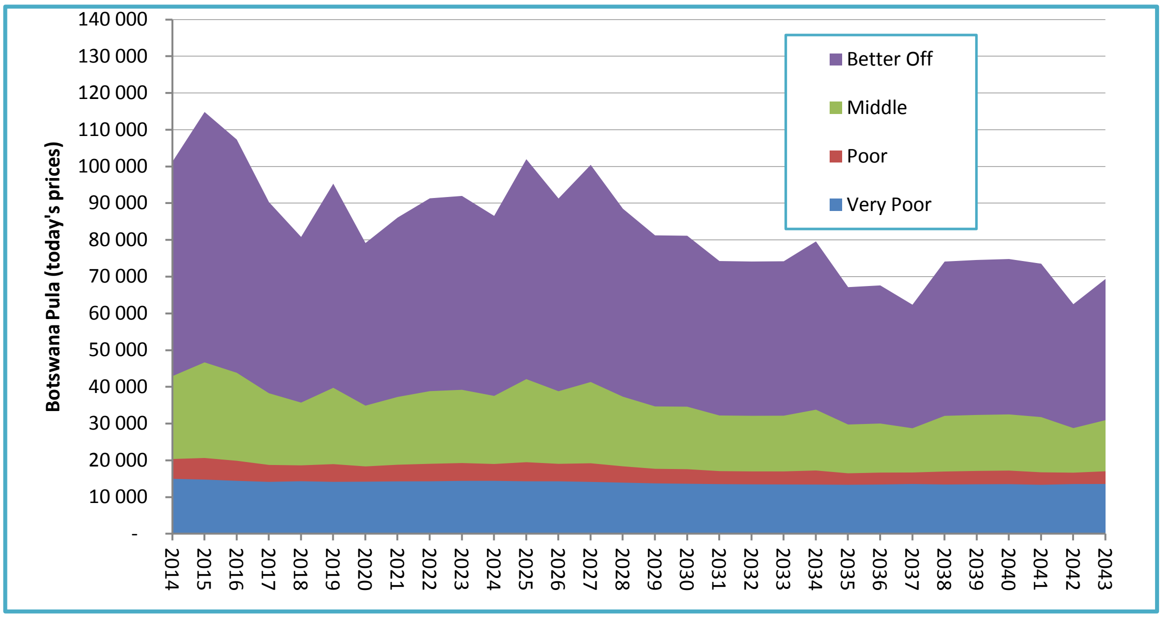
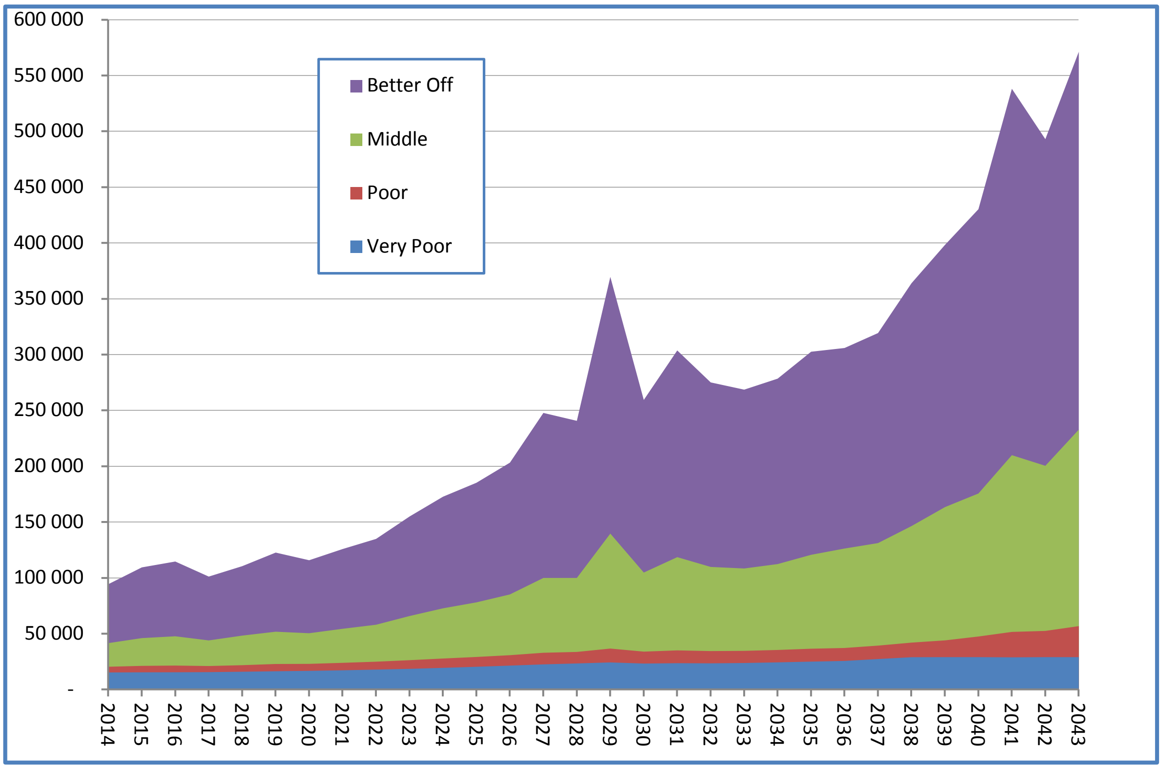


Figure 20 – Annual income time-line for the second-wettest climate model (Model 5) in BWOAL

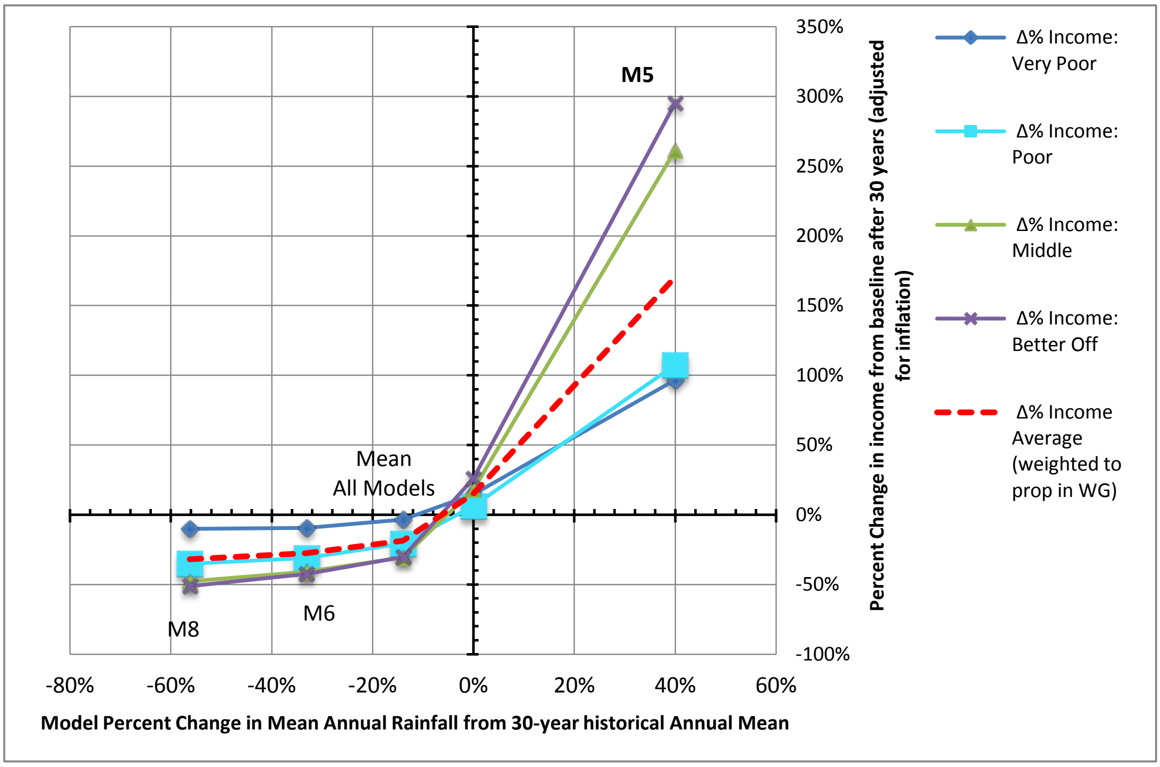


In the median of all the climate forecast models, a picture emerges of variable income, with periodic livestock population "peaks" and "crashes", the latter occurring in the aftermath of droughts. This is an unstable situation and it projects a steady decline in real income.

However the wettest models illustrate the positive influence of an increase in rainfall that is astounding. All wealth groups would benefit but the 'better off' would see the greatest gains. Hence there will be a widening of the income gap across all four wealth groups. There are also noticeable "peaks" and "crashes", as result of sometimes too-strong growth and the overburdening of the environment. The reason for this positive growth is that the extra rainfall projected by the models will not only provide for more and better quality forage, dramatically reducing livestock death rates, it will also feed the underground aquifers and this will open up possibilities for using more open land, drawing the extra water needed from a larger number of boreholes.

Taken together, the change in incomes between now and the ten-year average at the end of the period (i.e. 2034-2043) for each climate scenario can be plotted against the change in average annual rainfall for the same period. This gives some idea of the ***sensitivity*** of the livelihood to rainfall climate change and the plot for Botswana Open Access Livestock livelihood zone is shown below in Figure 16.

Figure 21 – Livelihood sensitivity to climate change



The average income of the zone is derived by combining the incomes of each wealth group, weighted in proportion to distribution of households. The plot of this average income gives a trend-line with a quite definite logarithmic shape and the approximate equation is:

$$I = 0.2867e^{1.4818r} - 1$$

Where I is the average change in income and r is the total annual rainfall for the year. The r-squared value for this equation is: $R^2 = 0.89079$

The results, showing such wide ranging incomes variations for different rainfall outcomes, highlights that ***climate change is indeed a matter of great importance to livelihoods*** in this zone.

Mozambique

The situation in Mozambique is quite different. The livelihood zone studied in this pilot derives a very large portion of income from fishing—for which the impact of climate change is still difficult to forecast. Studies on air and sea temperature changes, increases in CO_2 concentration (which can acidify water) and other climatic factors such as increases in the numbers of severe storms, are needed to understand the impact on this livelihood properly.

Figure 22 – Annual income time-line for the second-driest climate model (Model 8) in MZZ14

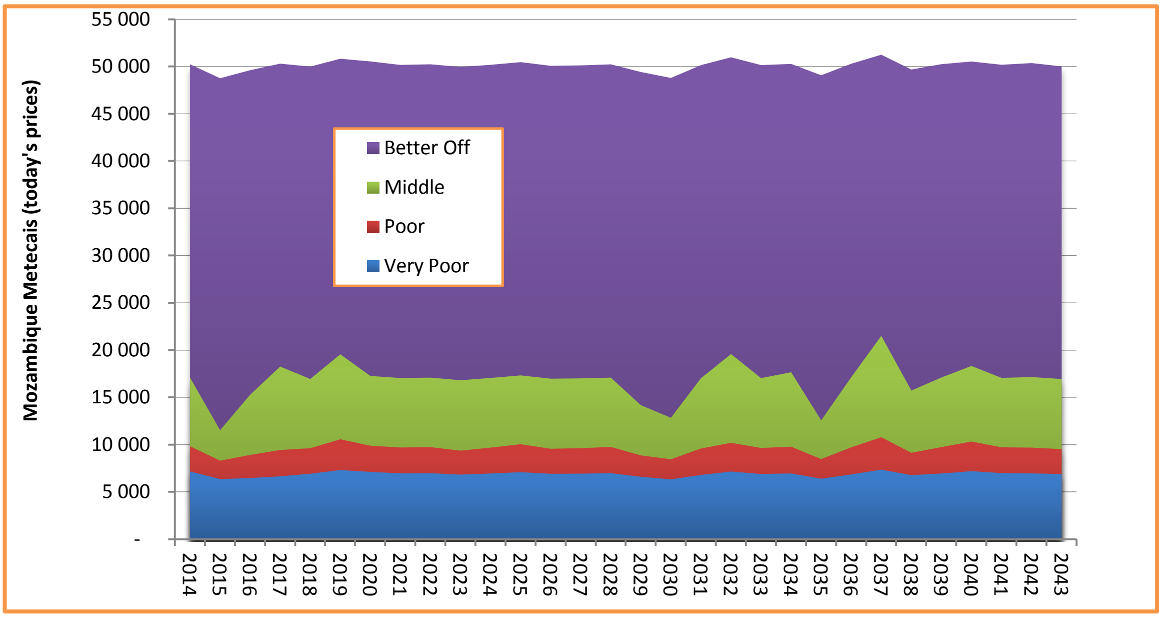
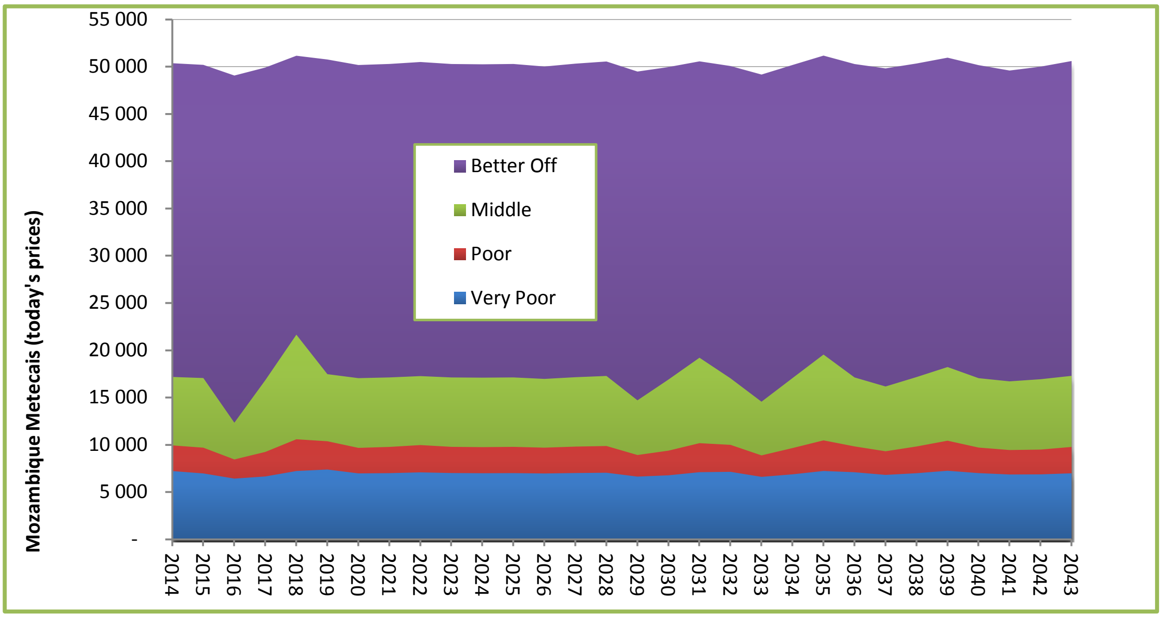


Figure 23 – Annual income time-line for the median climate model (Model 4) in MZZ14



The wealth group that is most exposed to climate changes is the 'middle', as they have neither the boat ownership to profit from fishing, nor is fishing paid-labour as profitable for them as farming. The time-series graph of annual income for the second-driest scenario shows quite clearly the instability of this wealth group. The income of the other wealth groups, while a little bit variable, is nevertheless much more stable.

Figure 24 – Annual income time-line for the mean of all climate models (mean ensemble models) in MZZ14

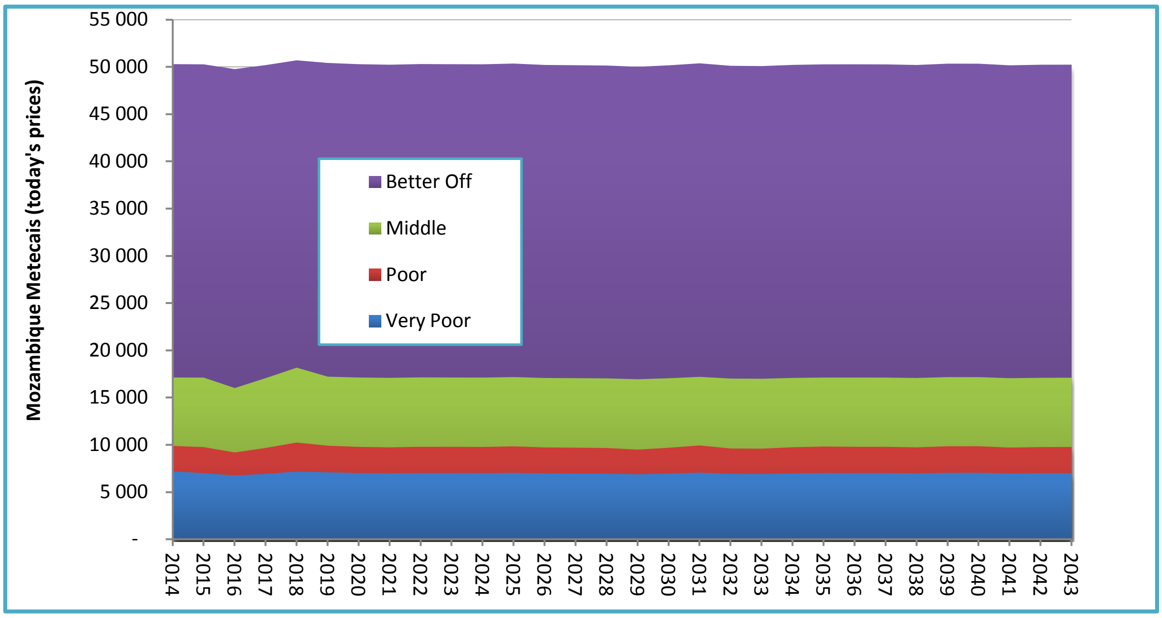
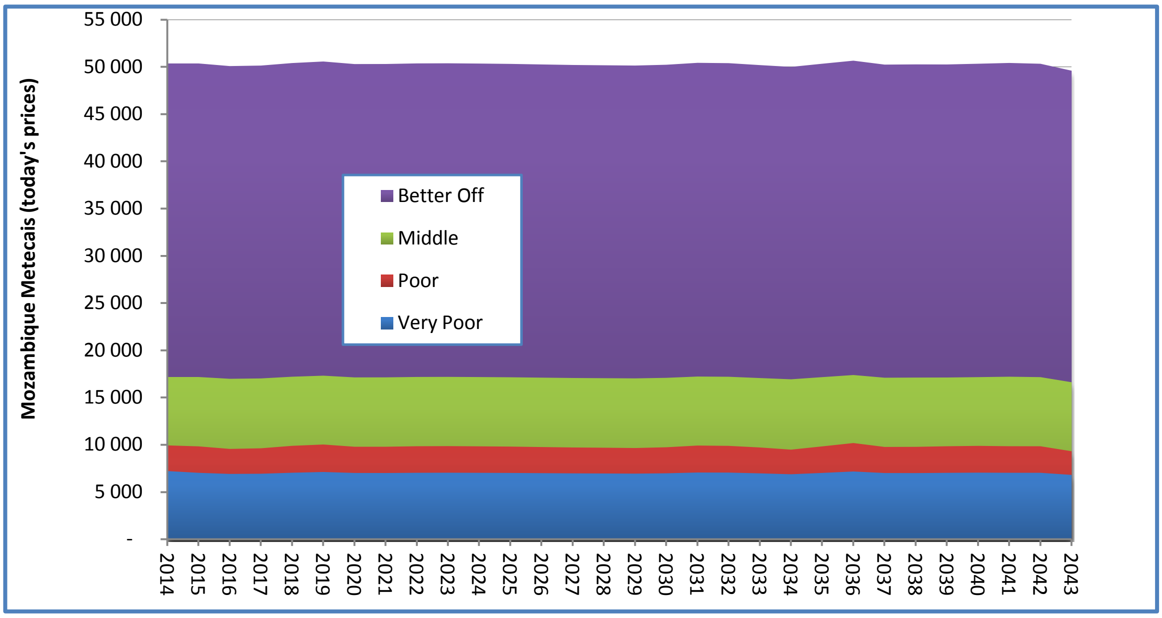


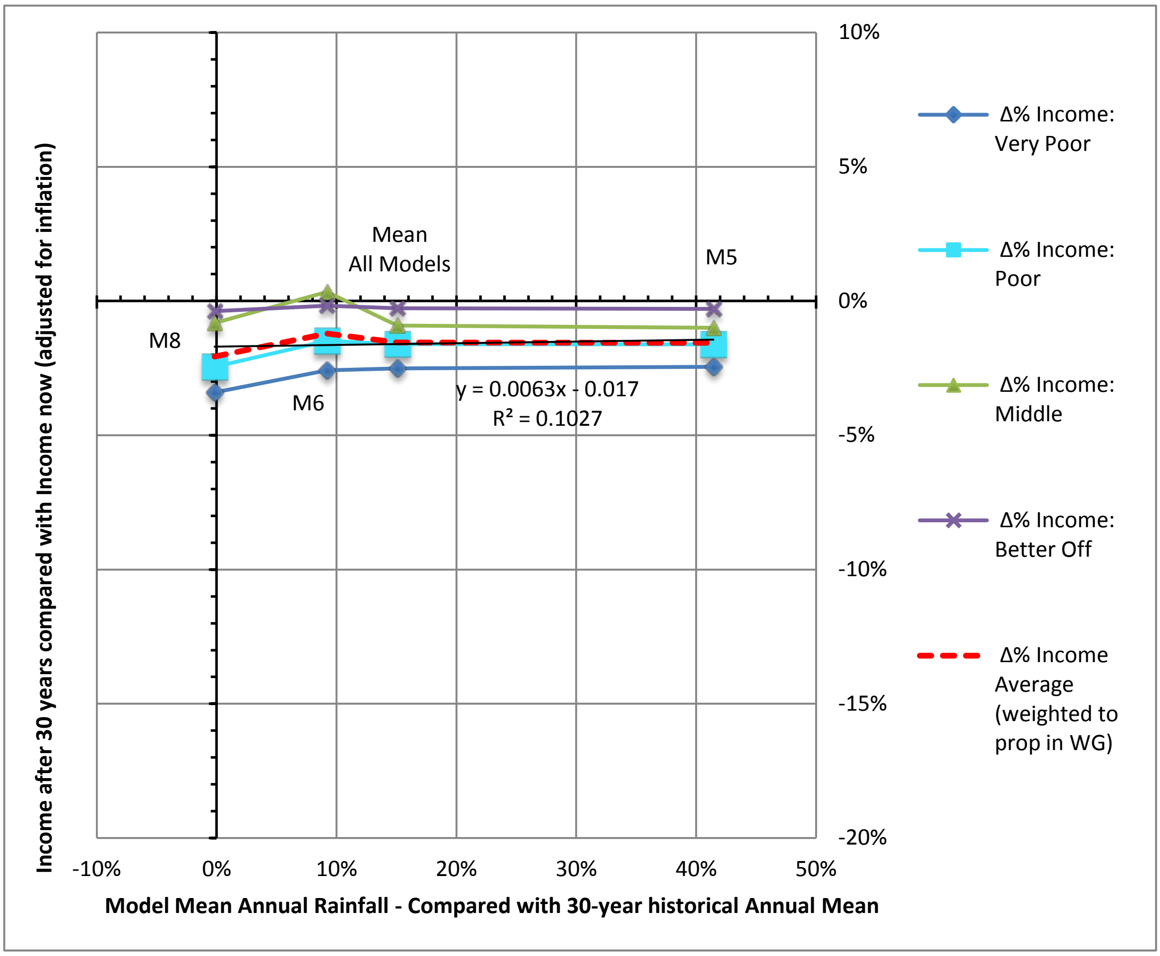
Figure 25 – Annual income time-line for the second-wettest climate model (Model 9) in Mozambique Coastal Zambezia (*Littoral de Zambezia*) livelihood zone



The mean of all scenarios results in a situation with a substantial increase in rainfall over the livelihood zone. This increase keeps incomes quite constant, as losses from poor crop performance are less likely. Nevertheless, there are threats to the livelihoods; these are mitigated by strategies that show relatively good adaptation to climate variability and climate change already. This includes growing rice and cassava—the former handles water-logging and the latter handles drought. Good markets for these products may evolve in Tete, given the huge investments in mining and industry underway there.

The analysis of the Quelimane livelihood zone in Mozambique shows that there is only a very slight impact on the main livelihood income in this zone, while the crops (maize, rice, groundnut, cassava, sweet potato) would still not be too badly affected. Therefore, one may deduce that the livelihoods in the Quelimane livelihood zone do not exhibit significant sensitivity to changes in future rainfall. This is borne out in the sensitivity graph shown in Figure 21 below. This graph is plot showing the changes in income after thirty years for each wealth group model in the Coastal Zambezia livelihood zone in Mozambique against the change in average rainfall after the same period.

Figure 26 – Livelihood sensitivity to climate change



Constraints on the pilot study

It is important to be clear that this analysis aimed to assess the sensitivity of key livelihoods in the Quelimane livelihood zone to rainfall. In order to rigorously interrogate the impact of climate change, other variables (i.e. temperature changes, sea level rise, etc.) must be analysed in addition to rainfall. It is often the case when the combination of the onset of various climatic influences at the same time, that causes the most damage. This would require a more complex approach, which was out of the scope of this pilot study.

Let us take Quelimane and its surrounding areas as an example. The area around Quelimane is interesting because of its proximity to the ocean (on the western or coastal side) but also its proximity to a large river – the Cuacua (on the eastern or inland side). This is interesting because should Quelimane experience sea level rise in the future, and should there be an increase in the frequency of coastal surges in addition to the increase in the frequency of intense rainfall (and also potential flooding), the combination of these different events would have a significant impact on the population and environment in and around Quelimane.

Saline intrusion is an example of one likely impact that would result due to the occurrence of such an episode. High sea levels and coastal surges (due to the onset of a cyclone or strong winds) would cause sea water to spread further than usually across land in the vicinity of the coast line. Should flooding occur at the same time from the inland side of the Quelimane area, this heightens the risk of the flood waters mixing with the sea water from the ocean on areas of land that would under normal circumstance not be exposed to sea water.

Exposure to sea water poses a threat of saline intrusion. Saline intrusion has the potential to cause imbalances in the nutrients (pH) of the soil with resultant impacts on the fertility of these soils. This in turn may adversely influence the suitability of this land for their usual purposes, such as small scale agriculture.

It is therefore important to look at climate variables in their entirety. This was recognised by the team conducting this pilot study. However, given the time and resource constraints to perform this initial analysis, it was not possible to analyse all climate variables. Data constrains are also very important to bear in mind. It is often the case that detailed data at a localised level, may not always exist or be difficult to access. Under these circumstances, it would not be possible to look at each and every climatic variable. These considerations should therefore be kept in mind when selecting sites that are suitable for conducted these kinds of analysis.

This pilot however, has uncovered the components of importance to taking this innovative approach forward. Through uncovering these components of a successful study, these kinds of findings support the fact that it is viable to combine the methods for livelihoods analysis and climate analysis for gaining a better understanding of livelihood sensitivity to future climate.

The knock-on effects that have been presented in the preceding discussion highlight the importance of being able to draw on different expertise to fully interpret the combined model. These expertise are crucial as they facilitate the provision of additional perspectives on the dynamics of the social and ecological systems being analysed and the resultant impacts due to climate hazards.

The phenomenon and impacts of climate change are wide-ranging and highly complex. And so, it is crucial that rigorous models of the relationships between the livelihood asset being analyzed and the components of climate (i.e. rainfall, temperature, etc.) are established. The outputs produced by these models must be tested and validated as a means of verifying their robustness.

In line with this, it would be useful to have a set of multi-disciplinary expertise that can be drawn upon to consult with in interrupting the results produced by the models and checking the completeness of the models developed. It is important to note that this does not suggest that a large core team is required. Rather, it is only a select set of expertise that is required to consult with in interrupting the outputs achieved through the models. This pilot has uncovered that the expertise of importance relate to agriculture and livestock production systems. By identifying various expertise and experts in these fields, the core team conducting the analyses will be able to engage with these experts and so gain their input into the interpretation of the outputs of models of the productions systems being analysed (such as livestock and/or crop production systems).

Discussion of the findings from the analysis

The techniques used to model future climate are complex and the information produced by these models (i.e. the GCMs) is often quite difficult to interpret. One of the challenges encountered in this pilot is the very different picture of climate that the various climate models project for the future (even when looking at a specific location). The model outputs for the Open Access Livestock livelihood zone in Botswana provide a demonstration of this challenge. As we can see in Figure 5 above, there is a split between models that project wetting and those that project drying, for example. These kinds of observations reveal why it is clear that there is a need to exercise caution when interpreting the information produced by the GCM's.

Understanding biophysical system and historical context

One element that assists in providing a good basis for interpreting the information produced by the GCM's is to have a clear understanding of the biophysical system and historical context of the particular sites being analyzed. These insights facilitate the identification of feasible scenarios for analyzing and interpreting future climate in a particular area. For instance, in the case of the wettest model (CNRM-CM5 (i.e.M2)) for the Tshane station in Botswana, this model shows that this area of Botswana is projected to received 29% more rainfall on average over the period 2013-2043 (when compared with average annual rainfall for the period 1981-2011)). Average annual rainfall for the Tshane area is estimated to be 320 mm per annum for the period 1981-2011, and so one is able to deduce that a 29% increase in average annual rainfall is quite a large increase; especially in this relatively dry part of Botswana.

Therefore, given this context it is not likely that the wettest model (CNRM-CM5 (i.e.M2)) for the Tshane station in Botswana provides estimates of future climate that has a high probability of occurring. Thus an analysis of this particular model would not necessarily be a priority for informing policy makers.

Difficulties in identifying extreme events

The way in which increased wetting or increased drying might occur in the future provides another important consideration for analysis. For instance, it is probable that wetter years may transpire as more extreme occurrences of climate, as opposed to higher total *annual* rainfall. The level of data currently available on the CSAG database does not allow for disaggregation of rainfall data into weekly periods. As projected rainfall data is provided as monthly figures, it is not possible to identify cases of short duration intense/extreme rainfall events, such as prolonged periods (in weeks) of high rainfall. This form of information, if it were possible to obtain, would provide a clearer perspective on the occurrence of events such as floods.

Another important component of the analysis of future climate impacts would include deeper interrogations of potential knock-on effects of extreme events (droughts, flooding, higher temperatures). For instance, if a model projects drying and the monthly projections of the model also reveal increased length of the dry season over consecutive years, should such circumstances be followed by heavy rainfall events, adverse impacts on the biophysical system may occur. Increased soil erosion due to high run-off is one example of such an impact. These kinds of impacts can additionally have an effect on livelihood assets, as well as having an impact on socio-economic factors such as human health (from malnourishment, heat stress, etc.) and school attendance/education (i.e. in the case where children are either ill due to malnourishment or having to stay home to fulfil other household duties due to ailing adults).

Integration of additional data and extension of analyses

In discussing aspects related to data, it is important to understand the objective of the pilot and then to discuss aspects of data in this context. As this was a pilot, there was limited time for the analyses and so the level of analyses was constrained by time and resource constraints. Despite this, the pilot has allowed for the analysis of the sensitivity of livelihoods to climate as well as uncovering areas that can be strengthened in further work.

In terms of the data used in the pilot, pervious sections have noted that this pilot mainly made use of rainfall data. Integration of temperature data into future work will add another valuable layer to the analysis. Identifying the threshold of various crops and livestock systems to aspects such as increased temperature and rainfall (i.e. maximum temperature where by damage to crops starts to occur, the level of water logging that will adversely affect the health of various crops) should be further explored and will add to the depth of the analysis in further work. Information and data gathering and deeper integrations of the relationships between factors relating to key livelihood assets (i.e. goat birth rates, goat death rates) and climate variability (i.e. extended dry season, prolonged drought, episodes of short duration/intense rainfall) should also be explored further.

While these relationships can still be strengthened in further work, this does not mean to say that the relationships in this pilot are not representative of the relationship between future climate and the livelihood assets analysed. As this was a pilot study, this rather sets the basis for taking this work forward and uncovers how these relationships can be explored further and strengthened. These insights thus contribute to establishing the pilots overarching goal of understanding the pathways for and establishing the viability of combining the methodologies.

The activities conducted during the pilot have already revealed useful tools that can be integrated into future work. An example of one such tool is the Agricultural Production Systems Simulator (APSIM). APSIM is a modelling framework that simulates biophysical processes in farming systems, particularly as it relates to the economic and ecological outcomes of management practices in the face of climate risk. APSIM is one tool that can be used to strengthen the understanding of the relationships between various crop yields and climate variables. Consultation with experts in specialist fields relevant to the particular systems under analysis will additionally supplement these aspects to allow for valuable contributions, validation and an element of ‘ground truthing’ of the relationships that are established. These inputs will additionally support the building/construction of the models developed within this pilot. Integrating these activities into further work will therefore likely involve having a larger team to draw from than that of the original team that conducted this initial pilot.

Conclusion

This documents reports on the activities and analyses undertaken during a pilot study conducted by consultants from The Wahenga Institute and OneWorld Sustainable Investments, under the direction of the Southern Africa Development Community. It is important to note that this was only a pilot study. This pilot study had the main aim of testing the viability of combining the methodologies used to analyse livelihoods and those used for analysis of future climate. The purpose for doing this was to test and begin to create methods that allow for gaining an understanding of the impact of climate change on livelihoods. The pilot study further seeks to understand the sensitivity of two livelihoods zones (one in Botswana and one in Mozambique) to climate variability using a series of analyses that were based on future climate scenarios as projected by the Global Circulation Models (GCMs).

From the discussion provided in this report, it is evident that there is value in the procedures of understanding livelihood sensitivity to climate, as has been explored in this pilot. Furthermore, it is clear that it is possible to combine the methodologies used to analyse livelihoods and those used for the analysis of future climate. The methods for doing this have been laid out in this report.

It is important to note that the feasibility for producing an informative analysis of this kind is highly dependent on the availability of data and the quality of this data. In order to source historic weather and also projected future climate (as provided by the GCMs), it is prerequisite that there is at least one weather station within any particular livelihood zone. The fifth phase of the Coupled Model Intercomparison Project (CMIP5) data that is sourced from the Climate Information Portal[13] (CIP), hosted by the Climate Systems Analysis Group (CSAG), at the University of Cape Town (UCT) a varied scale of weather stations across the Southern African region. For example, CMIP5 has data for a vast number of weather station in countries such as South Africa and Malawi. On the other hand, countries such as Namibia, Botswana and Mozambique have only a few weather station from which to draw GCM data from.

Having said this, this pilot was a starting point and has uncovered the means for further strengthening this process. In the discussions of the findings, concluding remarks are made and key points for consideration are presented. Suggestions in taking this work further have also been provided within the discussions in this section.

Within these sections, the underlying theme points to the need for a multi-disciplinary team in taking this work forward.

By bringing a multi-disciplinary team together, various expertise can be drawn together. Integrating these expertise will provide a holistic understanding of the cascading effects on livelihoods that result from climatic events as well as allowing for an analysis of potential feedbacks that may exist within a production or livelihood system. The phenomenon and impacts of climate change are wide-ranging and highly complex. Most importantly, by integrating various expertises in such an analysis would assist in unpacking the complexity of the environmental, social and economic systems. This will provide deeper insights into the key thresholds and tipping points within particular production systems and offer context on where potential multiple pressures converge. These perspectives then provide a strengthened evidence base for informing approaches that would inevitably facilitate the building of resilience of social and environmental systems to the impacts of climate change.

[13] CSAG Climate Information Portal - http://cip.csag.uct.ac.za/webclient/introduction

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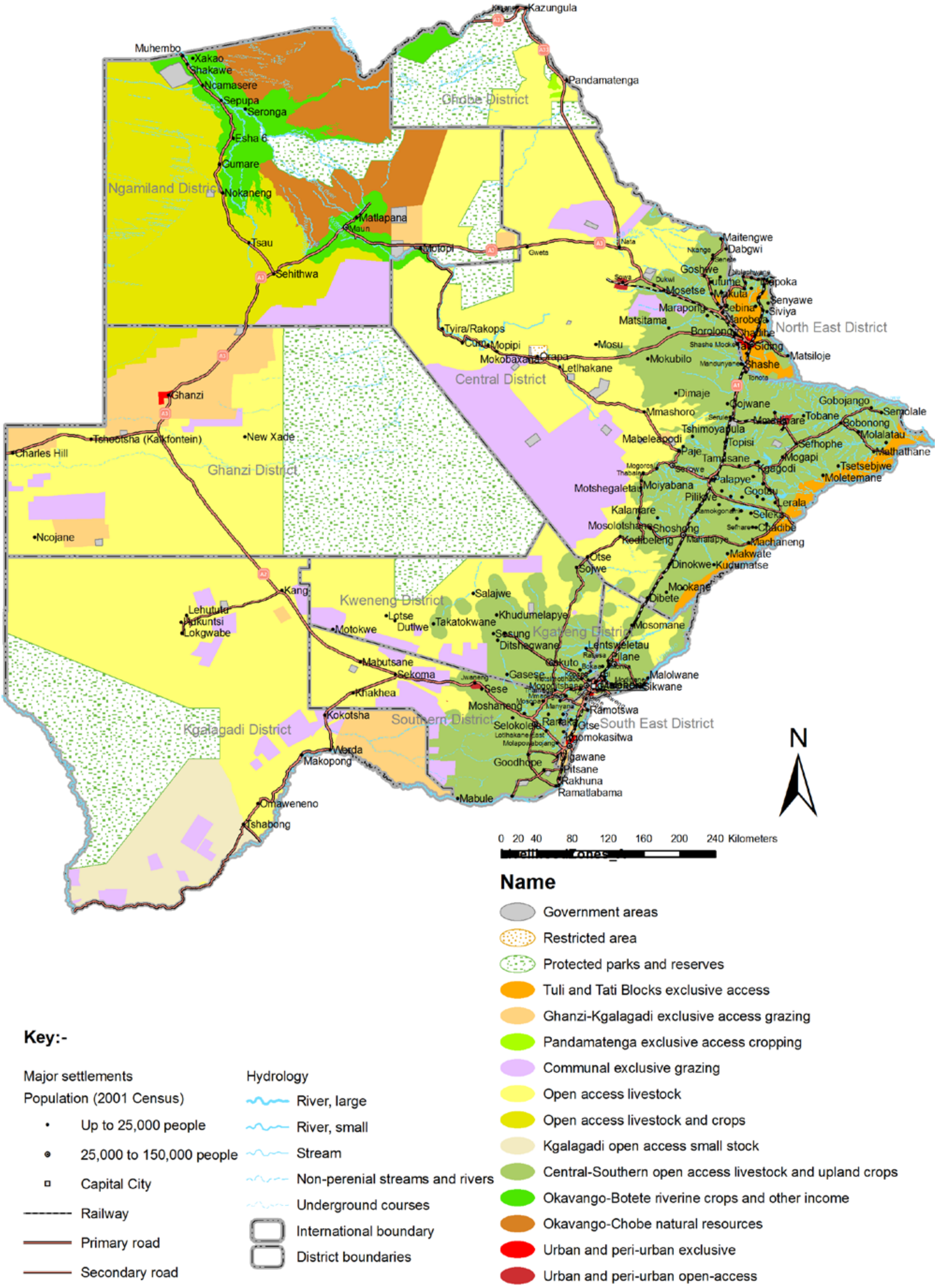
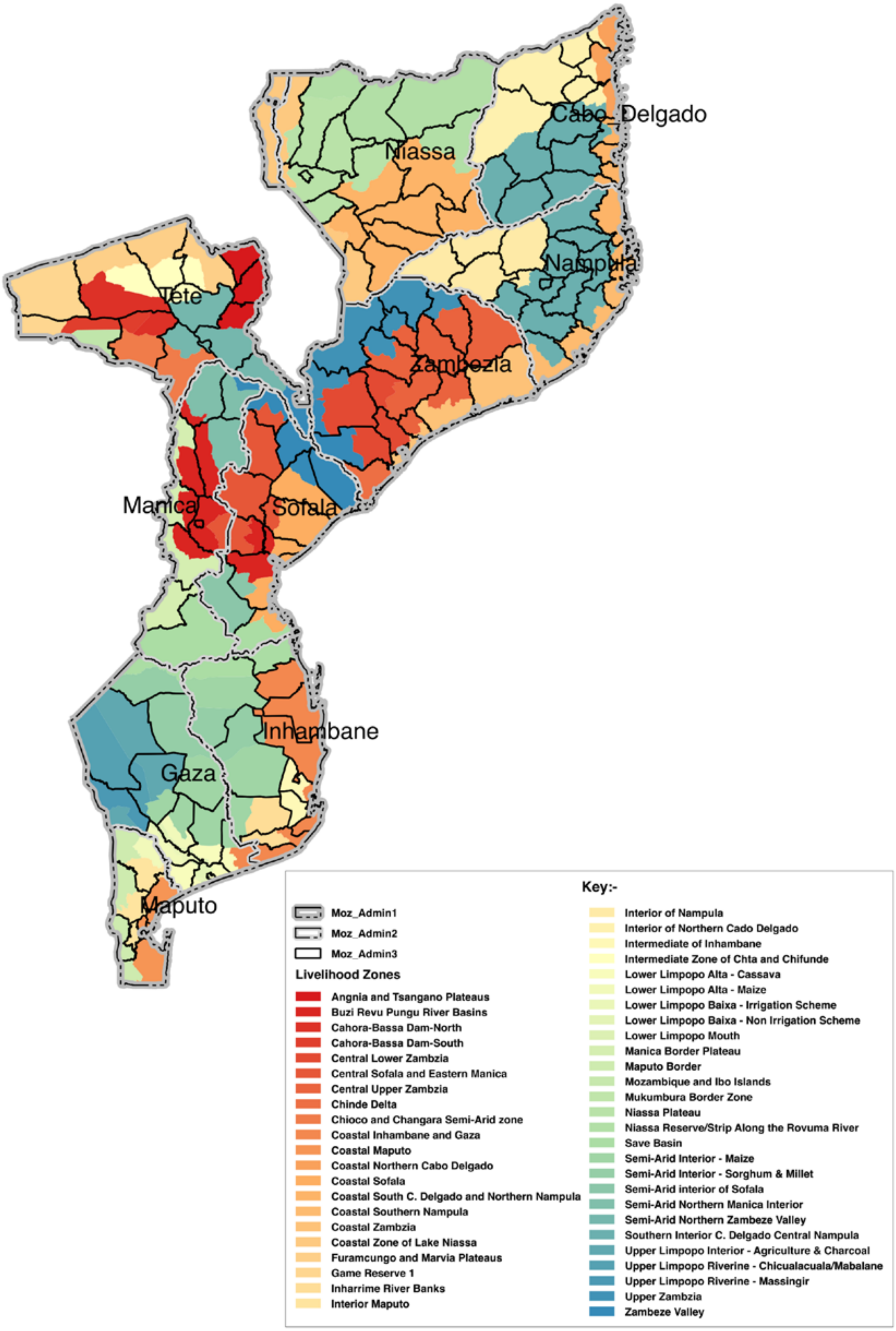
Appendix I: Livelihood Zone Map of Botswana



Appendix II: Livelihood Zone Map of Mozambique



Appendix III: Herd Dynamics Tables for the Climate Scenarios

The herd dynamics tables presented below span thirty years from 2014, that is, up to 2043. Mortality and livestock numbers are predicted according to the relationships defined in Figure 10 and Figure 11.

Table IX – Herd dynamics applied over a period of thirty years (2014 to 2043), based on the second-driest climate model (Model 8)

Year	Rainfall (mm)	Herd: start of year	Adult females	Births	Sales	Deaths	Herd: end of year
2014	190	30	17	9	8	4	27
2015	85	28	16	9	13	7	17
2016	45	17	10	5	9	6	7
2017	189	7	4	2	2	1	6
2018	219	6	3	2	1	1	6
2019	98	6	3	2	3	1	4
2020	174	4	2	1	1	1	3
2021	103	3	2	1	1	1	2
2022	130	2	1	1	1	0	2
2023	195	2	1	1	1	0	2
2024	115	2	1	1	2	0	1
2025	120	1	1	0	0	0	1
2026	273	1	1	0	0	0	1
2027	81	1	1	0	0	0	1
2028	151	1	1	0	0	0	1
2029	201	1	1	0	0	0	1
2030	98	1	1	0	0	0	1
2031	125	1	1	0	0	0	1
2032	153	1	1	0	0	0	1
2033	132	1	1	0	0	0	1
2034	118	1	1	0	0	0	1
2035	104	1	1	0	0	0	1
2036	70	1	1	0	0	0	1
2037	158	1	1	0	0	0	1
2038	223	1	1	0	0	0	1
2039	135	1	1	0	0	0	1
2040	158	1	1	0	0	0	1
2041	109	1	1	0	0	0	1
2042	168	1	1	0	0	0	1
2043	155	1	1	0	0	0	1

Table X – Herd dynamics applied over a period of thirty years (2014 to 2043), with mortality predicted according to rainfall, based on the median rainfall model (Model 6)

Year	Rainfall	Herd: start of year	Adult females	Births	Sales	Deaths	Herd: end of year
2014	209	32	19	10	9	4	29
2015	70	37	21	12	18	10	21
2016	122	21	12	7	9	4	15
2017	185	15	9	5	5	2	13
2018	169	13	8	4	4	2	11
2019	128	11	6	3	4	2	8
2020	164	8	5	3	3	1	7
2021	230	7	4	2	1	1	7
2022	190	8	5	3	3	1	7
2023	161	7	4	2	2	1	6
2024	187	6	3	2	2	1	5
2025	97	7	4	2	2	2	5
2026	151	5	3	2	2	1	4
2027	82	4	2	1	2	1	2
2028	131	2	1	1	1	0	2
2029	120	3	2	1	1	1	2
2030	144	2	1	1	1	0	2
2031	110	3	2	1	1	1	2
2032	213	2	1	1	1	0	2
2033	159	2	1	1	1	0	2
2034	192	2	1	1	1	0	2

Year	Rainfall	Herd: start of year	Adult females	Births	Sales	Deaths	Herd: end of year
2035	202	2	1	1	1	0	2
2036	170	2	1	1	1	0	2
2037	262	2	1	1	1	0	2
2038	176	2	1	1	1	0	2
2039	221	2	1	1	1	0	2
2040	246	2	1	1	1	0	2
2041	128	2	1	1	1	0	2
2042	331	2	1	1	1	0	2
2043	213	2	1	1	1	0	2

Table XI – Herd dynamics applied over a period of thirty years (2014 to 2043), with mortality predicted according to rainfall, based on the mean of all rainfall models (mean ensemble)

Year	Rainfall	Herd: start of year	Adult females	Births	Sales	Deaths	Herd: end of year
2014	284	30	17	9	6	3	30
2015	166	31	18	10	10	5	26
2016	151	26	15	8	8	5	21
2017	233	21	12	7	5	3	20
2018	402	20	12	6	3	1	22
2019	193	23	13	7	7	3	20
2020	297	20	12	6	3	2	21
2021	300	21	12	7	4	2	22
2022	271	23	13	7	5	2	23
2023	289	23	13	7	5	2	23
2024	293	23	13	7	4	2	24
2025	189	25	14	8	7	4	22
2026	269	22	13	7	5	2	22
2027	177	22	13	7	7	3	19
2028	212	19	11	6	5	3	17
2029	186	17	10	5	4	3	15
2030	220	15	9	5	4	2	14
2031	211	14	8	4	3	2	13
2032	221	13	8	4	3	2	12
2033	244	12	7	4	3	1	12
2034	231	12	7	4	4	1	11
2035	241	11	6	3	2	1	11
2036	276	11	6	3	2	1	11
2037	341	11	6	3	1	1	12
2038	239	12	7	4	3	1	12
2039	269	12	7	4	3	1	12
2040	286	12	7	4	3	1	12
2041	199	12	7	4	3	2	11
2042	362	11	6	3	1	1	12
2043	309	12	7	4	2	1	13

Table XII – Herd dynamics applied over a period of thirty years (2014 to 2043), with mortality predicted according to rainfall, based on the second-wettest rainfall model (Model 5)

Year	Rainfall	Herd: start of year	Adult females	Births	Sales	Deaths	Herd: end of year
2014	492	35	20	11	7	4	35
2015	264	35	20	11	8	4	34
2016	249	34	20	11	5	2	38
2017	370	39	23	12	5	2	44
2018	702	45	26	14	8	3	48
2019	335	48	28	15	6	3	54
2020	391	55	32	17	7	3	62
2021	410	63	36	20	9	4	70
2022	379	72	42	23	11	3	81
2023	478	83	48	26	13	3	93
2024	477	94	54	29	13	4	106
2025	445	108	63	34	16	5	121
2026	419	125	72	39	23	11	130
2027	305	130	75	41	19	6	146
2028	416	157	91	49	50	26	130

Year	Rainfall	Herd: start of year	Adult females	Births	Sales	Deaths	Herd: end of year
2029	161	130	75	41	24	11	136
2030	314	139	80	44	34	16	133
2031	239	133	77	42	27	12	136
2032	292	136	79	43	25	11	143
2033	316	144	83	45	26	11	152
2034	321	154	89	48	30	14	158
2035	294	159	92	50	24	6	179
2036	663	181	105	57	28	7	203
2037	462	207	120	65	36	16	220
2038	327	225	130	71	34	9	253
2039	631	551	319	173	105	0	619
2040	478	619	358	194	99	18	696
2041	275	696	403	218	63	69	782
2042	432	782	453	245	116	32	879
2043	596	879	509	276	167	0	988