DROUGHTS AND DECISIONS

PASTORALISM, DECISION JUNCTURES AND RAIN FORECASTING

MSc Thesis – Civil Engineering – Water Management

By

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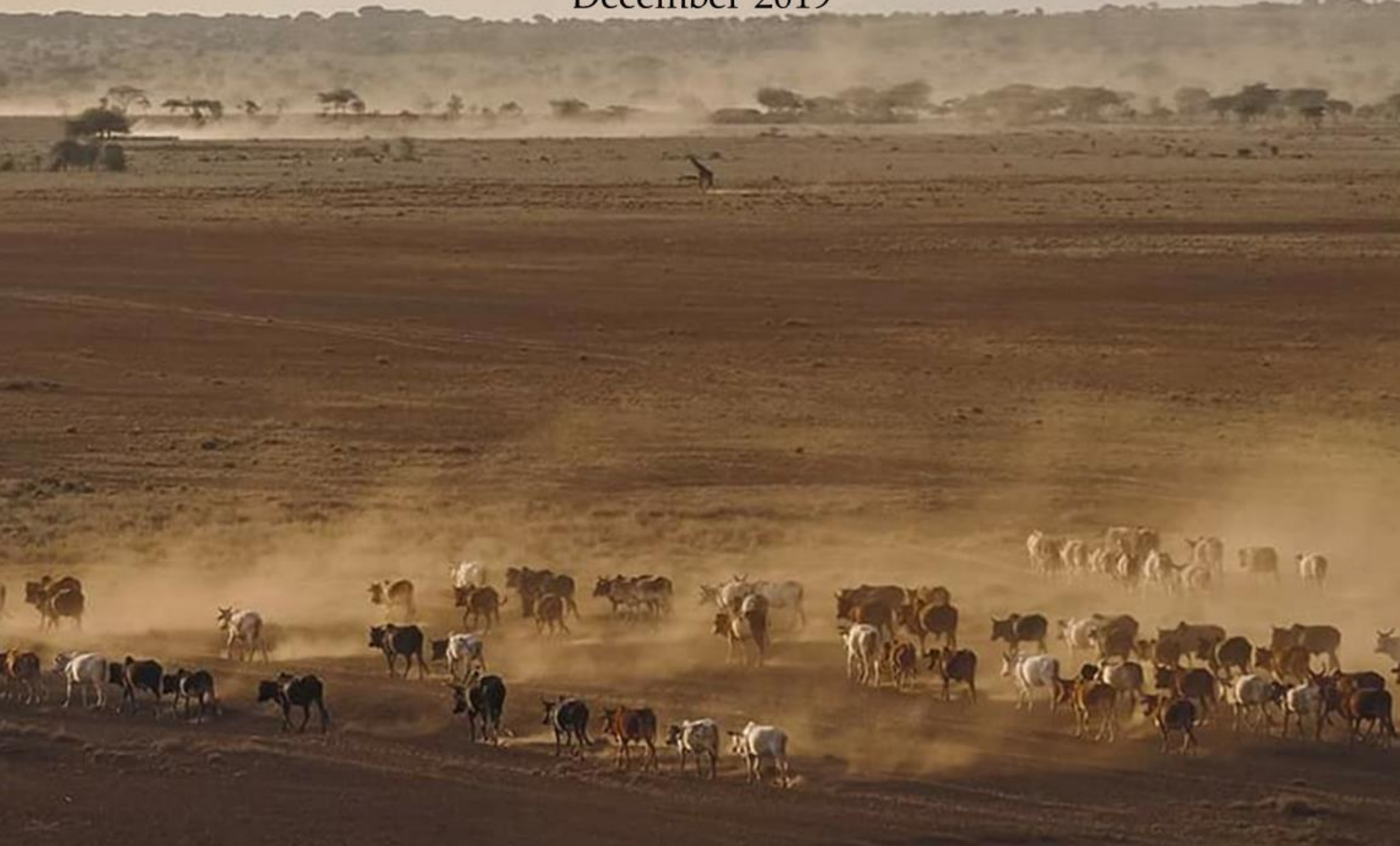

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Sauti Moja
One voice
Tanzania

Cover photo taken in Sinya, Tanzania, June 2017 (photo credit: Sanne Huijsman)

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PREFACE

Writing this thesis has been a journey of interdisciplinarity, cultural differences, and physical challenges. Throughout the 4 years of traveling back and forth to East Africa for a university field course on livelihoods, my interest in the area has grown and specifically in Longido District in Northern Tanzania. The relationships with several people in Sinya and Longido, and their lessons on assets and challenges, directed me towards the topic of drought management in the area. With an interest in spatial-temporal data, international development studies, and water management, I was passionate about looking into whether the combination of these fields could contribute positively to the livelihoods of these people.

This thesis for the Master of Science in Civil Engineering – Water Management at the Technical University of Delft, is the result of that ambition. It is one step in many more to come. However, it is an important step within the field of forecasting weather conditions and can benefit researchers, data providers, and project implementers who continue with this topic.

I wish to thank my supervisors, for their guidance, support, and flexibility. Furthermore, I would like to offer my special thanks to the Sauti Moja Tanzania staff who have put much time and energy in this project and offered valuable support. Additionally, I am very grateful of the assistance with translation provided by Nosim, Naisoi and Emanuel. It has been an unforgettable journey which I got to share with you and could not have done without you. Moreover, I would like to thank the host families in Sinya, Longido, and Arusha who have been very welcoming and who had the patience in sharing valuable lessons with me. A special thanks to Corey Wright who lent me his car and tent in Longido. Finally, I would like to thank my family and friends, who have encouraged me and supported me throughout the entire process.

This research was supported by the Holland Scholarship Fund, the Lamminga Fund, and the Ufund, through which it became financially possible for me to conduct several months of fieldwork in Tanzania and present my findings at the Waternet symposium in Johannesburg.

Esmee Mulder

Delft, 21 October 2019

SUMMARY

The livelihood of the Maasai pastoral communities in Longido District of Northern Tanzania are impacted by droughts regularly and are facing expectations of increasing variability in rainfall patterns the coming years due to climate change. The goal of this research is to explore if weather forecasts and remote sensing data can be tailored to existing coping strategies and decision-making. Furthermore, it is assessed if this tailored information provides enough skill to effectively complement local knowledge and drought management strategies. The study generated important methodological and theoretical findings, both of which have practical implications for policy and technological development.

An ethnographic and participatory approach, including four months of immersion with local families, was used to document local knowledge and strategies, and understand what specific weather information may benefit pastoralists. The study focused on *alamei* periods, a term that refers to times of drought and scarcity in the Maasai language. Weather information around particular important 'decision junctures' was demonstrated to be most relevant. One of these decision junctures is in the month of March when the grass availability has decreased and the rainfall in April is expected but does not come with certainty. It is at these junctures that rainfall predictions become particularly valuable.

In the research the skill of the ECMWF model to forecast the above dimensions was analysed. The seasonal forecasts from this model were used to predict whether the 5-day accumulated rainfall would stay below a threshold in the upcoming month. After applying a quantile-to-quantile mapping technique to correct for the bias the forecasting skill of March was relatively high (ROC-score = 0.78) and the skill of April over the fieldwork area poor (0.59). A higher skill for April was found for using forecasts over a larger area (0.79). However, in both situations the reanalysis data provided too high values, which makes the direct applicability doubtful. For an extended area, no bias correction was required and the model skill was relatively good (0.84 for March and 0.76 for April). However, this scale is too large to be useful for *alamei* management strategies by the households in Sinya.

It is recommended to use other weather models, particularly those with a higher resolution, to assess whether a model exists which can predict the required information with enough skill at the required scale. Moreover, it is recommended to assess whether assimilation of local weather observations improve the forecasts. Additionally, it is recommended to research whether other variables which are easier to predict and are related to rainfall, can prove of similar use for the Maasai communities in Longido. However, for this to be useful for the households in Sinya, the scale has to be small enough and the amount of rainfall needs to be communicated in terms of 'enough for sufficient grass regrowth' or 'not enough for sufficient grass regrowth'. Furthermore, a clear explanation of the concept of probability should be provided to ensure the expectations of the users match the capability of the forecasts.

Even if this information can be predicted with some skill, several important discussion points remain. First of all, the reanalysis data should be validated with ground data. Moreover, further research is required on the rainfall threshold and other potential factors which may play a role in grass regrowth. Finally, the role and adverse impacts of sharing this type of forecast information should be discussed with people from the study area, who have knowledge on the complexity of such information provision. This information is only one part of the complex system of managing *alamei* in Sinya and should therefore be treated and communicated as such. Too-often, as learned through this study, the adverse effects and limitations of such information is not given due consideration in development policy and practice.

CONTENT

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LIST OF ABBREVIATIONS

CGT	*Constructionist Grounded Theory*
CN	*Correct Negative*
DSGA	*Dry Season Grazing Area*
ECMWF	*European Centre for Medium-Range Weather Forecasts*
ENSO	*El Niño Southern Oscillation*
FA	*False Alarm*
FC	*Forecast*
FGD	*Focus Group Discussion*
GCM	*General Circulation Model*
GIS	*Geographical Information System*
IOD	*Indian Ocean Dipole*
IPO	*Inter-decadal Pacific Oscillation*
LIOL	*Land is Our Life*
NDVI	*Normalized Difference Vegetation Index*
NGO	*Non-Governmental Organization*
RE	*Reanalysis*
ROC	*Receiver Operating Characteristic*
RS	*Remote Sensing*
SM-TZ	*Sauti Moja Tanzania*
SST	*Sea Surface Temperature*
TLU	*Tropical Livestock Unit*
TMA	*Tanzania Meteorological Agency*

1. INTRODUCTION

"In June [2009] people started moving with their livestock. In August no one remained. Those who did, their livestock died."

– Maasai elder from Sinya, Tanzania

In the Northern-Tanzanian semi-arid rangelands, droughts occur frequently, rainfall patterns are shifting and increasingly variable, and water resources are shrinking (Msangi et al., 2014; United Republic of Tanzania, 2012). Even though the IPCC predicted rainfall to increase in East Africa, in practice droughts have shown an increase in the past decades, a phenomenon also referred to as the East African climate paradox (Niang et al., 2014; Rowell et al., 2015). For semi-nomadic pastoral Maasai communities in Northern Tanzania, the changing precipitation patterns and increasing droughts, form great challenges to their livelihood. Periods of little rainfall and grass scarcity are called *alamei* in Maa, the Maasai language. Transhumance (moving their livestock over vast distances across semi-arid rangelands) is one of the main strategies for many Maasai households to cope with *alamei* (Goldman and Riosmena, 2013; Trench et al., 2009). However, due to land privatization in Southern-Kenya, expansion of agriculture especially around Mount Kilimanjaro, and changing policies on grazing in conservation areas, the available lands for grazing in times of *alamei* are decreasing, making it increasingly challenging for the Maasai pastoralists to cope with *alamei* (Galvin, 2009; Goldman and Riosmena, 2013; Miller et al., 2014). As part of climate change mitigation and adaptation projects, and increasing livelihood resilience, satellite data and climate models are used in many areas in the world to monitor and predict droughts (AghaKouchak et al., 2015; Bijaber et al., 2018; Boschetti et al., 2013; Vrieling et al., 2016). For the heavily under-resourced district, and a country with a limited amount of weather stations, these macro technologies may provide valuable data for *alamei*-related weather predictions in Longido District, Tanzania. Nevertheless, for such weather predictions to be valuable, it is essential that these predictions are tailored to the needs of the pastoral households living in these areas.

Therefore, the goal of this research is to explore if weather forecast and remote sensing data can be tailored to *existing* coping strategies and decision-making of households in a Maasai community in Sinya in Longido District. Furthermore, it is assessed if this tailored information provides enough skill to effectively complement local knowledge and a*lamei* management strategies. Whether information provision is only one part of the larger complex system of *alamei* management decisions and should thus be treated as an addition to existing strategies rather than as a separate approach. To achieve this, the research entails a 4-month fieldwork component in which an understanding is obtained of the *alamei* management strategies, decision junctures (important decision periods) and available knowledge on weather predictions in Sinya. Additionally, this component includes the identification of what type of weather information is considered valuable to contribute to these *alamei* management strategies and decisions, and how such information, if used, will reach the majority of the households in the area. The second phase entails the assessment of the seasonal forecasts of the European Centre for Medium-Range Weather Forecasts (ECMWF) model, a global climate model, to understand whether the identified weather information can be provided with enough accuracy and at the appropriate scale. This leads to recommendations for the implementation of *alamei*-based weather information systems and for required model improvement to achieve this goal in remote, under-resourced, pastoral areas such as Sinya, Tanzania.

This paper is set out as follows. In the following section (1.1) the goals, objectives and research questions are shared. Next, in section 1.2, the study area is introduced, followed by an introduction to the partner organization in section 1.3. Chapter 2 provides background information on relevant topics and concepts such as the Maasai ethnic group, droughts and weather forecasting. In this chapter the ECMWF model which is used for this research is introduced too. In chapter 3 the methodology is discussed, in which both the methods used in the fieldwork and the methods used for the model skill determination are described. In the next chapter, chapter 4, the fieldwork findings are presented, followed by a description of the type of weather information which is deemed valuable, and the results on the analysis that demonstrates whether this identified information can be provided with enough skill. In chapter 5 the challenges related to the model skill and important considerations for the weather information distribution are discussed. Finally, in chapter 6 the conclusions and recommendations are shared.

1.1. GOALS, OBJECTIVES & RESEARCH QUESTIONS

The goals objectives and research questions of this study are provided below.

Goals

- Contribute to improving *alamei* management in Maasailand in Northern-Tanzania
- Contribute to knowledge on targeted weather information provision in rural low-resourced areas
- Contribute to knowledge on weather information usefulness for pastoralist drought management

Objectives

- Provide an overview of the opportunities and constraints of weather information provision for *alamei* management in Maasailand in Northern-Tanzania.
- Provide recommendations on the implementation of weather information provision for *alamei* management in Maasailand in Northern-Tanzania.
- Propose what further research should be conducted or what advancements on data collection is required for successful targeted weather information provision in Maasailand in Northern-Tanzania

Research Questions

The main research questions are the following: How can weather outlooks contribute to *alamei* management strategies of the Maasai communities in Sinya, Tanzania? Can such weather information currently be provided with enough skill? And what are the recommendations based on these findings to improve the current weather outlook system to fulfil this purpose?

To answer these questions, the following sub-questions are researched:

1. What is the current situation in Sinya?
    a. How is *alamei* experienced in Sinya?
    b. Do people predict *alamei* periods?
    c. Do people receive weather information?
    d. What actions are taken to manage *alamei*?
    e. What does the timeframe of action-taking and resource observation look like?
    f. Can (technology-based) weather forecasts contribute to *alamei* management? How?
        i. Which info is required, when, how communicated, of what areas?
2. What weather outlook (system) is currently available?
    a. Technical
        i. What information does this outlook system provide?

ii. What is the current skill of the weather outlook?
iii. What is the information based on?
iv. At what scale is the information provided?
b. Communication
i. With what lead time is the information provided?
ii. How are the system outputs communicated?
iii. Does it reach the people in Sinya?
3. With what skill can the recommended weather information be predicted?
4. What are recommendations for improvement?
a. Technical
b. Communication

1.2. STUDY AREA

The study area entails the Ward of Sinya in Enduimet Division in Longido District in Tanzania (Figure 1). The fieldwork area is part of a semi-arid, hot ecosystem in which 300-600mm of rain falls on average annually (Longido District Council, 2018). The area knows bimodal rainfall patterns in which the short rains usually occur in November till January and the long rains in February till May (Miller et al., 2014). The rainfall is very patchy and localized (Western and Finch, 1986). The average temperatures are between 15 and 30 °C (Longido District Council, 2018; Western and Finch, 1986). An overview of further characteristics of the study area is provided in Table 1.

Sinya ward is chosen as study site considering that due to environmental conditions, its inhabitants cannot practice agriculture and thus mainly rely on pastoralism. Compared to the neighbouring wards where some agriculture is practiced, the livelihood of the households is Sinya ward may be more vulnerable to stresses and shocks such as an *alamei*, due to the limited opportunities for livelihood diversification[1]. Furthermore, the type of weather information which is required for households which practice agriculture in addition to pastoralism, may differ from households who only practice pastoralism. Moreover, Sinya is a suitable location since the organization who hosted this research, Sauti Moja Tanzania, has close connections with the chairman of one of Sinya's villages, who assisted with the logistics. This made it feasible to talk to a large amount of people in different group settings in a relatively short period of time.

[1] This argument is based on Scoones (1998) framework on sustainable livelihoods.

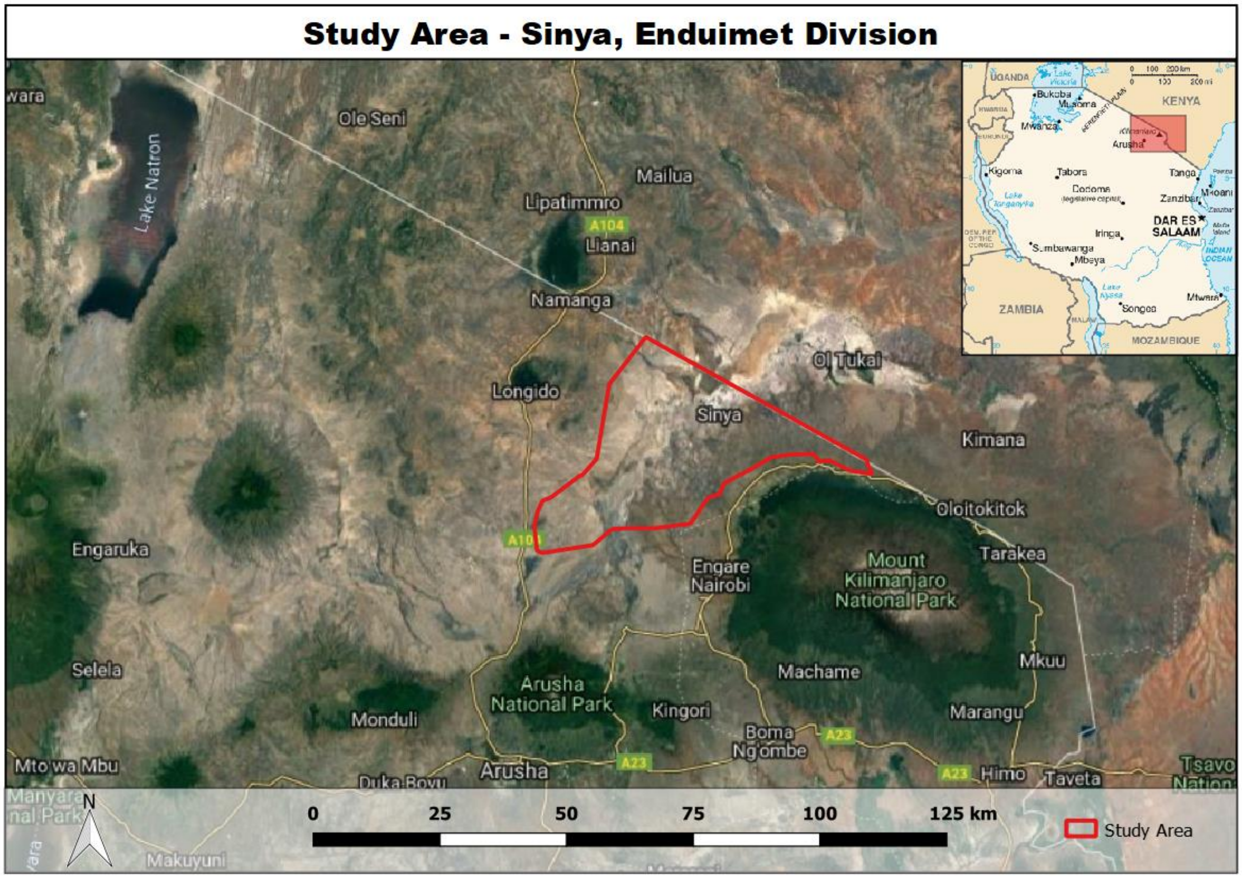

FIGURE 1 STUDY AREA
SOURCE UPPER RIGHT: HTTPS://WWW.DRIVINGDIRECTIONSANDMAPS.COM/TANZANIA-GOOGLE-MAP/
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TABLE 1 STUDY AREA OVERVIEW

Topic	Info	Source
Study Site	Sinya Ward, Enduimet Division, Longido District, Arusha Region, Tanzania	(Longido District Council, 2018)
Area	1,282 km^2 (Enduimet Division) 9,220 km^2 (Longido District)	(Longido District Council, 2018; Trench et al., 2009)
Climate	Semi-Arid, Hot 300-600 mm annual rainfall correlated with altitude Bimodal rainfall patterns ➢ November – January (short rains) ➢ February – May (long rains) Patchy, variable, localized rainfall Temperature 15-30°C	(Longido District Council, 2018; Miller et al., 2014; Western and Finch, 1986)
Prominent drought years	1944-1947, '52-54, '61, '74-77, '83-84, '93-94, '97, 2009, 2016-2017	(Longido District Council, 2018; Miller et al., 2014)
Ecology	Dry-Land ➢ Woodland ➢ Bushland ➢ Grassland (incl. seasonal inundated) ➢ Bareland/rock Vegetation generally follows rainfall patterns	(Longido District Council, 2018; Western and Finch, 1986)

Population	35,881 population Enduimet Division (in 2018) 5,033 population Sinya (in 2018) 981 households in Sinya (in 2018) 8/km^2 population density Longido District	(Longido District Council, 2018; Trench et al., 2009)
Ethnic groups in Enduimet Division	Ilkisongo Maasai (vast majority) Waarusha Maasai (mainly in agriculturally productive lands)	(Trench et al., 2009)
Livelihood in Enduimet Division	Pastoralism Agro-Pastoralism Agriculture	(Longido District Council, 2018)
Nested Governance	Based on age-class system	(Miller et al., 2014)
Water Sources	Groundwater main water source Episodic rivers Wells, Boreholes as main water access points	(Longido District Council, 2018; Miller et al., 2014; Trench et al., 2009)

1.3. PARTNER ORGANIZATION

The host organization for this research is Sauti Moja Tanzania (SM-TZ). SM-TZ is an autonomous agency and has been registered as a national non-government organization (NGO) since 2010. The NGO aims at "offering a platform to a marginalized population" and "seeks to foster a united voice among local Maasai communities" (SM-TZ, n.d.). The project to which this research is linked is called the *Land is our Life (LIOL)* project which "aims to protect traditional uses and management of land. It intends to educate and mobilize Maasai residents of Longido District, Tanzania, in order to have their voices and interests heard in the face of many recent changes to land use and governance" (SM-TZ, n.d.). Additionally, the LIOL project seeks to strengthen indigenous systems of governance, in order to maintain the resiliency of the landscape and indigenous livelihoods. This is especially important due to multiple changes in government land- and conservation policies. SM-TZ is a small local NGO with a team of 10 Tanzanians and is based in Longido town. They have a broad network throughout Longido District and have several years of experience in working with research projects in the Enduimet Division.

2. THEORETICAL BACKGROUND

This chapter provides background information on the key topics of this research. First, the Maasai ethnic group is introduced in section 2.1. This section focusses on the household composition, the pastoral livelihood, and livelihood strategies. Next, section 2.2 discusses the concept of drought. In this section droughts are defined and the drivers of the droughts in the study area are touched upon. In the final section, 2.3, drought forecasting is discussed. Here, the elements which make up a forecasting system are shared, followed by the various methodologies of obtaining forecasting information and the use of models for forecasting. Additionally, this section provides information on the ECMWF model, which was used in the research.

2.1. PASTORAL LIVELIHOOD AND THE MAASAI ETHNIC GROUP

"Pastoralism is the finely-honed symbiotic relationship between local ecology, domesticated livestock and people in resource-scarce, climatically marginal and highly variable conditions. It represents a complex form of natural resource management, involving a continuous ecological balance[2] between pastures, livestock and people."

-(Nori and Davies, 2007, p. 7)

This section gives a brief background on pastoralism and the Maasai ethnic group. First, a Maasai homestead is be described, including the role divisions between gender and age groups (section 2.1.1). Second, the composition of livestock in the households of the study area is described (section 2.1.2). In the final section (0), the land management system for grazing purposes is discussed.

2.1.1. HOUSEHOLD COMPOSITION AND ROLE DIVISION

A Maasai homestead is called an *nkang* in Maa, the language of the Maasai (Homewood and Rodgers, 1991). It consists of a number of houses which are constructed in a circle around the corrals (fenced-off areas for livestock). There are separate corrals for calves, kids, lambs, goats, sheep, and cows. The houses and corrals are fenced-off by an outer fence made of thorn bushes. This whole unit of houses, corrals and outer fence is in Swahili commonly referred to as a *boma* (Homewood and Rodgers, 1991). Within one such unit, several households may live. One household consists of a husband, a wife or wives, their children and other dependants. The several households within a *nkang* collaborate in livestock management, such as grazing decisions and herding labour (Homewood and Rodgers, 1991). The women in the *nkang* are responsible for livestock milk management, cooking, provision of firewood, provision of water, child care, house building and repair, and sometimes for looking after the young or sick livestock (Homewood and Rodgers, 1991; Yurco, 2018). The *lioni* (young boys), young girls, and *morans* (male youth) are usually the herders, though sometimes accompanied by male elders (Homewood and Rodgers, 1991). Elders are responsible for the livestock trade and spend much time discussing matters on grazing, disputes, compensation payments, and family-related business such as marriage settlements and education (Homewood and Rodgers, 1991).

2.1.2. LIVESTOCK

According to Longido District Council (2018) 90% of the households in the Enduimet Division in which the study area Sinya is located, own livestock. In a 2009 study, it became evident that the heard size and composition in Longido District is highly varied, of which 7% of the households own 50% of all livestock (Trench et al., 2009). On average, in Longido District, one household owns 51 Tropical livestock units (TLU) (SD = ±99; range 0-830), with 4.2 TLU per adult (SD = ±6; range 0-41) (Trench et al., 2009). One TLU equals 250kg, which is converted to one cow or ten goats/sheep (Jahnke et al., 1988). The households in the study area own cows, goats, sheep, and often a few donkeys to assist in carrying water.

[2] It should be noted that the idea of a *balance* or *equilibrium* of dryland ecosystems, such as in Maasailand, is a debated topic (Boone and Wang, 2007; Ellis and Swift, 1988; Pickup et al., 1998; von Wehrden et al., 2012). This counter argument proposes that the fluctuations of such ecosystems can often be explained more by abiotic factors (e.g. rainfall dynamics), rather than biotic (e.g. grazing dynamics) (Ellis and Swift, 1988).

2.1.3. Grazing land management

Before proceeding to the study's findings, it is worth noting some characteristics of the Maasai's spatial organization and management institutions. Many Maasai if you ask them, claim they can graze anywhere they want (within Maasailand). According to Potkanski (1994) "at the broadest conceptual level, all pastures belong to all Maasai" (p. 17). However, in practice, there are primary users at a locality level, called *enkutoto*. The study area of this research, Enduimet division, is such an *enkutoto.* The *enkutoto* is located in a larger area called the *oloshon*, which is the largest administrative unit of the Maasai traditional territorial system (Bekure et al., 1991). These sections are constructed in such a way that they provide sufficient resources in wet and dry seasons for its residents and their herds. At the *enkutoto* level, grazing management takes place by its own authorities, referred to as 'traditional leaders' in this research, or *ilaigwanak* in Maa. The *enkutoto* consists of areas for dry season and wet season grazing, as well as designated areas for the sick, young and pregnant livestock. The latter area has different names for various Maasai sub-sections, and is referred to as *olokeri, ololili* or *olopololi* (Potkanski, 1994). Through community mapping, Rowley (2013) created a map of these areas in Longido district (Figure 2). Rowley commented that this is only the first version of a map which should be further improved through additional field verification. However, for the purpose of this study, it gives an impression how areas in an *enkutoto* can be divided.

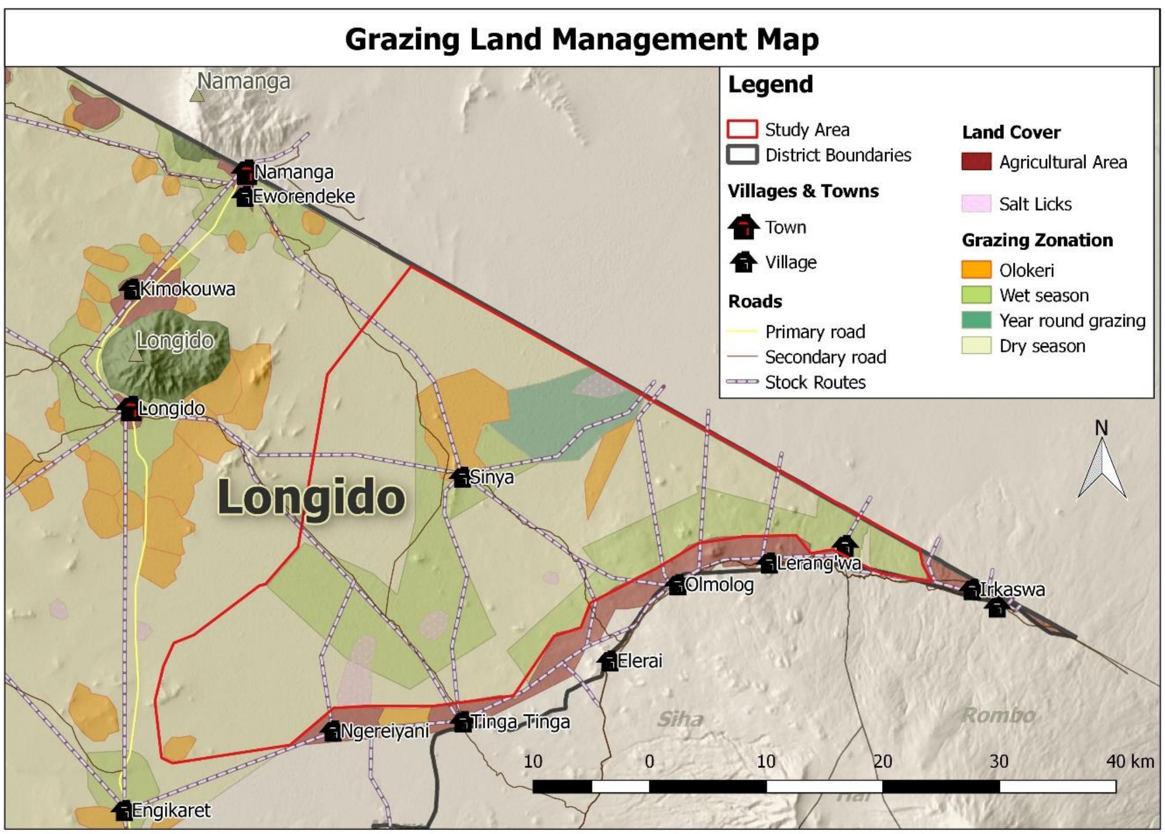

FIGURE 2 MAP WHICH ROUGHLY SKETCHES THE GRAZING AREAS IN ENDUIMET DIVISION. THIS MAP IS CREATED THROUGH COMMUNITY MAPPING BY ROWLEY (2013). *OLOKERI* REFERS TO THE GRAZING AREA WHICH IS DESIGNATED TO THE YOUNG, SICK AND PREGNANT LIVESTOCK.

The residents of the *enkutoto,* the primary users of the resources in that area, have the rights to the pastures (Potkanski, 1994). However, in case of an emergency, such as a drought, the primary users must offer access to all other Maasai or to all members of the *oloshon*. The underlaying assumption is that the resources in the *enkutoto* of which the visitors are from, have been exhausted resulting in forced mobility of this group (Potkanski, 1994). Though herders must plan their migration routes each year, commonly they graze in the same *enkutoto* when the resources in their *enkutoto* run out. These initial relationships are based on the social capital of the family, for example through marriage. The guests who have grazed in the hosting *enkutoto* for several seasons are thus well known by the primary users and have over time obtained an informal institutionalized role as secondary user. This means that they do not have to ask for grazing permission. Nevertheless, in extreme droughts, new relationships may need to be created. This often takes place at a group level, rather than an individual level, where a group of herders negotiates with the community members of the host *enkutoto* (Potkanski, 1994).

2.2.DROUGHT

Before discussing drought forecasting methods, a common understanding on what is meant by the term 'drought' is required. This will be discussed in section 2.2.1. Next, an overview is given to what drives the droughts in the study area. This is done in section 2.2.2.

2.2.1. DROUGHT DEFINITIONS

A drought is a below average water availability which last for a sustained period of time and is regionally extensive (Wanders, 2018). Commonly four types of droughts are distinguished: meteorological, agricultural (soil moisture), hydrological, and socioeconomic (AghaKouchak et al., 2015; Hao et al., 2017; Mishra and Singh, 2010; Wanders, 2018; Wilhite and Glantz, 1985). Mishra and Singh (2010) provide an overview of the definitions of these types of droughts, which are summarized below:

a) **Meteorological:** "a lack of precipitation over a region for a period of time" (Mishra and Singh, 2010, p. 206)
b) **Agricultural:** "a period with declining soil moisture and consequent crop failure without any reference to surface water resources" (Mishra and Singh, 2010, p. 206)
c) **Hydrological:** "related to a period with inadequate surface and subsurface water resources for established water uses of a given water resources management system" (Mishra and Singh, 2010, p. 206)
d) **Socio-economic:** "associated with failure of water resources systems to meet water demands and thus associating droughts with supply of and demand for an economic good (water). Socio-economic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply." (Mishra and Singh, 2010, p. 206)

These drought categories are interconnected and can thus not always be treated as isolated entities. Additionally, a long meteorological drought may lead to a hydrological drought over time, while a short meteorological drought may not have any significant impact on the other classes. Figure 3 shows the relationships between the duration of the droughts and the type of droughts. Typically, impactful droughts develop over a period of three or more months (Wilhite, 2000). However, this can depend greatly on the timing of the precipitation deficiency (Wilhite, 2000). Though many elements of the hydrological cycle may have different responses to droughts, all drought types are related to sustained precipitation deficit (AghaKouchak et al., 2015).

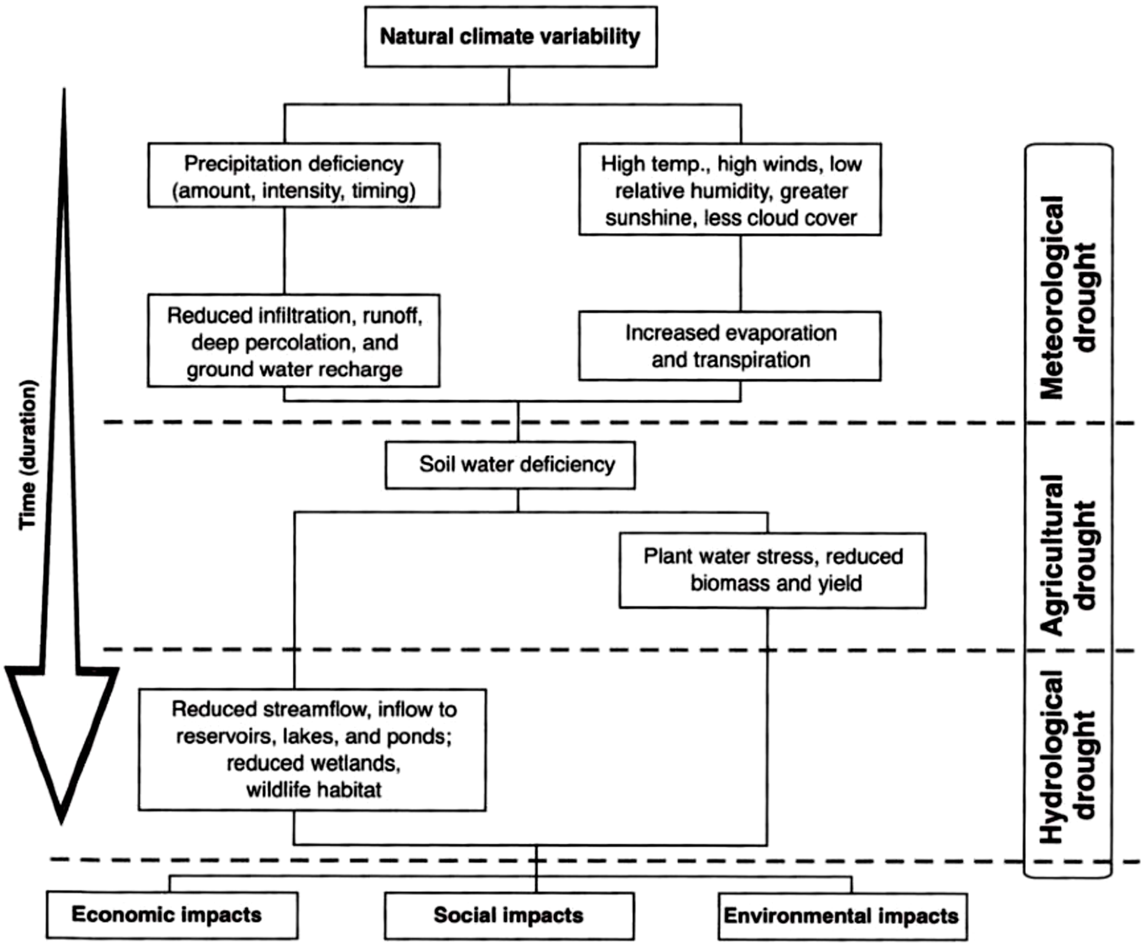

FIGURE 3 THE RELATIONSHIPS BETWEEN VARIOUS TYPES OF DROUGHT AND DURATION OF DROUGHT EVENTS (WILHITE, 2000)

However, this theoretical approach of defining terms is not always as clear in the field. In Swahili, the national language of Tanzania, the words for drought (*ukame*) and dry season (*kiangazi*) are used interchangeably. Moreover, in Maa, the language of the Maasai, the word for dry season and drought is the same (alamei), though for a severe drought the word *'sapuk'* is added which refers to a severe dry season (Goldman et al., 2016). The difference in perception of the concept 'drought' forms an important part of the fieldwork component of this research. Therefore, the definition of *alamei* which is used by the research participants is further discussed in chapter 4.

2.2.2. DROUGHT DRIVERS IN EAST AFRICA

Numerous researchers argue that the droughts in East Africa are influenced by El Niño Southern Oscillation and the Indian Ocean Dipole events (Awange et al., 2016; Kijazi and Reason, 2009; Miller, 2015; Mpelasoka et al., 2018; Tierney et al., 2013). Over the study area, El Niño causes above-normal rainfall especially in the short rains (October-December) while La Niña causes a decrease in rainfall (Kijazi and Reason, 2009; Miller, 2015; Mpelasoka et al., 2018; Tierney et al., 2013). In addition to the El Niño Southern Oscillation (ENSO), other oscillations are correlated to the East African drought years too such as the Inter-decadal Pacific Oscillation (IPO) and the Northern Atlantic Oscillation (NAO). These oscillations both have a positive correlation with drought years in this area (Mpelasoka et al., 2018). Additionally, the Indian Ocean Dipole (IOD) is correlated to droughts in East Africa, which is similarly as

ENSO negatively correlated to the drought years (Awange et al., 2016; Kijazi and Reason, 2009; Mpelasoka et al., 2018) and is playing a larger role than ENSO according to Awange et al. (2016). Finally, post El Niño years have been correlated to droughts, showing a below-normal rainfall (Miller, 2015). The impact of droughts in East Africa is approximately one to three years (Mpelasoka et al., 2018).

The overall driver which is related to the above oscillations is the Walker circulation anomaly, which controls the East African precipitation anomalies (Kijazi and Reason, 2009; Miller, 2015; Mpelasoka et al., 2018; Tierney et al., 2013). Originally the Walker circulation was referred to as "the large-scale atmospheric circulation along the longitude-height plane over the equatorial Pacific Ocean" (Lau and Yang, 2015, p. 177). However, nowadays generally the Walker circulation refers to the whole system of circulation cells along the equatorial longitude-height plane (Lau and Yang, 2015). Sea surface temperature (SST) changes above both the Pacific and the Indian Ocean influence the Walker circulation and thus the East African precipitation patterns (Tierney et al., 2013).

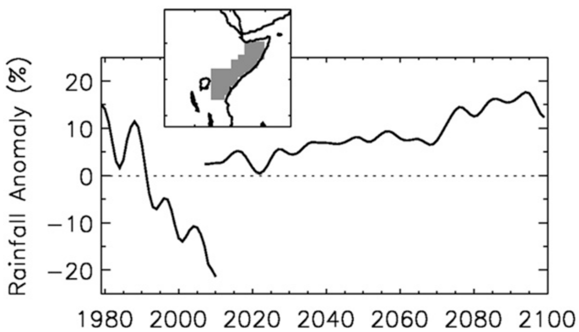

FIGURE 4 THE EAST AFRICAN CLIMATE PARADOX: OBSERVED RAINFALL ANOMALIES (LEFT LINE) VERSUS PREDICTED ANOMALIES (RIGHT LINE) OVER EAST AFRICA. THE BOX IN THE TOP INDICATES THE AREA TO WHICH THESE ANOMALIES REFER , NAMELY SOMALIA, PARTS OF ETHIOPIA, KENYA AND TANZANIA (ROWELL ET AL., 2015)

The Indian Ocean SST mainly cause the long-term multidecadal rainfall variabilities and the Pacific Ocean SST the short term inter-annual up-to-10-year anomalies (Tierney et al., 2013). The tropical SST have such a significant impact on the precipitation anomalies causing the recent droughts, that it can be the explanation for the East African Climate Paradox (Rowell et al., 2015; Tierney et al., 2013). The East African climate paradox is the predictions of wetting of the area, amongst other the IPCC reports, versus the reality of more droughts (Rowell et al., 2015) (Figure 4).

2.3. DROUGHT FORECASTING

In this section, and overview is provided of what drought forecasting entails. In the first section, 2.3.1, the process of creating a drought outlook system is described. Next, in section 2.3.2 the tools which are used in drought outlook system designs are discussed. Finally, in section 2.3.3, drought forecasting through climate models is explained and a description is provided of the model which is used in this research.

2.3.1. DROUGHT OUTLOOK SYSTEMS

Pulwarty and Sivakumar (2014) define a drought outlook system as a collection of data and analyses over an area of interest that (1) informs drought decision responses for the area, (2) provides risk assessment and scenarios, and (3) communicates response options to key decision-making actors. Such an outlook system includes several phases: (1) developing the warning, this includes monitoring the occurrence of previous droughts and forecasting future droughts; (2) sending off the warning to the either the decision maker or directly to those at risk, a decision made in the design phase of the outlook system; (3) receiving the warning; (4) responding to the warning; (5) feedback to those who developed the warning (Glantz, 2009; Pulwarty and Sivakumar, 2014; UNISDR, 2006).

According to Glantz (2009) and Pulwarty & Sivakumar (2014), several elements are important to consider when setting up a drought outlook system. Firstly, the following elements should be well thought through:

(1) the relationship between, and the timing of the first signs of a drought potentially occurring, (2) the actual alarm, and (3) the response actions. Questions related to this are: what lead time is required for the decisions and actions to have enough preparation time; when is it too far in advance that the forecast is too uncertain; and when are the first signs viable of a potential event occurring? Balancing these three components ensures that a window of opportunity can be identified and an action plan can be made (Pulwarty and Sivakumar, 2014).

Secondly, the expectations of the various stakeholders should be discussed. This can be achieved by creating a mutual understanding on what is meant by 'early' between the creators of the system and the users (Glantz, 2009). Additionally, expectations can be managed by discussing what a warning should entail, who must be warned, whether all stakeholders should be warned at the same time, and what the limitations are of the warning system (Glantz, 2009).

Finally, an increasing amount of researchers argue the importance of a co-design process of an outlook system with the users (Glantz, 2009; Hao et al., 2017; Pulwarty and Sivakumar, 2014; UNISDR, 2006). Pulwarty and Sivakumar (2014) argue that including local knowledges and practices in outlook system planning promotes "mutual trust, acceptability, common understanding and the communities sense of ownership and self-confidence" (p.18). They argue that it is important to tailor outlook systems to communities' needs and ensure their access to the official early warning information, a process which should be supported by policies. Besides a co-design process with the users, Pulwarty and Sivakumar (2014) emphasize the need for multi-sectoral and interdisciplinary collaboration. They state that all stakeholders have to be included and attention should be paid to having this collaboration during all stages of the early warning process, so from system design to implementation and evaluation. Currently, outlook systems are often national or global and the link between such systems and the community-based approach are relatively weak (Pulwarty and Sivakumar, 2014).

2.3.2. OUTLOOK SYSTEM TOOLS

According to Glantz (2009) and Hao et al. (2017), outlook system can be based on various tools such as local knowledge, geographical information systems, remote sensing, and weather forecasting models. These four tools are briefly described in this section.

Local knowledge

Local knowledge entails "the manners and customs that are cultivated intergenerationally by a group of people who have an intricate awareness of their own local environment" (Glantz, 2009, p. 5). According to Glantz (2009), the value of indigenous knowledge is in how this has enabled the community to adapt over time and adjust to the environment (Glantz, 2009). Additionally, the cultural 'memory' often goes back further than the technology-based data sources. Local knowledge is increasingly recognized as a vital tool in mitigation and adaptation strategies of current climatic threats and is incorporated in programs by the United Nations and NGO's around the world (Glantz, 2009).

Geographical Information Systems (GIS)

Geographical information systems (GIS), as a second powerful tool for outlook systems, "are organized collections of computer hardware, software, geographical data and personnel designed to efficiently capture, store, update, manipulate, and analyse all forms of geographically referenced information" (Khorram et al., 2012). An example of an application of GIS is using spatial datasets containing pixel values or consisting of shapes with attributes and laying them over one another or manipulating them. This process can be performed to obtain a better understanding on the impact of an event such as a drought in that area (Glantz, 2009).

Remote Sensing (RS)

Remote sensing (RS) is defined as "the acquisition and measurement of information about certain properties of phenomena, objects, or materials by a recording device not in physical contact with the features under surveillance" (Khorram et al., 2012). However, this is a very broad definition which includes hospital equipment such as MRI scanners and X-ray machines. In the context of earth observation, RS is narrowed down to acquisition and measurement of electromagnetic energy, which is either emitted or reflected by objects and areas on or in the earth surface, oceans, land surface, and the atmosphere (Khorram et al., 2012). RS measurement devices can be installed on an unmanned aerial vehicle (UAV or drone), on airplanes, or on satellites orbiting the earth. For the comparison of the precipitation data with the vegetation dynamics of the study area, this research only considers satellite-based remote sensing for the vegetation monitoring. This decision was made since vegetation monitoring requires a long-term continuous dataset of large areas, which is not available through UAV's or airplanes. However, for the model which produces precipitation forecasts and reanalysis, other dataset types of RS technologies are used in addition to satellite data. This model is further discussed in section 2.3.3.

Weather forecasting models

While RS is often used for *monitoring* droughts, weather forecasting models can provide drought *outlooks*. RS data can be used to determine the historic conditions to finetune and validate the forecast models. Commonly used weather forecast models can only predict the weather up to two weeks in advance with increasing uncertainty, mainly due to the high uncertainty related to the complex atmospheric dynamics (ECMWF, 2017). However, models which focus on slower, long-term processes such as oceanic circulation and processes in the cryosphere, provide a slightly higher predictive ability to forecast for up to several months (ECMWF, 2017). More background on weather forecast models for drought forecasting is provided in section 2.3.3.

2.3.3. DROUGHT FORECASTING THROUGH MODELS

The aim in this section is to give a short overview of what drought forecasting models entail and what model was used for this research. First, some key terminology is discussed. Then, the components of and differences between forecasting models is described. Finally, the ECMWF model which was used in this research is introduced.

Key concepts

There are several key concepts which are used within forecast warning systems. Various countries and systems have their own terminology (Glantz, 2009). The terminology which is used in this research is provided below:

- **Reanalysis data** are archived observations which have been 'reanalysed' through forecasts models and data assimilation systems to create a dataset which describes historical conditions. (Poli, 2014)

- **Skill** generally measures how well the forecasts match with the observed conditions. The skill of a model is determined by comparing observed or reanalysis data to the forecast data (ECMWF, 2017).
- **Ensemble** is the combination of individual forecasts of which initial states are perturbated (slightly modified) to represent the uncertainty caused by errors in the initial state (ECMWF, 2017)
- **Lead time** is the amount of time between the warning release and the event. Though this is an agreeable concept for events with a relatively clearly identifiable event onset such as floods, volcanic eruptions and tsunamis, it becomes less specific for drought forecasting. Droughts are long-term phenomena, which makes it very challenging to indicate when a drought is 'starting'. Therefore, lead time in this study is used as the amount of time required for the actors between receiving the warning and finishing the responding action. It should be noted that if it takes many days for the warning to reach the actors, this additional time period will have to be added to the required system lead time.

Model-based drought forecasting approach

Drought predictions are based on either statistical approaches or on dynamical approaches (Hao et al., 2017). Statistical approaches aim to find empirical relationships in historical records. They do not consider underlying physical processes. Examples of statistical approaches are regression models and ensemble streamflow predictions (Hao et al., 2017). Dynamical approaches are often based on current general circulation models (GCMs), which are used for weather forecasts and seasonal climate models (Hao et al., 2017). GCMs are based on physical processes such as atmospheric and oceanic circulation, land surface processes, and processes in the cryosphere (ECMWF, 2017). In addition to these two approaches, drought predictions can also be based on a combination of the two, also known as hybrid statistical-dynamical method (Hao et al., 2017). An example of such a model is the SEAS5 model which is discussed below. To monitor and predict droughts, several indicators are used. These indicators require thresholds to be set in order to define a drought once this threshold is exceeded (Hao et al., 2017). However, no consensus has been reached thus far on set values of such thresholds (Hao et al., 2017). Additionally, there is not one single indicator which can predict and forecast all types of droughts in all areas in the world (Hao et al., 2017; Henny A. J. van Lanen et al., 2008). Therefore, a combination of indicators is often used. This is where the input of and tailoring to end users comes into play.

Weather forecasts are often limited to maximum 10 to 15 days, due to the uncertainty of the atmospheric evolution (ECMWF, 2017). Small errors can drastically change the forecasts. Additionally, due to limited ground measurements, initial conditions are not known perfectly (ECMWF, 2017). There is a lower spatial distribution of ground measurements in Sub-Saharan Africa compared to Europe and the US, resulting in less accurate forecasts in this part of the world (Pulwarty and Sivakumar, 2014). However, longer-term predictions are still possible due to the more slowly evolving parts of the Earth System such as the oceans and the cryosphere (ECMWF, 2017). An example of a phenomena which can be predicted on long-term timescale is the El Niño Southern Oscillation (ENSO). This coupled ocean-atmosphere system can be predicted on a seasonal timescale. Since various studies (Awange et al., 2016; Kijazi and Reason, 2009; Miller, 2015; Mpelasoka et al., 2018; Singh, 2017; Tierney et al., 2013) pointed out the relationship between large ocean-atmospheric systems and droughts in East Africa (section 2.2.2), the long-term forecast have the potential to provide information on possible future droughts in the study area. Besides large-scale ocean-atmospheric systems, snow cover, soil wetness and stratospheric winds influence seasonal climate as well.

However, it should be noted that the predictability of the seasonal forecasts remain relatively low, especially for smaller spatial scales (several hundreds of km, rather than several thousands) (ECMWF, 2017).

ECMWF SEAS5 model

The ECMWF forecasting model which is used in this research is the SEAS5 model. It provides long-range forecasts from 0 to 7 months every month. Additionally, the model produces an annual range forecast from 0 to 13 months quarterly. The model is based on 51 ensemble members for the long-range forecasts for the year 2017 onward and 25 ensemble members for the years prior to that. It has a horizontal resolution of 36 kilometres, has 91 vertical levels and reaches 0.01 hPa at the model top (Blanchonnet, 2014). The system consists of three parts; an oceanic analysis, a global coupled ocean-atmosphere general circulation model and a post-processing suite. The first two parts respectively are for estimating the initial state of the ocean and the evolution of the ocean and atmospheric conditions. The final part is to create forecast products (ECMWF, 2017). For this thesis the total precipitation and evaporation data of the single level 24-hourly forecasts are used for each month of interest. More information on how these datasets are used in this research is provided in chapter 3.

The forecasts are produced using numerical models which solve numerous complex hydrodynamic equations. These equations describe the atmospheric and oceanic processes and evolution, considering a number of parameterizations. More detail on the SEAS5 model specifications, its methodology, and its outputs, can be found in the ECMWF SEAS5 user guide (ECMWF, 2017). Additionally, more information on the ECMWF forecasts and approaches can be found in the ECMWF Forecast User Guide (Owens and Hewson, 2018).

3. METHODOLOGY

The study was conducted in two phases, the fieldwork phase and the model skill determination phase. The fieldwork component explored current *alamei* strategies, available knowledges and information on weather predictions, and initiated the design of an *alamei*-related weather information system. This entailed several approaches and methods. The methods included interviews, focus groups, and a family portrait and are described in more detail in section 3.1. The methods which are used to determine with what skill the ECMWF model can predict the identified weather information are described in section 3.2.

3.1.FIELDWORK

The fieldwork was conducted over a period of 4 months in February-April 2019 and August 2019. The goal of the fieldwork was to determine (1) what *alamei* management strategies are currently applied by the households in Sinya, (2) what local knowledge is available on weather predictions, (3) what technology-based weather predictions reach the community members in Sinya, and (4) what weather information would be valuable according to the households to contribute to the existing *alamei* management strategies. After having obtained information on these topics, the design of a potential system, which provides this required weather information, was discussed, focusing on what area the information should be on, how far in advance the information is required and how this information can be effectively communicated to reach as many households in Sinya as possible. Data was gathered through key-informant interviews (section 3.1.1), focus group discussions (section 3.1.2) and a 'family portrait' strategy (Cochrane et al., 2005; Serneels et al., 2009), which included in-depth discussions with a case-study family (section 3.1.3). In total, more than 30 formal and informal interviews were conducted, 12 focus group session were held, with a total of over 45 people participating. The family, for which a livelihood strategy portrait was made, was visited 4 times, across 6 months. The findings have been analysed using *Grounded Theory*, an approach of which a brief overview is provided in section 3.1.4, and which is discussed in more detail by Charmaz (2006), Strauss and Corbin (1990) and Willig (2013).

3.1.1. KEY-INFORMANT INTERVIEWS

Key informants for this research are Maasai leaders such as village chairmen, traditional leaders, and the ward executive. Additionally, key informant interviews were conducted with NGO project managers, government leaders and a rangeland-ecologist. Finally, informal interviews were conducted with hosts in the study area. These key informants all have their own role in decision making and may therefore have different perspectives on what weather information is beneficial for household-level *alamei* management. The interviews are semi-structured and modified iteratively throughout the fieldwork period. An example of an interview guide for this research is provided in Annex I - Interview Guide.

3.1.2. FOCUS GROUP DISCUSSION

Focus group discussions (FGD's) are conducted with groups of women, young men (*morans*) and elderly men. Women are mainly responsible for the household water supply and for the livestock which stay close to home, such as the sick and the young. Elderly men play an important role in decision making concerning where the livestock will graze, establishing agreements with hosts if required, and have usually herded livestock for many years as young men. Some of the elderly men still herd livestock, especially when the household labour force is limited. The *morans* are responsible for livestock herding, especially when they travel long distances or stay in temporary camps. Often, the *morans* are assisted by the young boys (*lioni*). Due to this role division, all parties will have different perspectives to contribute to the discussions and thus to the research. For each group type, two groups of seven were arranged, e.g. two groups of seven women, two groups of seven *morans*, etc. These groups got together four times. An overview on what topics were covered during each session is shown in Table 2.

TABLE 2 OVERVIEW OF FGD SESSIONS

Session 1	Identifying what an *alamei* entails according to the participants, when the last major *alamei's* occurred, what these *alamei's* looked like, and what strategies households used to manage them.
Session 2	Designing an outlook system: what information is required, of what areas, with what lead time and how should it be communicated so that as many people as possible in Sinya receive it.
Session 3	The seasonal outlook game: A game on decision making based on uncertain seasonal outlooks. The purpose of this is to stimulate discussion and get an idea of the response to uncertainty in forecasts. This game is further explained in Annex II - Seasonal-Outlook Game.
Session 4	The final session was conducted in August. In this session the findings of the previous fieldwork period were verified. Additionally, a seasonal calendar was created and motivations to move to a temporary camp or stay at home were discussed. The creation of the seasonal calendar is discussed in Annex III - Seasonal Calendar.

3.1.3. FAMILY LIVELIHOOD PORTRAIT

To obtain more detail on *alamei* management strategies and understand what it looks like in practice for a household, one household was followed and revisited four times: in the beginning and end of March 2019, in early April 2019 and in early August 2019. During the first visit three women of the household explained the household structure and the livestock composition and three men explained the choices they made in past *alamei's*. In the following sessions discussions were held with the men to follow the decision-making process during the current *alamei*. For the first session, 4 different families were visited. After that one family was chosen which was most engaged and provided the richest discussions.

3.1.4. CONSTRUCTIONIST GROUNDED THEORY (CGT)

The interviews and discussions were audio recorded, under informed consent, and transcribed by the translator. Interview notes were maintained and coded together with the transcriptions according to key themes that arose. This methodology is based on an approach called grounded theory. Grounded theory is developed as a method to ensure researchers can move from data- to a context specific theory (Willig, 2013). Therefore, the theory is 'grounded' in the data rather than based on predefined categories, variables or analytical construct (Willig, 2013). The ideology behind grounded theory is for the researcher to let go of his or her preconceptions as much as possible and start the data collection open-mindedly.

The method entails the identification of categories from the data and the integration of these categories. The categories are redefined during the research, to ensure they suit the data as well as possible. From this process the context-specific theory can be developed. The process and category definitions are continuously recorded in memo's. An overview of the CGT process is provided in Figure 5. More information on this process and the various strategies is provided in Figure 5.

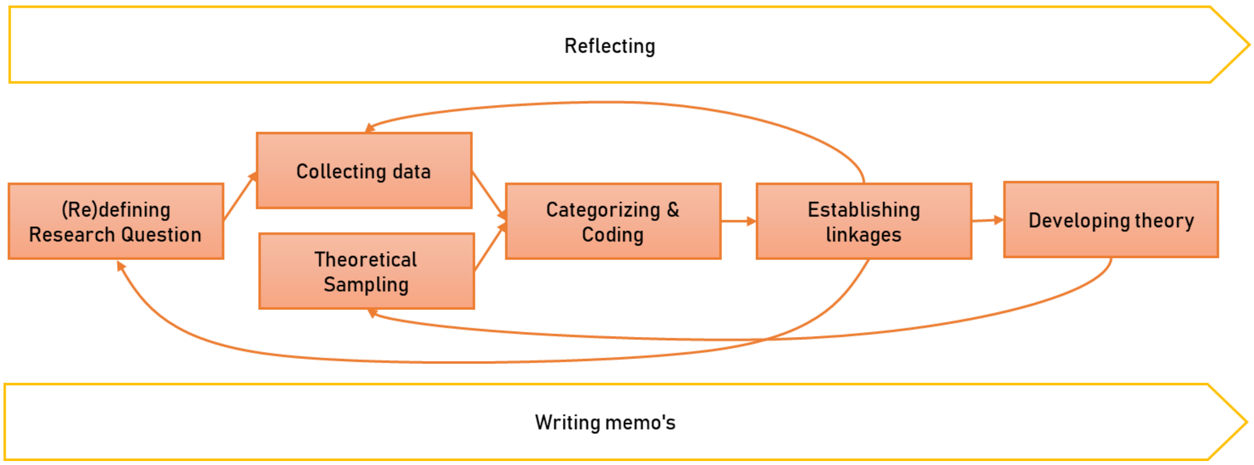

FIGURE 5 FLOW-CHART OF CONSTRUCTIONIST GROUNDED THEORY

For this research the so-called constructionist version of grounded theory is used. The difference between this version and the classical version of grounded theory is that the classical version of the method strives for the 'emergence' and 'discovery' of categories and theories, while the constructionists acknowledges that the categories and theories are a construct of the researcher her- or himself (Willig, 2013). Classical grounded theory is based on the idea that there is a truth which must be discovered, and which is thus already there at the beginning of the research, though hidden (Willig, 2013). Constructionist grounded theory recognizes the personal, theoretical, and philosophical background of the researcher and acknowledges that this background and personal assumptions influences the developed categories and theories (Willig, 2013). The reported outcomes are thus one version of the data interpretation and not the only truth (see section 3.1.5). The method of (constructionist) grounded theory is chosen to provide a framework for the qualitative research process in an organized and relatively structured way, such that the process can be followed, understood, and if desired, reconstructed, by future researchers.

3.1.5. POSITIONALITY

In this section I would like to acknowledge some elements of my positionality during the fieldwork. Though having spent many months in Tanzania and Maasailand over a period of 5-years, I grew up in the Netherlands, with a different cultural background than the background of the participants of this research. Due to extensive travelling and cross-cultural projects, I have experience in switching between different customs. However, as non-Maasai, there are many codes which I have not mastered yet. I am aware that the combination of this, my limited Kiswahili skills and my lack of knowledge on Maa, has influenced both situations and responses, as well as my interpretation of these situations and responses during the fieldwork. Additionally, as a white, young, female, I am aware that participants have their biases, stereotypes and expectations towards me too, which may influence their interpretations of and responses to the discussions. The translators which assisted during this research, the Sauti Moja staff, my Maasai friends, and the host families in Longido, Sinya, and Arusha, have all contributed to further reflections on this topic.

3.2. MODEL SKILL DETERMINATION

Figure 6 provides an overview of the methodology which is used to determine the model skill. What exactly the model should predict, is based on the fieldwork findings (chapter 4) and is the following:

- The required forecast information is a prediction on whether a certain threshold of rainfall over a period of 5 days is exceeded. This threshold should be based on the amount of precipitation required for *sufficient* grass regrowth.
- The forecast should be provided a month in advance with a prediction on whether the threshold is or is not exceeded in the following month.
- The particular months of interest for this research are March and April (see chapter 4 for further explanation).
- The forecast should be over the Enduimet Division in which Sinya is located.

These findings are discussed in more detail in chapter 4.

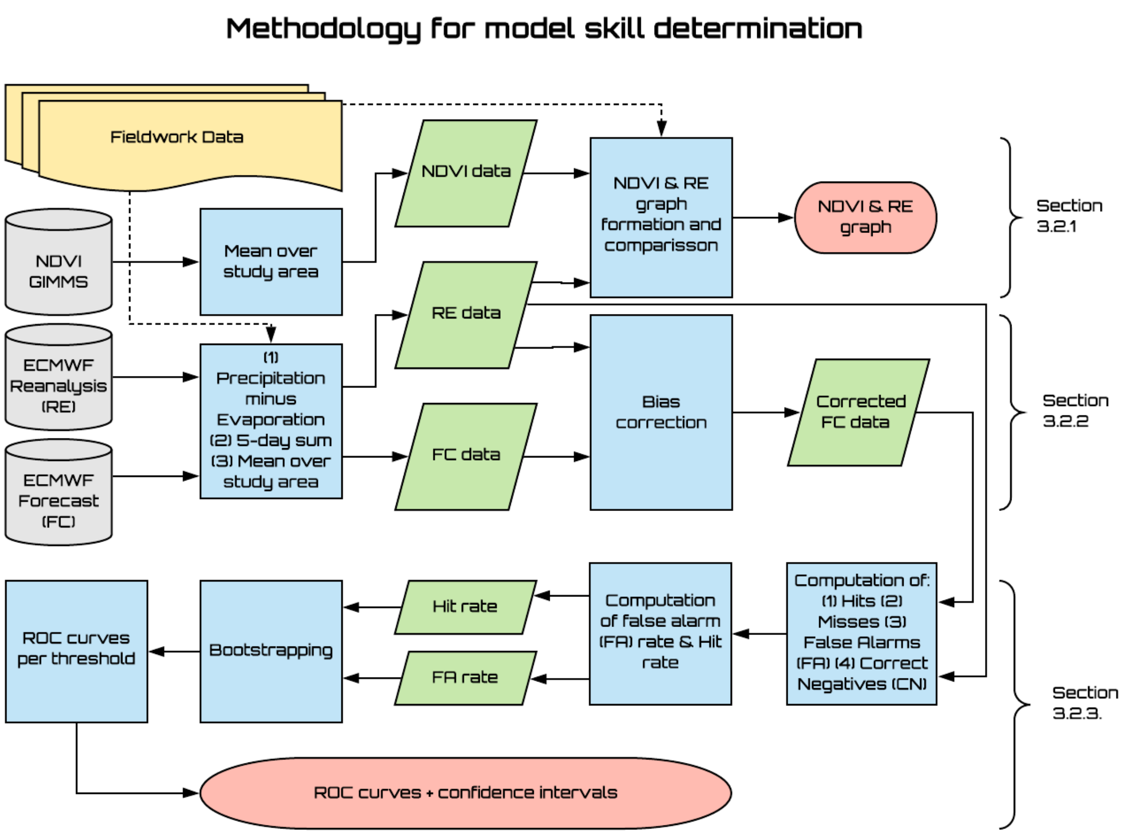

FIGURE 6 AN OVERVIEW OF THE METHODOLOGY WHICH IS USED FOR THE DETERMINATION OF THE MODEL SKILL

The steps of Figure 6 are conducted using the python programming language in *Jupyter Notebook* and are explained in further detail below. First, the reanalysis dataset is compared with the NDVI dataset and fieldwork findings to obtain a rough impression on whether the reanalysis dataset has some applicability to the study area (section 3.2.1). Next, as described in section 3.2.2, a bias correction is performed on the forecast dataset. Finally, the ROC curves are created and bootstrapped (section 3.2.3). The full script can be found in Annex IV - Python Script

3.2.1. Dataset comparison

Since the ECMWF model only encompasses 6 pixels in the study area, a rough impression should be obtained first, to see whether this reanalysis data provides any similarities with the ground situation. For this an NDVI (Normalized Difference Vegetation Index) timeseries was constructed over the study area, from the GIMMS dataset[3], to provide an overview of the vegetation dynamics. This timeseries was then compared to the reanalysis total precipitation (minus evaporation) dataset[4], using stories from the field, to see whether the reanalysis shows rainfall peaks during periods at which precipitation occurred according to the participants.

3.2.2. Bias correction

When first plotting the sorted forecast values[5] and the sorted reanalysis values, against the probability of occurrence, it quickly became evident that the forecast data values are significantly lower than the reanalysis data. Therefore, a bias correction was performed, through quantile-to-quantile mapping, to ensure a realistic comparison is made between the datasets when determining the model skill. For the bias correction, the probability of occurrence plots were used to compute a conversion formula based on interpolation. This conversion formula assigns a precipitation value for each forecast quantile which matches the quantile of the reanalysis dataset. The python code for this conversion can be found in Annex IV - Python Script. The bias correction was performed for all forecast ensemble members.

3.2.3. Bootstrapping & ROC curves

From the corrected forecast data and the reanalysis data, the hit-rate and false alarm rate were computed. First, per ensemble member, it was determined whether a hit, miss, false alarm (FA) or correct negative (CN) occurred. The conditions for these classifications are provided in Table 3. The threshold is a selected *amount of total precipitation over a period of 5 days.* Since the exact amount which is required for grass to regrow over the study area is unknown, the procedure is conducted for several thresholds.

Once the Hits, Misses, FA's, and CN's are known per ensemble member, a matrix is created for these rates per probability of occurrence. This means that the conditions of Table 4 are looped over the hit/miss/FA/CN ensemble data for x% of agreeing ensemble members, where the x loops from 1/25 ensemble members to 25/25 ensemble members.

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[3] The Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) used in this study was processed and produced by the NASA/Goddard Space Flight Center's Global Inventory Modelling and Mapping Studies (GIMMS) Group through funding support of the Global Agricultural Monitoring project by USDA's Foreign Agricultural Service (FAS). The data is retrieved from: https://gimms.gsfc.nasa.gov/download/MODIS/

[4] Precipitation and evaporation reanalysis data was obtained from the *ERA5 hourly data on single levels from 1979 to present* dataset which is the fifth generation ECMWF atmospheric reanalysis of global climate, for the years 1993-June 2019, and retrieved from: https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=form

[5] The forecast data is obtained through the MARS ECMWF's meteorological archive, for the years 1993-June2019. Further information can be found at https://confluence.ecmwf.int/display/UDOC/MARS+user+documentation

TABLE 3 THE CONDITIONS FOR THE HIT, MISS, FALSE ALARM (FA), AND CORRECT NEGATIVE (CN) CLASSIFICATIONS PER ENSEMBLE MEMBER

Class	Condition
Hit_ens	When both the ensemble member and the reanalysis state that the threshold is not exceeded at any point during the month of interest
Miss_ens	When the ensemble member states that the threshold is exceeded at some point in the month of interest and the reanalysis states this threshold is not exceeded
FA_ens	When the ensemble member states that the threshold is not exceeded at any point in the month of interest and the reanalysis states this threshold is exceeded
CN_ens	When both the ensemble member and the reanalysis state that the threshold is exceeded at some point during the month of interest

TABLE 4 THE CONDITIONS FOR THE HIT, MISS, FALSE ALARM (FA), AND CORRECT NEGATIVE (CN) CLASSIFICATIONS PER X% ENSEMBLE MEMBER

Class	Condition
Hit	If x% of ensemble members are recorded as a hit and the threshold exceedance of the reanalysis dataset is False, then the final classification for the month of interest is a ‘Hit’.
Miss	When the x% condition of hits in ensemble members is not reached and the reanalysis threshold exceedance is False.
FA	If x% of ensemble members are recorded as a false alarm and the threshold exceedance of the reanalysis dataset is True, then the final classification for the month of interest is a ‘FA’.
CN	When the x% condition of FA in ensemble members is not reached and the reanalysis threshold exceedance is True.

The result from this procedure is an array for the selected month and a selected threshold of 25 values which are either ‘Hit’, ‘Miss’, ‘FA’, or ‘CN’. This array is then used to calculate the FA-rate and the Hit-rate for this selected month and threshold. These rates are computed using the following relationship:

$$Hit_{rate} = \frac{Hit}{Hit + Miss}$$

$$FalseAlarm_{rate} = \frac{FA}{FA + CN}$$

This computation produces two arrays, both with the length of 25 values: one array for the hit-rates (per x% ensemble members) and one for the FA-rates. These arrays are then plotted against each other in a Receiver Operating Characteristic (ROC) curve diagram (Figure 7). This ROC is created for each threshold.

Finally, to obtain an understanding of the consistency of these curves, the FA-rates and Hit-rates for the selected month and threshold are bootstrapped. First, the arrays with the rates are reproduced 1000 times using the same values of the original FA- and hit-rates but in random order and with the possibility of repetition of the same value a random amount of times. This results in 1000 times 25 points with an FA- and hit-rate value. Next, these points are all plotted in the ROC curve of the original FA- and Hit-rates. Finally, density contour lines are computed to retrieve information on the spatial distribution and density of these 25,000 points.

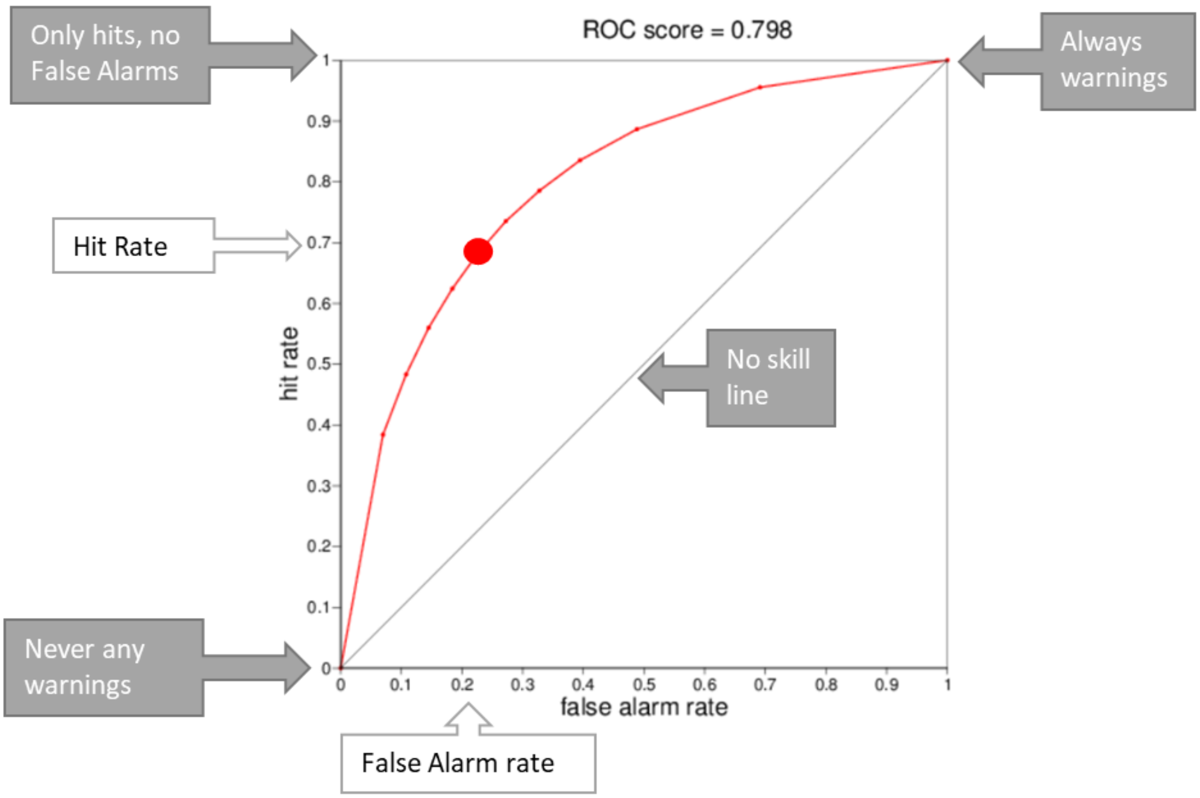

FIGURE 7 AN EXPLANATION OF HOW TO READ A ROC DIAGRAM. THIS EXAMPLE IS MODIFIED FROM (OWENS AND HEWSON, 2018)

4. RESULTS

The results consist of the findings from the fieldwork and the results from the model skill determination. The fieldwork findings on what type of weather information is required, over what area, with which lead-time, are used to determine what the model should be able to produce in order for it to be valuable for the households in Sinya for *alamei* management. Below, the main findings of the fieldwork are highlighted first (section 4.1), after which the findings of the model skill are shared (section 4.2).

4.1. FIELDWORK FINDINGS

This section summarizes the fieldwork findings. A full overview of the fieldwork results is provided in Annex V – Fieldwork Report. Below, the concept of what an *alamei* entails for the participants is discussed first (section 4.1.1). Next, the identified existing strategies on *alamei* management are discussed, including as seasonal calendar on decision junctures (section 4.1.2). Section 4.1.3 provides an overview of what local knowledge on weather predictions exists in the study area and section 4.1.4 shares the findings on the availability of technology-based weather information. The next section, section 4.1.5, sets-out the weather information which the participants indicated to be valuable for *alamei* management, and the corresponding actions which can be taken based on these predictions. Finally, section 4.1.6 shares the findings on the potential adverse impacts and challenges related to prediction uncertainty.

4.1.1. THE CONCEPT 'ALAMEI'

In the focus group discussions and key informant interviews it became evident that the word *alamei* goes further than 'drought' or 'dry season'. As a young educated Maasai women describes "*Alamei* is the time of suffering, a time of lack of food" it is "dead time". In another key informant interview *alamei* is translated as "being hungry". Another informant describes *alamei* as a period when there is not enough grass and water available. Interestingly, if there is not enough water but there is enough grass, the period is not defined as an *alamei*, but rather a time of water shortage. An *alamei* occurs every year, though a big *alamei* only occurs once every so many years, for example in 2009. Similar as the subdivision of the term 'drought' (chapter 2.2.1), *alamei* can be subdivided in different types too. The first subdivision is "*alamei* of the people", when there is not enough food available for the household members for example. This type shows some resemblance with the socio-economic type of drought (chapter 2.2.1). The second is "*alamei* of the livestock". This type of *alamei* is defined as a period of grass and water shortage, which links closely to the agricultural and hydrological droughts of chapter 2.2.1, but can also be connected to socio-economic droughts. These different types of *alamei* are not mutually exclusive and continuously influence each other. Therefore, both types will be the focus of this study. However, the focus on weather information provision is more strongly related to meteorological droughts (chapter 2.2.1), which is according to many key informants and focus group participants *one of* the main causes of *alamei*.

4.1.2. ALAMEI MANAGEMENT STRATEGIES

Two dominant livelihood strategies were identified when discussing *alamei* management. The first one is transhumance (moving around with livestock to find grass and water). The second is selling livestock to buy food for the family and if required for the livestock itself. Expectedly, one of the main indicators which influences decision making during times of *alamei*, is the availability of grass. If the grass is slowly starting to run out close to home, herders start looking for areas where there is more grass available. If these areas are found within dry season grazing areas (DSGA) of the *enkutoto* (chapter 2.1.3), which are managed by the communities and their leaders, a temporary camp is occupied and the cows are taken there. Goats and sheep are usually left behind since they can live off the shrubs and seeds of trees. This difference between browsers (goats and sheep) and grazers (cows) plays a dominant role in *alamei* management strategies and decision making. If there is not enough grass available close to home or in the DSGA, the head of the household starts negotiations with farmers and/or relatives who are located in grass abundant areas. Figure 8 provides an overview of where herders have indicated to have grazed their livestock in the previous dry periods. Grazing outside of the DSGA sometimes requires crossing the border to Kenya. However, grazing in Kenya is not preferred by many households since it is expensive. As the head of a household explains "[in Kenya] we even buy water for our livestock." Additionally, in Kenya, households need to pay for access to grasses and for accommodation. However, moving across great distances to find grazing areas in Tanzania is also expensive. As one elder explained, such movements often incur many penalties and legal trouble: "we are passing roads, particularly to Boma Ng'ombe, where there are so many farms, […] the cows can enter the farm". Herders get sent to the police station when this happens and "to get out, it is so costly", he explains.

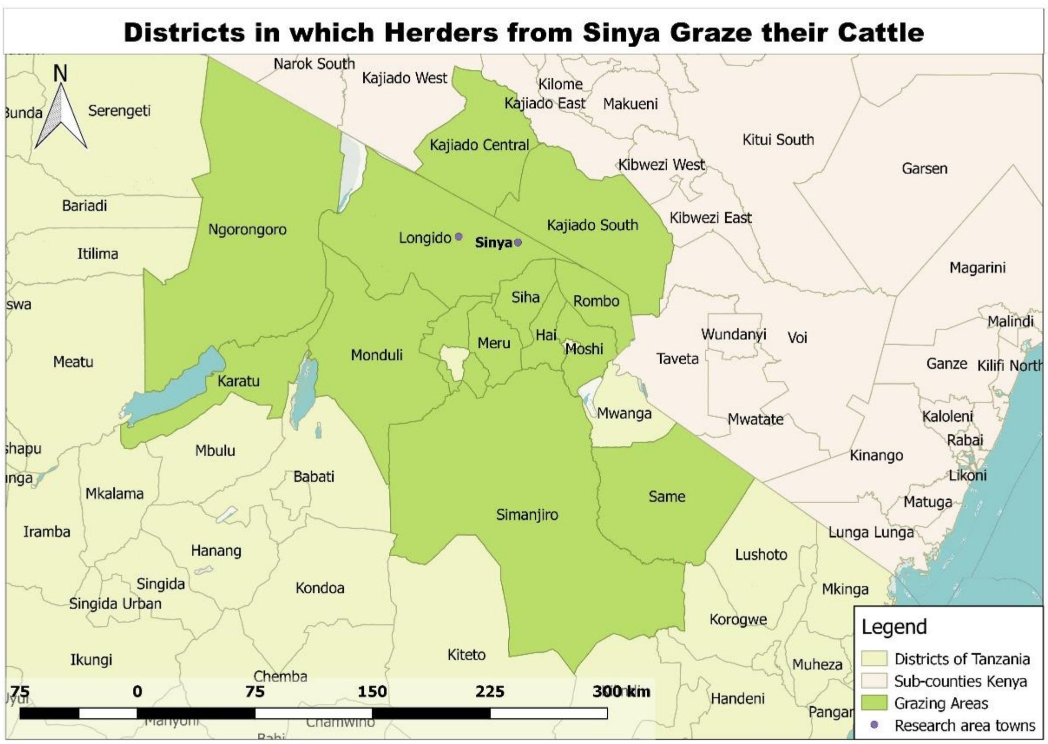

FIGURE 8 CATTLE GRAZING AREAS INDICATED BY THE FOCUS GROUP PARTICIPANTS AND KEY INFORMANTS IN SINYA. IT SHOULD BE NOTED THAT GRAZING IN A REGULAR *ALAMEI* IS USUALLY ONLY IN THE *ENKUTOTO*. HOWEVER, IN A LARGE *ALAMEI*, THE FURTHER AREAS ARE USED FOR GRAZING TOO.
SOURCE MAP: ADMINISTRATIVE BOUNDARIES FROM HTTPS://DATA.HUMDATA.ORG/

According to another participant, the decision on where to move "depends on rain and grasses; if grasses are finished there, then we try to find out where there is rain and grasses". This information is often received through relatives and friends by phone. He explained that he has two options now in the current *alamei* (August 2019); go to a farm in a place called Boma Ng'ombe (70 kms south of Sinya) or go to Kenya. The decision to move to Boma Ng'ombe or to Kenya depends on long-term food availability. The man explains that, they use their "imagination" to find out "which place is more satisfactory for the cows for a certain period of time". They want to find out for how long food will be available for the cows. This includes considering grass availability, expected grass depletion rates and feed availability sold by farmers. The men research the latter by talking to farmers before shifting to see how much food for the cows they can buy from them; “can I get enough food to survive the whole dry season?”. Additionally, they look at “the cost of the food” and “the cost of the fines”, because “you can get so many fines”. Another factor which plays a role in the decision-making is “discrimination”. A participant says that in Kenya there is much discrimination towards Tanzanians “[they would say], you Tanzanian, you just go”. Sometimes, “you have no option and then you go to Kenya”. At the time of the field research, one of the participants explains he is leading more towards going to Kenya, than to Boma Ng’ombe, because in Boma Ng’ombe “grass can finish quickly”. Though the required research and preparations are made well in advance, the final decision on where to go will usually not be made “until there is no more grass left where the cows are currently grazing” and the actual grass availability at that time at the destination is confirmed.

An overview of when these decisions are made and when grass is usually available close to home is provided in Figure 9. This research focuses on the first decision period in February-March. This choice was made as most of the fieldwork was conducted in these months and the decision-making process could therefore accurately be followed. However, it should be noted that weather information in the second decision period (August-October) can likely benefit *alamei* management too. It is recommended that a similar approach is used as in this research, to assess together with the community members of Sinya, what type of weather information, of what area, with which lead time, would be useful in the second decision period.

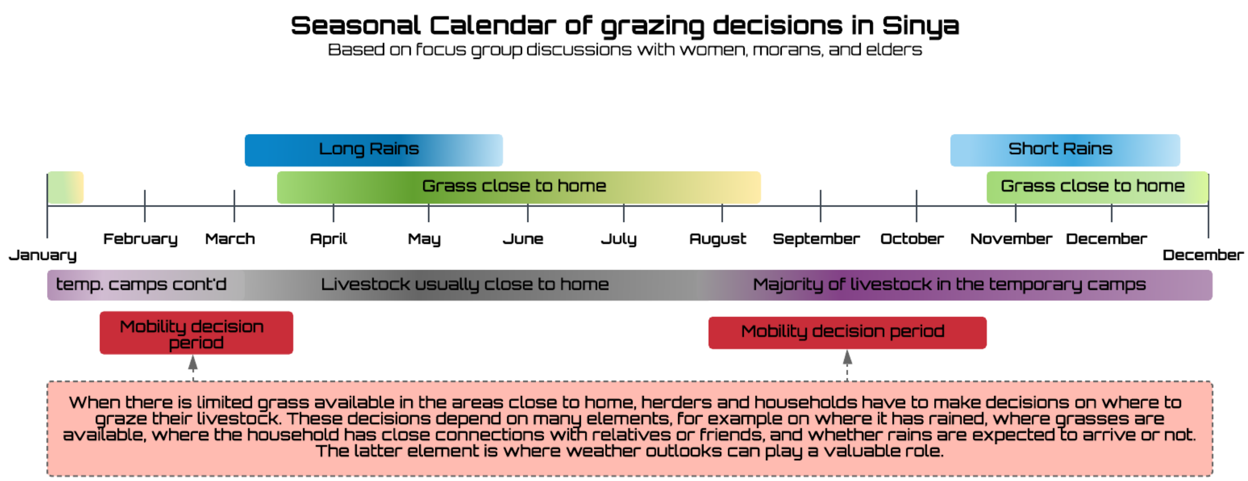

FIGURE 9 THIS SEASONAL CALENDAR PROVIDES AN OVERVIEW OF TIME PERIODS IN WHICH GRAZING DECISIONS ARE MADE, PARTICULARLY, WHERE TO MOVE TO WHEN GRASS AVAILABILITY CLOSE TO HOME IS LIMITED. THIS OVERVIEW IS CONSTRUCTED THROUGH FOCUS GROUP DISCUSSIONS WITH WOMEN, *MORANS*, AND ELDERS. IT RESEMBLES THE RAIN, GRASS, AND GRAZING SITUATION OVER A YEAR WHICH IS IDENTIFIED BY THE PARTICIPANTS AS ‘NORMAL’. THE SATURATION OF THE COLOUR INDICATES AN IMPRESSION ON THE QUANTITY OF THE ELEMENT. FOR EXAMPLE, THE DEEPER THE BLUE, THE MORE RAIN USUALLY FALLS IN THAT PERIOD.

However, not all families can afford moving far away with their livestock. As an elder describes: “The problem is manpower, some people may lack manpower. You might have two boys. One looks after the goats, the other looks after the cows. So, it is impossible for the one who is looking after the cows to stay at the temporary camp by himself, since it is difficult to manage by one person.” Other reasons for not deciding to move to a temporary camp is due to high risk of livestock becoming ill and due to having other responsibilities in the village, an argument used by most of the leaders with little manpower in the household.

For both these households with a small labour force, and for the households who are preparing to move further away, a strategy is to sell some livestock to buy food. The money is usually used for buying this food straight away and is usually not stored in, for instance, a bank. A traditional leader explains: "When you put money in the bank that is no protection. When I sell livestock, I buy everything that I want, I buy food for the children and food for the cows." Additionally, it should be noted that the closest bank is in Namanga, a town which is approximately 40km away in an area with no public transport. In 2017, as part of a governmental climate change adaptation project in collaboration with IIED, a storage house for food was built in Sinya. Ideally, households can decide to sell some livestock when there is no *alamei* and the food prices are low and store the bought food in this house for times of *alamei*. However, during the visit in August 2019, none of the key informants nor any of the focus group participants had stored any food there.

4.1.3. Local knowledge on weather predictions

In the focus groups and key-informant interviews, it became evident that especially some elders, have knowledge on predicting weather conditions and grass regrowth. The main indicators for these predictions are cloud and rainfall observations, wind strength and direction, positions of star constellations, and signs from animal observations. Table 5 provides an overview of these indicators and their corresponding signs of upcoming grass and weather conditions. Even though this knowledge exists, overall it can be concluded that currently, little of this knowledge is received or used by inhabitants of Sinya. This is supported by statements such as: "Only God can predict" and not believing information coming from "a person" rather from the "radio and tv", a medium which is only accessible to very few individuals in Sinya.

Table 5 Local knowledge in Sinya on weather information

Indicator	Signs
Clouds & rainfall observation	Since Sinya is located in a relatively flat landscape, cloud formations and rainfall can be observed over large distances. Inhabitants of Sinya use these observations to obtain an idea of where grass regrowth is highly likely. If rainfall occurs over the same area for several days, they may go there to see whether grass has indeed regrown and bring their livestock once they confirmed.
Wind strength and direction	An example of using the wind for weather predictions is described by one of the key informants. He explains that the long rains (Nov-Jan) usually come from the ocean and the short rains (Feb-May) from the south. In mid-October the winds usually change direction. He states that if this does not happen, the short rains will be late.
Position of star constellations	An example of using the position of star constellations as a weather indicator, is given by an elderly man who is often consulted on weather information. He says that: "It will rain this month [April], because in May and June, those stars [referring to a constellation which according to him looks like a group of houses in a circle] will go down, which means it won't rain again, but now they are up so it will rain." However, he shares that even though he can see whether the rain season or dry season is coming based on these stars, he cannot predict a large *alamei*.
Animal observations	"The elephants are the sign of the rain", one key informant states. Other animals which are often related to upcoming rainfall according to focus group participants and key informants are scorpions and frogs. Additionally, various signs in livestock behaviour are interpreted to indicate rains are coming. For example, whether a cow

	sleeps with stretched or bent legs, whether they give birth, or whether they excrete faeces at night.

4.1.4. Available information on (technical) weather forecasts

The Tanzania Meteorological Agency (TMA) provides daily, 10-day period, and seasonal weather outlooks on their website, which includes drought and rainfall information. However, due to the lack of smartphones and electricity in Sinya this information is only available for those few individuals with a radio or tv on which TMA provides weather forecasts. Additionally, the scale at which this information is provided is very large. Especially, for the 10-day period and longer-term forecasts, one small piece of information such as “above average rain is predicted in Kilimanjaro, Arusha, and northern Manyara regions”, is given for an area larger than 95,000 km^2. This is more than twice the size of the Netherlands and encompasses the largest mountain of the continent and the second largest mountain of Tanzania. This results in forecasts that often do not match the situation on the ground in Sinya.[6]

4.1.5. Valuable information for alamei management in Sinya

Based on the focus group discussions and the discussions of these results with various key informants, the following forecast information is identified as valuable for *alamei* management in Sinya (Table 6). It should be noted that there was much consensus on *what* information should be provided. However, *how* this information can best be communicated to ensure as many households as possible receive it in Sinya, has often led to longer discussions and little consensus.

Table 6 Valuable weather information and its communication

Type of weather information	The unanimous agreement is that it would be valuable to know when it will rain, where it will rain and how much it will rain. The latter is mainly valuable in order to estimate whether it will be enough for grasses to regrow. The participants indicated that grass regrowth usually takes several days (2-5) and requires the soil to be wet during this amount of days too. Therefore, this research will focus on predicting whether a 5-day cumulative rainfall threshold will *not* be exceeded for the grass to regrow. This is another way of forecasting whether the rain conditions will be poor enough to increase the likelihood of an *alamei*.
Area & scale	The districts in which herders from Sinya claim to have grazed their cattle in bad *alamei* years are presented in Figure 8. However, receiving one prediction over this whole area (as currently is the case with TMA) is not considered valuable. Therefore, the scale should be small enough for herders to know which area to monitor and who to contact. Receiving one prediction for the whole Enduimet Division, which covers an area of 1282 km^2 (Longido District Council, 2018), is for example considered good enough, as smaller areas within this location are reachable within a considerable time. Yet, it becomes important for the herders to know when it is *not* going to rain *enough* in Enduimet Division, to start preparing for moving further away.
Lead-time	The lead-time has been a debated topic in the focus groups as it depends on the grass availability, where it will rain, and what strategies should thus be applied.

[6] This conclusion is based on systematically comparing the forecasts with visual ground observations during the 4-month fieldwork period. Additionally, the weather information and ground situation was discussed daily with community members.

	However, eventually it has been agreed that *if the grass availability is low* and *if the rains are expected to come,* it would be good to know if these rains are not going to come, in which case preparation for the upcoming *alamei* may look slightly different. This is the case in for example February and March, when the rains in March and April are still expected to come but have not always provided enough precipitation. A lead time of one month would be sufficient for this.
Communication method	As mentioned, the method of communication of this weather information has been debatable. Originally ideas of communication through tv, radio and SMS came up in the discussions. However, only one key-informant has a tv and two participants have a radio. Since only a few individuals have a smartphone but every household has access to a regular mobile phone, SMS messages with weather information seemed a good option. However, numerous households do not have a member who can read. Maa is not a written language and most people in Sinya do not speak or have limited skills in Kiswahili. Therefore, some consensus was reached that a meeting or a phone call 'chain' in which weather information is spread, would be more suitable, since it matches the current methods of communication. However, who should start this chain of phone calls or who should spread the word in the meeting is again debated as no one wants to be the one who has spread information which turns out not to be true. Therefore, a project officer at an NGO proposed a group of volunteers who learn how to access the (improved) weather information and how to interpret and communicate it.

If such a dryer-than usual period described in Table 6 is forecasted, the participants indicated to be able to respond by taking the following actions: (1) selling livestock earlier and (2) planning where to move their cattle earlier. A leader shares that if the forecast is accurate enough, he will sell some cows when they are still fat and buy the food when it is not too expensive. Another leader says that if he would know a large *alamei* is coming, he would sell some livestock and use the money to invest in a house or something else. However, selling large numbers of livestock will, according to him, only be done if the forecast has a high accuracy. Moving livestock earlier is for most herders only an option if the grass availability close to home is very limited. As one elderly man shares "You cannot just move from home to anywhere. You will look like a crazy person. Because there are grasses here, why would you move?". However, a key informant argues that if a forecast is accurate enough, households will start to orient themselves earlier on the moving options.

4.1.6. ADVERSE IMPACTS AND PREDICTION UNCERTAINTY

"Even people I listen to are wrong sometimes, but you follow them the first time, and if it is wrong, you know not to follow them next time."

– Maasai leader

The quote above does not only emphasize the importance of clear communication and high accuracy of the predictions, it also touches upon a potential major adverse impact of these weather predictions. As mentioned in Table 6, none of the participants, nor leaders want to be responsible for providing a prediction which does not come true. They are worried for losing the trust of the community members. On this topic of uncertainty, a key informant states that "technology for weather forecasts has to be improved and refined, otherwise, it is a waste of time". He says that he does believe it can be valuable, but that most people in the area are very sceptical and thus will only act if they have faith in the predictions system.

However, even if the users have faith in the predictions, the potential adverse impacts should be considered when implementing such a system. A key informant shares that he used a 'grazing app' which was part of a project by a large international NGO. However, the app 'misled' him and he moved his cattle to an area where the app showed grasses were present according to him. These grasses turned out to be other vegetation, which was not edible, causing most of his cattle to die. Usually, a key part of the mobility strategy is scouting the area for grass before moving the livestock, however, in this case the informant relied on this new technology. The NGO explained that the app only shows 'greenness' and not 'grass', however, this was not known by the user. Though the NGO provides trainings on how to use the app, due to lack of funding, the trainings could not continue in this study area. This case study raises the question on whether receiving no information may be better than receiving information which is misunderstood. It touches upon the complexity of project implementation of new technologies and is further discussed in chapter 5.

4.2. MODEL SKILL

From the fieldwork the following weather forecast elements are identified and used for the model skill analysis: a forecast (1) in February and March (2) for the months March and April (3) over the Enduimet Division (4) on whether a grass regrowth threshold will *not* be exceeded (5) cumulatively over a period of 5 days (6) at any time in the selected month. Now that it has become more evident what type of weather information is considered valuable for household members in Sinya and what actions can be taken based on this information to improve *alamei* management (section 4.1.5), the challenge becomes predicting this information with enough accuracy. Below, the results are provided of the model skill determination analysis. In section 4.2.1, the results of the agreement between the NDVI data and the reanalysis data is provided. In the next section, section 4.2.2, the results are shared on the model bias correction which was required before determining the model skill. The final section, section 4.2.3, shows the resulting Receiver Operating Characteristic (ROC) curves from the bootstrapped, bias corrected, forecast and reanalysis data.

4.2.1. NDVI AND REANALYSIS DATA MATCHING

The NDVI and precipitation reanalysis data are plotted to obtain a rough impression on whether the reanalysis data provides some information of the ground situation. Overall Figure 10 shows many precipitation peaks corresponding to a peak in the NDVI. This is as expected assuming that the NDVI is mainly influenced by precipitation. However, since parts of the study area are in a flood plain, peaks in NDVI with low precipitation values can be explained by floodwater originating from other areas. Some small details can be observed such as a small amount of rainfall at the end of April and the beginning of May 2019, which led to a small increase in grass availability in the area as indicated by the participants during a revisit in August 2019. Occasionally the reanalysis data shows a rainfall peak while the NDVI does not increase. This can be due to factors which are not related to precipitation values such as grazing density and winds, but it could also indicate a mismatch between the reanalysis precipitation data and the actual precipitation. Therefore, this graph should be considered critically. However, overall, due to the high number of matching peaks between the two datasets and the identification of some known details, the reanalysis dataset is considered suitable for the scope of this research.

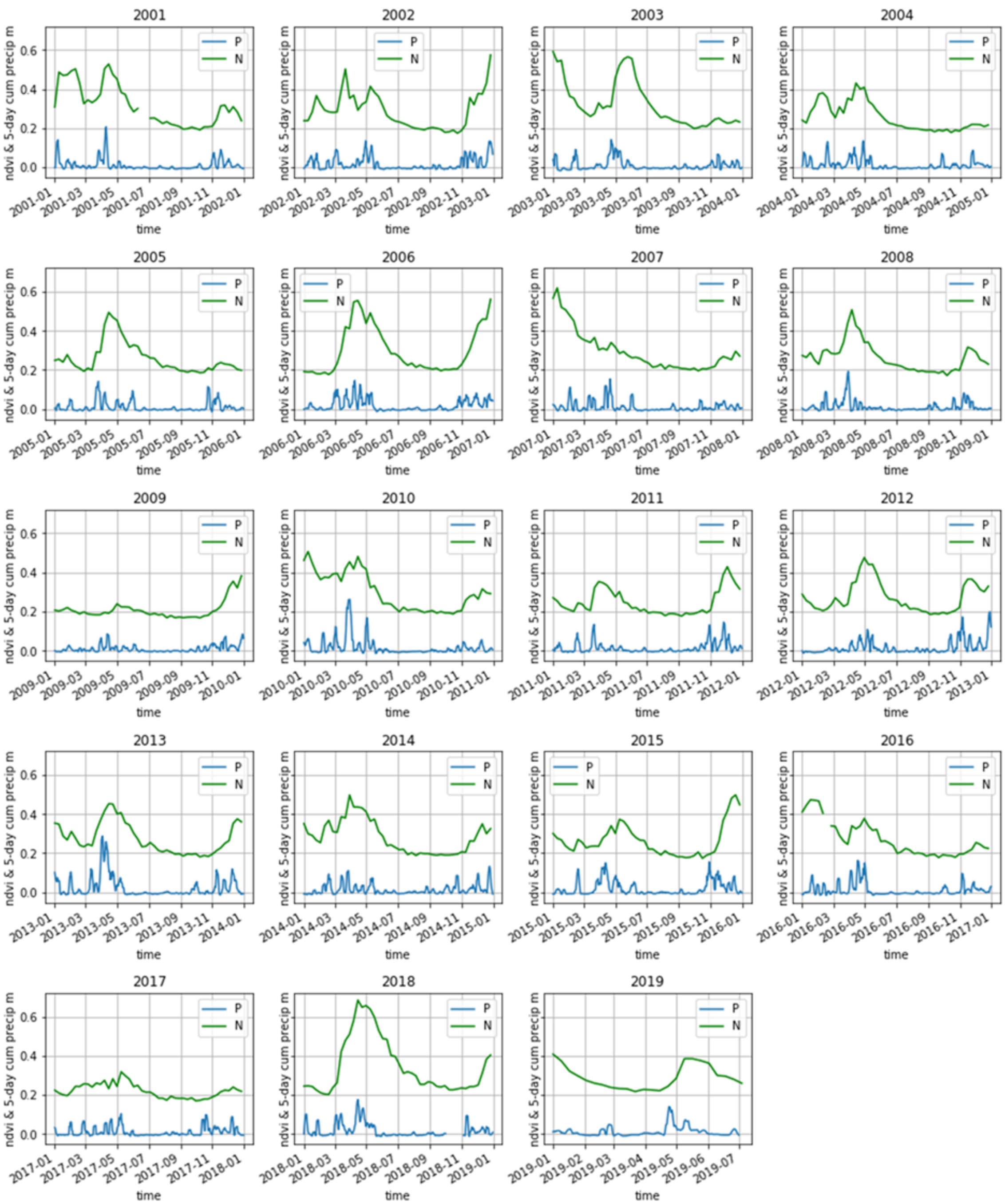

FIGURE 10 NDVI AND REANALYSIS DATA OVER TIME OVER THE STUDY AREA

4.2.2. BIAS CORRECTION

Figure 11 portrays the sorted values of forecast data and reanalysis data with their corresponding probability of occurrence for the months of March and April. It shows that the forecast data provides significantly lower rainfall values than the reanalysis data. Therefore, the bias in the forecast data is corrected with a quantile correction formula (as explained in chapter 3). An example of a resulting corrected forecast is provided in Figure 12. As expected, the 5-day cumulative precipitation values for the corrected forecast are higher than those of the original forecast.

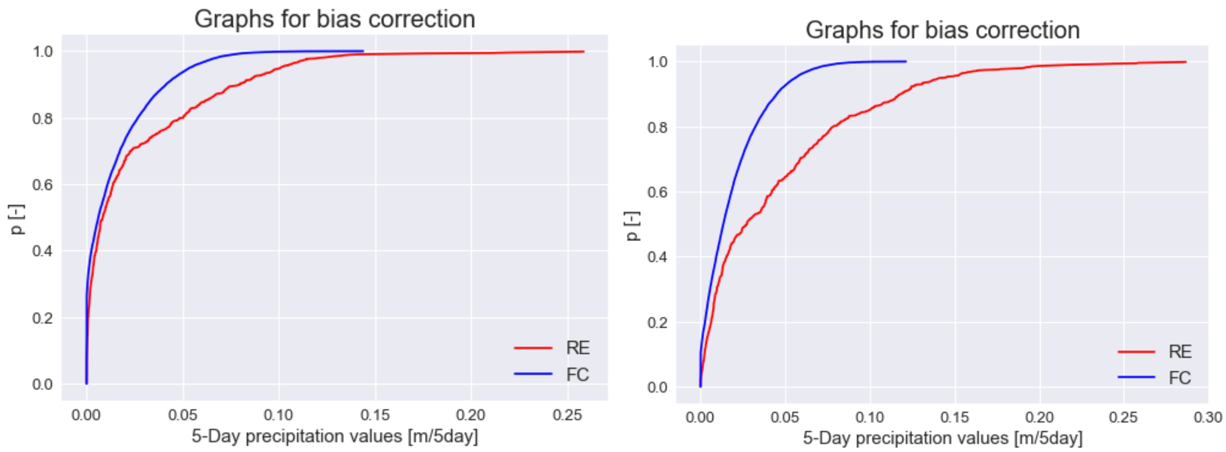

FIGURE 11 SORTED REANALYSIS (IN RED) AND FORECAST (IN BLUE) DATA WITH THEIR CORRESPONDING PROBABILITIES OF OCCURRENCE FOR THE YEARS 1993-2019 FOR THE MONTHS OF MARCH (LEFT) AND APRIL (RIGHT). THESE GRAPHS SHOW THAT THE FORECAST DATASET PROVIDES SIGNIFICANTLY LOWER RAINFALL VALUES THAN THE REANALYSIS DATA.

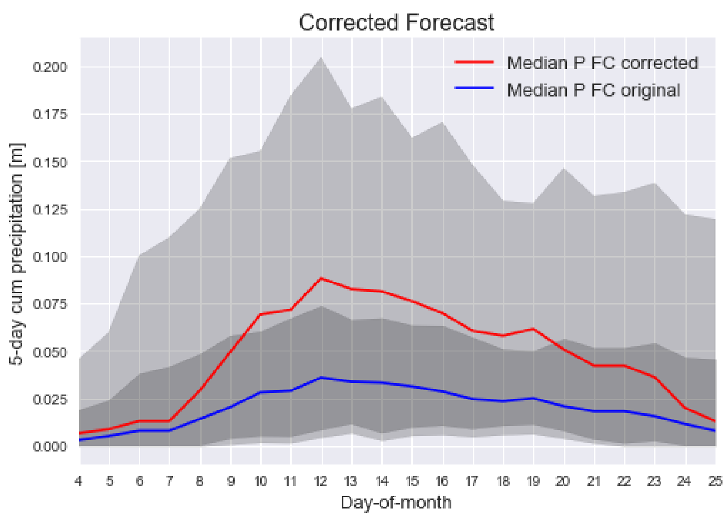

FIGURE 12 AN EXAMPLE OF A BIAS-CORRECTED FORECAST. THE RED LINE REPRESENTS THE MEDIAN OF ALL THE ENSEMBLE MEMBERS OF THE CORRECTED FORECAST AND THE BLUE LINE, THE MEDIAN OF THE ENSEMBLES OF THE ORIGINAL FORECAST DATA FOR THIS SPECIFIC MONTH OF THE FORECAST YEAR. THE GREY AREAS BEHIND THE GRAPHS SHOW THE 95TH AND 5TH PERCENTILE OF THE ENSEMBLE MEMBERS.

While the quantile-to-quantile mapping gives a clear overview of the bias in the datasets through a perspective of overall ‘over’ and ‘under’ prediction, a second approach is used to analyse the bias in these datasets. In this approach the 5-day cumulative precipitation forecast data is plotted directly against the 5-day cumulative precipitation reanalysis data. This analysis is a tool to assesses the bias on a point level, the bias difference between ensemble members, and this bias over time.

Figure 13 shows the relationship between one ensemble member plotted against the reanalysis data of one year. The R-squared value of the linear regression line is 0.88. This seems to indicate a clear bias. However, when plotting several other ensemble members, it becomes evident that the bias differs per ensemble member (Figure 14). It is recommended to conduct this analysis per ensemble member over time to see if there is a trend in the bias.

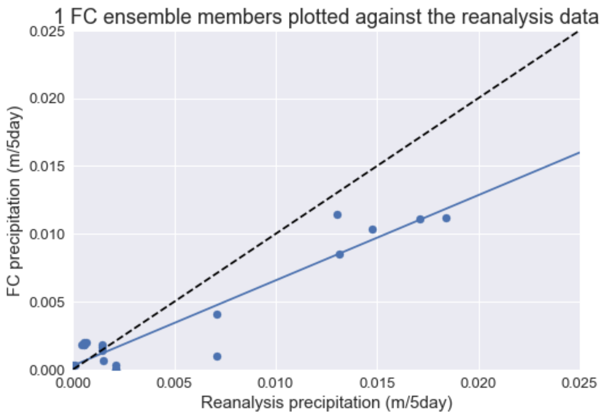

FIGURE 13 THE 5-DAY CUMULATIVE PRECIPITATION FORECAST DATA OF ONE ENSEMBLE MEMBER OF MARCH 1993, PLOTTED AGAINST THE 5-DAY CUMULATIVE PRECIPITATION REANALYSIS DATA OF MARCH 1993. THE BLUE LINE REPRESENTS THE LINEAR REGRESSION LINE, WITH AN R-SQUARED VALUE OF 0.88. THE BLACK DASHED LINE SHOWS THE LINE OF NO BIAS.

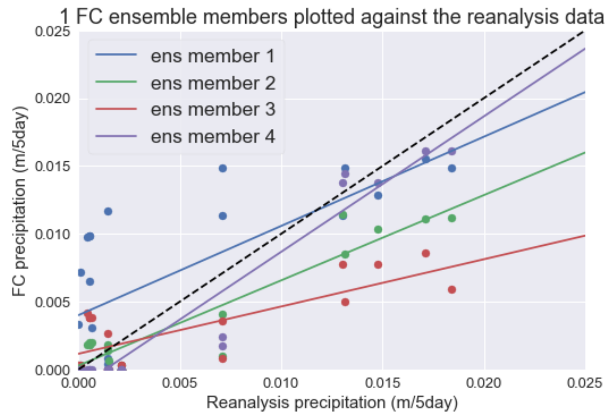

FIGURE 14 THE 5-DAY CUMULATIVE PRECIPITATION FORECAST DATA OF 4 DIFFERENT ENSEMBLE MEMBERS OF MARCH 1993, PLOTTED AGAINST THE 5-DAY CUMULATIVE PRECIPITATION REANALYSIS DATA OF MARCH 1993. THE COLOURED LINES REPRESENTS THE LINEAR REGRESSION LINES. THE BLACK DASHED LINE SHOWS THE LINE OF NO BIAS.

To understand whether there is a general yearly trend in the bias, all ensemble members are plotted for 4 different years against the 5-day cumulative precipitation reanalysis data (Figure 15). From this figure, no annual bias trend can be observed. However, it is recommended to perform this analysis for all 27 years to obtain a better impression. Figure 16 shows the density contour lines of these 4 years of reanalysis and forecast data plots. From both Figure 16 and Figure 15 it can be observed that in the lower values there is a bias towards higher forecasts data values and in the higher values there is a bias towards higher reanalysis values. This is in agreement with the bias graphs of the quantile-to-quantile mapping technique (Figure 11).

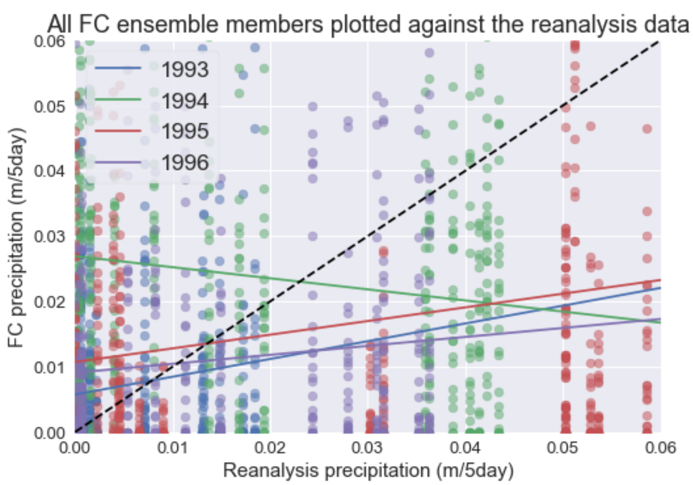

FIGURE 15 ALL 5-DAY CUMULATIVE PRECIPITATION FORECAST ENSEMBLE MEMBERS OF THE YEARS 1993-1996 PLOTTED AGAINST THE REANALYSIS DATA OF THOSE YEARS WITH THEIR CORRESPONDING LINEAR REGRESSION LINES. THE DASHED-BLACK LINE SHOWS THE LINE OF NO BIAS. NO CLEAR ANNUAL TREND CAN BE OBSERVED IN THE BIAS OVER THESE 4 YEARS.

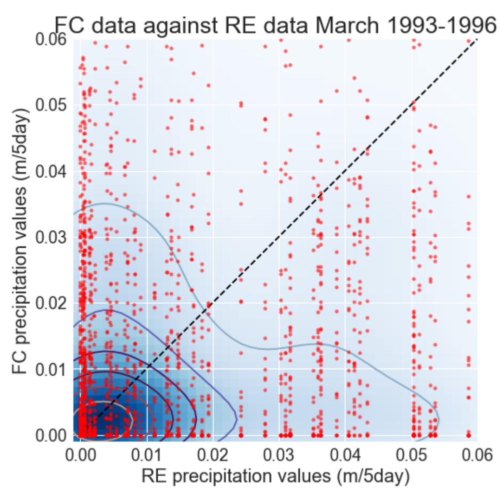

FIGURE 16 ALL 5-DAY CUMULATIVE PRECIPITATION FORECAST ENSEMBLE MEMBERS OF 1993-1996 PLOTTED AGAINST THE REANALYSIS DATA OF THOSE YEARS (RED DOTS) AND THEIR CORRESPONDING DENSITY CURVES (COLOURED LINES). THE DASHED BLACK LINE IS THE LINE OF NO BIAS.

4.2.3. Bootstrapping and ROC curves

A Receiver Operating Characteristic (ROC) curve is created for various rainfall thresholds. To obtain an understanding of the consistency of these curves, the false alarm rates and hit rates were bootstrapped for each threshold, according to the method explained in chapter 3. Figure 17 provides an example of such a ROC curve for the 5-day cumulative precipitation threshold of 0.08 meter for the month of March and 0.1m for April. As the most suitable value of the threshold is currently unknown, the thresholds in which events have occurred approximately as often as non-events have been used for this example. A lower threshold was taken for March compared to April since the precipitation values for March are slightly lower. For the results of other thresholds, see Annex VI - ROC curves per threshold for March and April.

The ROC curves and the corresponding density contour lines of Figure 17 are mainly above the dashed line, which represents the line in the graph where the forecasts are as likely to be correct as incorrect (see Chapter 3 for more information). This shows that the model has some skill of predicting in February whether the rainfall during March will never exceed 0.08m over a period of 5 days during the entire month. Additionally, it has some skill to predict in March whether 0.1m of rain will not fall over a period of 5 days during any moment in the month of April.

The skill for the March prediction is higher than the April prediction. This is concluded from the ROC score (the area under the curve) of which the score in March, 0.78 is higher than in April, 0.59. Additionally, most of the bootstrapped points for the April prediction are around the dashed-line of random forecasts and highly concentrated in the left-bottom corner which indicates no warnings occurred.

An example of a forecasting point is encircled in the March ROC-curve. The point indicates that out of six forecasts 1 is a false alarm and 5 are correct (hits). This specific point matches the situation in which a hit or false alarm is identified as such when 65% of the ensemble members predict the threshold will not be exceeded. Other points on the ROC curve resemble the hit- and FA-rate when for instance a larger number of ensemble members has to predict a threshold non-exceedance before it is called a hit (in which case the reanalysis agrees) or a false alarm (in which case the reanalysis does not agree).

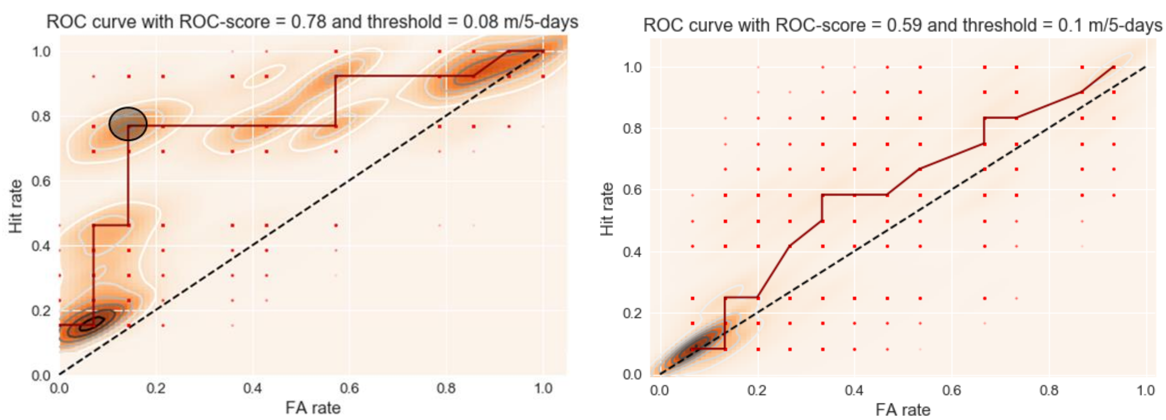

Figure 17 The ROC curve for non-exceedance of the 0.08m cumulative 5-day precipitation threshold for the month of March (left) and 0.1m for April (right). The black line indicates the 'random' forecast skill. If the ROC curve is on this line, the chance of a forecast being correct is 50/50. Anything below the line indicates that the forecast is more often incorrect than correct, and the curve above the graph shows that the model has some skill. In the background contour lines of the point density of the bootstrapped data are plotted. The darker the area within these contour lines, the higher the number of points within this area. The red dots show all the locations of the bootstrapped points. The circled area in the left graph is an example of where approximately 5 out of 6 forecasts are correct.

4.2.4. Computing the model skill for a larger scale

For a better understanding of the overall model skill and the influence of scale, two additional model skill analyses were conducted. For the first analysis, the reanalysis data over the study area was combined with the forecast dataset over a larger area. This analysis is conducted to assess whether the skill can be improved with a forecast which has a larger number of pixels, since the forecast data of the fieldwork area consists of only one pixel. The fieldwork area has a longitude of 36.7 by 37.4 and a latitude of -2.6 by -3 and the larger-scale forecast data has a longitude of 32.0 by 40.0 and a latitude of 0.0 by -6.0 (Figure 18). The resulting graphs for the bias correction and the ROC curve are provided respectively in Figure 19 and Figure 20.

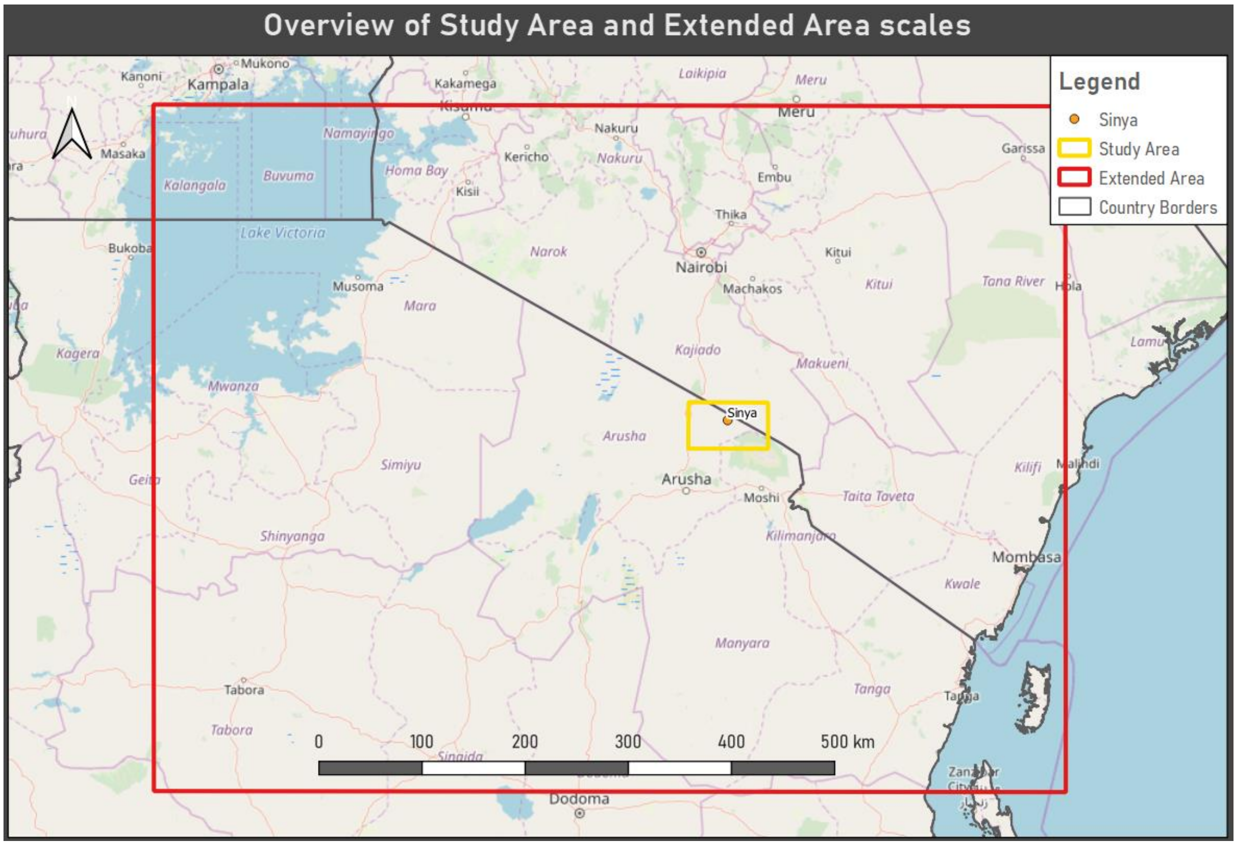

FIGURE 18 AN OVERVIEW OF THE SCALE OF THE STUDY AREA (LON 36.7 BY 37.4, LAT. -2.6 BY -3) AND THE EXTENDED AREA (LON 32.0 BY 40.0, LAT 0.0 BY -6.0) BACKGROUND MAP: © OPENSTREETMAP CONTRIBUTORS, CC-BY-SA

Figure 19 shows little difference in the sorted forecast values compared to the one-pixel values for the study area. A large difference is still observed between the reanalysis values and the forecast values of which the reanalysis values are significantly higher than the forecasted ones. However, the ROC curve for April of Figure 20 shows an improvement of which at the encircled point 3 out of 4 forecasts are correct, compared to the near random results of the analysis of the study area forecast data (Figure 17). The March forecasts continues to have a similar ROC-curve with a score of 0.78.

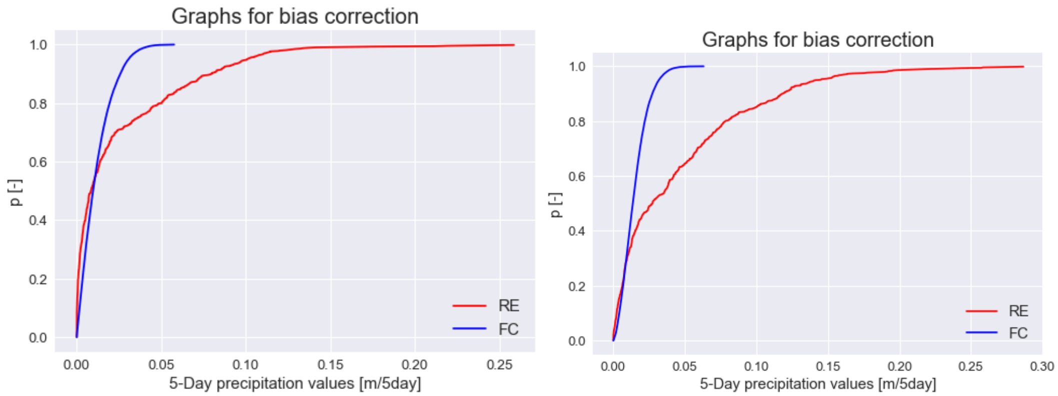

FIGURE 19 THE SORTED VALUES FOR THE EXTENDED AREA FORECASTS (IN BLUE) AND THE SORTED REANALYSIS VALUES OVER THE STUDY AREA (RED) FOR THE MONTHS OF MARCH (LEFT) AND APRIL (RIGHT). THE FORECAST DATA VALUES ARE EVEN LOWER OVER THE EXTENDED AREA COMPARED TO THE STUDY AREA, RESULTING IN A LARGER DIFFERENCE BETWEEN THE REANALYSIS DATA VALUES AND THE FORECAST DATA VALUES.

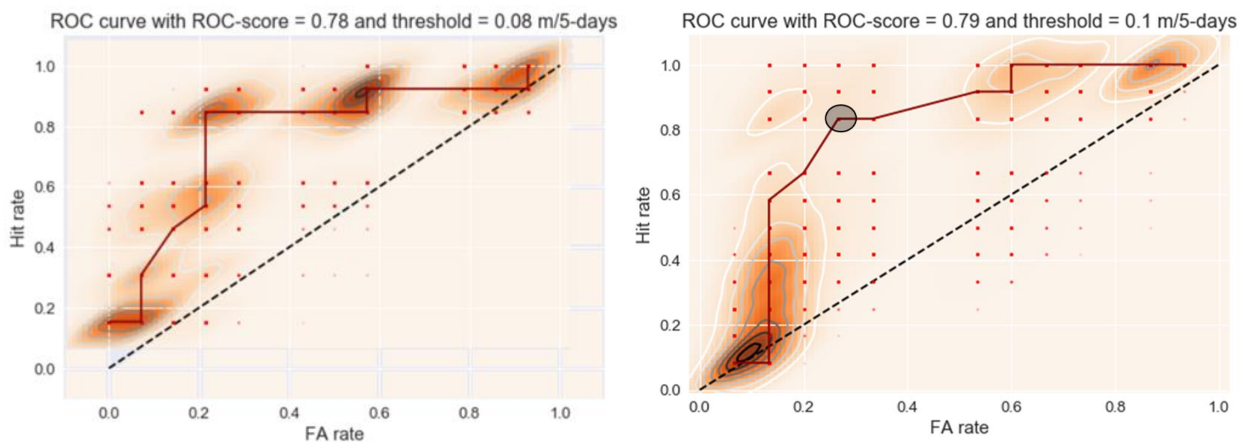

FIGURE 20 THE ROC CURVE FOR NON-EXCEEDANCE OF THE 0.08 M CUMULATIVE 5-DAY PRECIPITATION THRESHOLD FOR THE MONTH OF MARCH (LEFT) AND 0.1 M FOR APRIL (RIGHT). THE FORECAST DATA IS OVER AN EXTENDED AREA AND THE REANALYSIS DATA IS OF THE STUDY AREA. THE CIRCLED AREA IN THE RIGHT CURVE IS AN EXAMPLE OF WHERE APPROXIMATELY 3 OUT OF 4 FORECASTS ARE CORRECT.

In the second analysis, the larger-area forecasts data was combined with the reanalysis data of this same extended area. This analysis was conducted to assess whether the large difference between the forecasted precipitation values and the reanalysis precipitation values can be explained by the limited number of pixels. Additionally, this analysis gives a first indication on whether the model skill is highly scale dependent. The resulting graphs for the bias correction and the ROC curve are provided respectively in Figure 21 and Figure 22.

Figure 21 shows that the sorted values of the forecast data correspond well with the values of the reanalysis data. Since the values of the reanalysis data are lower than the values of this dataset over the study area, the model skill analysis of the thresholds used over the study area, do not prove useful. While for the first two analyses the reanalysis values reach almost up to 0.3 m/5-days, the values for the extended area barely exceed the 0.06m/5-days. This means that the threshold of 0.1m which was used in the previous analysis is never exceeded in this current analysis. Therefore, the model skill of this extended area is tested for a threshold of non-exceedance of 0.02 m/5-days for March and 0.03m/5-days for April (Figure 22). As for the previous analyses, the ROC curves for other thresholds can be found in Annex VI - ROC curves per threshold for March and April. In chapter 5 the causes and consequences of the difference between the high reanalysis values of the study area versus the low values of the extended area are discussed.

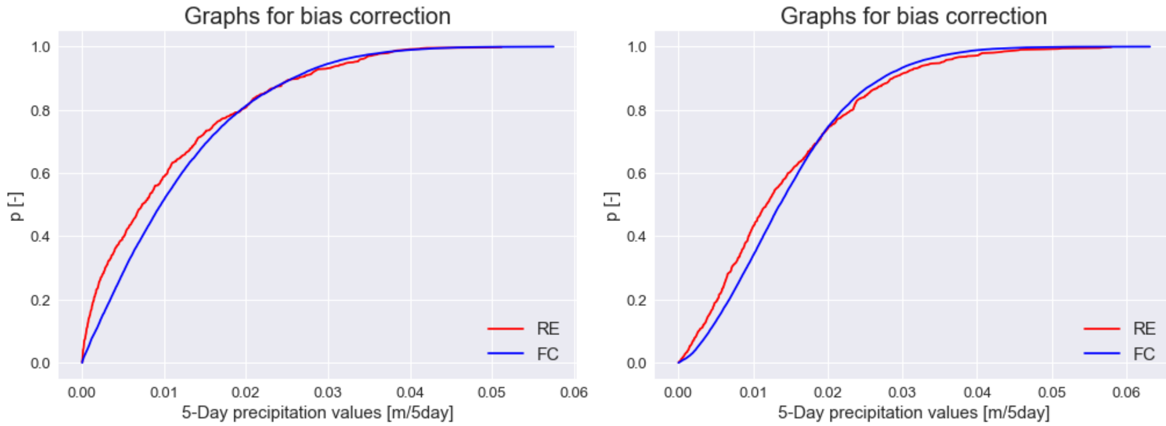

FIGURE 21 THE SORTED VALUES FOR THE EXTENDED AREA FORECASTS (IN BLUE) AND THE SORTED REANALYSIS VALUES OVER THE STUDY AREA (RED) FOR MARCH (LEFT) AND APRIL (RIGHT). THE FORECAST DATA VALUES AND REANALYSIS DATA VALUES OVER THE EXTENDED AREA ARE MORE IN AGREEANCE WITH EACH OTHER THAN IN THE PREVIOUS ANALYSES.

The ROC curve for March of Figure 22 shows a slight improvement compared to the ROC curves of Figure 17 and Figure 20. The ROC curve for April shows an increase in skill compared to Figure 17 and a similar skill as in Figure 20. It should be kept in mind that this prediction is of a different threshold and is over a much larger area. A correct prediction of such a large area, might not come true within the area of Sinya and thus make its direct use for the herders very limited.

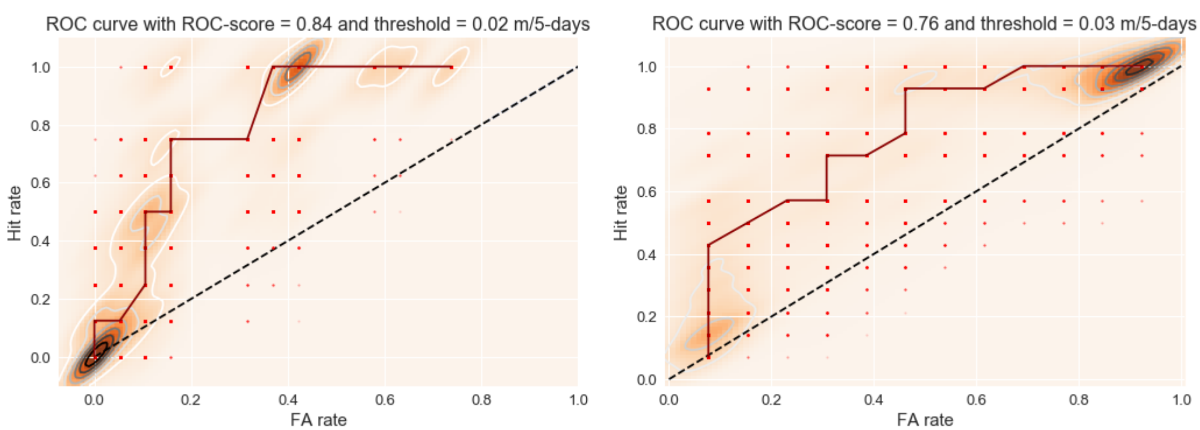

FIGURE 22 THE ROC CURVE FOR NON-EXCEEDANCE OF THE 0.02M CUMULATIVE 5-DAY PRECIPITATION THRESHOLD FOR THE MONTH OF MARCH (LEFT) AND 0.1 M FOR APRIL (RIGHT). BOTH THE FORECAST DATA AND THE REANALYSIS DATA ARE OVER A LARGER AREA THAN THE STUDY AREA.

5. DISCUSSION

Overall, receiving weather information on whether it is going to rain enough in the long rain season for the grasses to regrow, is considered valuable by the participants of this research in Sinya. However, predicting this information with enough skill has proved to be a challenge. These challenges and the corresponding recommendations are discussed below in section 5.1. Moreover, even if this information can be predicted with enough skill, there are many potential adverse impacts and vital implementation steps to consider before distributing this information. These impacts and considerations are discussed in section 5.2.

5.1. THE CHALLENGES OF THE MODEL SKILL

There are several challenges regarding the scale, the reanalysis dataset, and the threshold, which are used for this analysis. These are respectively discussed below in section 5.1.1, 5.1.2, and 5.1.3. In the last section, 5.1.4., the relationship between the model skill which is obtained in this research, and the overall model skill of the ECMWF forecasts is discussed.

5.1.1. Scale

For the fieldwork area, the forecast data only has the size of one pixel. This single pixel still proved to provide a relatively high model skill with a ROC score of 0.78 for the March forecast. However, the skill of April was much lower, with a score of 0.59. Extending the scale of the forecast, improved the model skill for April. However, in both situations and for both months the reanalysis data was too high over the fieldwork area. For example, the reanalysis data suggests that the cumulative precipitation in 5 days in April is throughout the month approximately equal to the amount of rainfall which falls in Longido over the entire month of April. This results in a bias correction of the forecast data to too high values, which makes the direct applicability of the model skill over the fieldwork area questionable. Additionally, the bias correction is purely empirical and should thus be checked on whether it is physically feasible.

When conducting the analysis over a larger area, better values for the reanalysis and forecast data were found. However, for this extended area the model skill decreased slightly for March to 0.67. More importantly, the extended area is too large for the specific information which the households in Sinya require. The small scale at which the weather information is required, forms a major challenge for such global models as ECMWF. It is recommended to consider other models which is further discussed in section 5.1.4.

Once a high enough skill of a small scale is achieved, the forecasts can be conducted for various areas surrounding Sinya. This will lead to estimations on where it will rain enough for grasses to regrow. This could complement information for herders on which areas to look into moving to. In doing so, it is recommended to include an analysis of contour maps with the average time and distance it takes herders to travel directly to these locations. These maps will assist decision making, especially for external parties who are less familiar with the livelihood strategies, for example to assess whether there will be a need for food aid.

However, this additional weather information may provide adverse impacts such as many herders moving to the same areas in which the grasses will consequentially be depleted faster. Nevertheless, within that assumption the adaptive capacity of these herders should be considered. Another adverse impact is that the negative consequences of a 'miss' prediction may grow. For example, if rain is predicted for an area and eventually does not arrive there, the herders may have travelled far to find nothing. Thus, once again, this information is only one part of the *alamei* management decision making. Local knowledge should continuedly be used, to mitigate such adverse impacts as much as possible.

5.1.2. REANALYSIS DATA

It is important to keep in mind that the precipitation reanalysis data is not a validated representation of the precipitation which actually fell in Sinya (see chapter 2 for more information on the formation of a reanalysis dataset). This means that the model skill analysis only provides the theoretical skill of the model and not the actual skill. For the computation of the actual skill, abundant ground data and preferably a nested model are required, which were both not available for this research. There are no weather stations in the study area, however, there are some national weather stations between 70 and 80 km away (Figure 23). It should be kept in mind that these stations may be in other climatic zones due to the presence of the two largest mountains of Tanzania (Kilimanjaro and Meru) close to the stations. Recently, as of 2017, the Trans-African HydroMeteorological Observatory (TAHMO) has installed two stations less than 40km away from Sinya, which may provide valuable input data for reanalysis verification (TAHMO, n.d.). Therefore, it is recommended that further research is conducted on validating the reanalysis dataset with relevant weather data from the suitable surrounding stations and ideally through ground truthing in Sinya too.

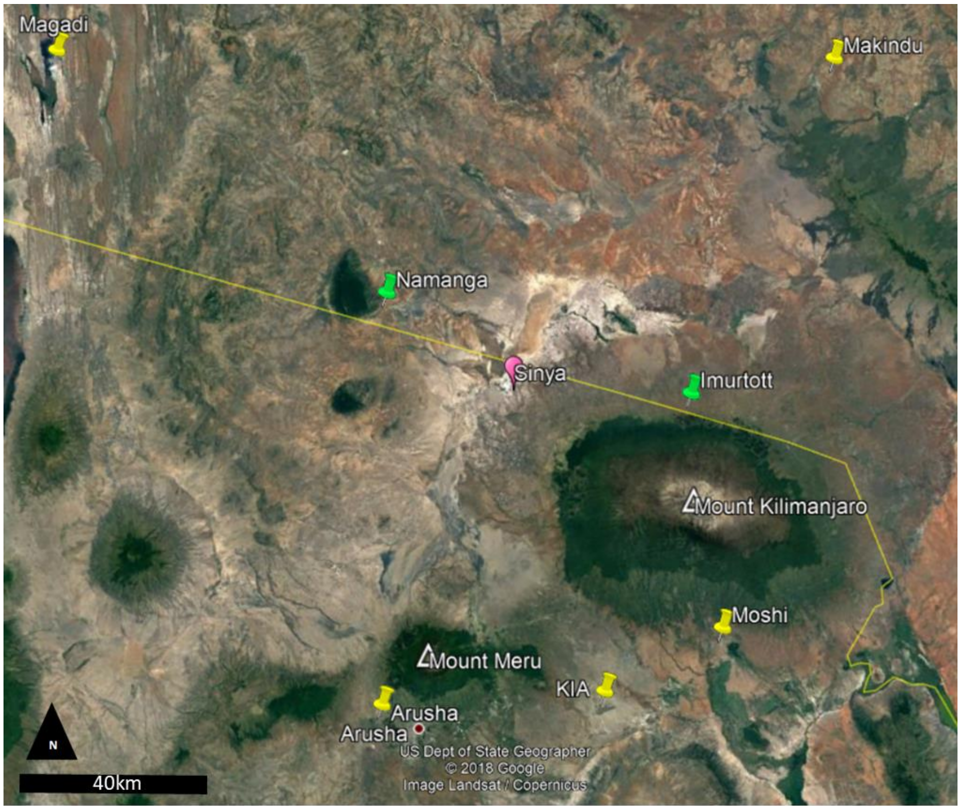

FIGURE 23 WEATHER STATIONS SURROUNDING SINYA. THE GREEN POINTS ARE WEATHER STATIONS BY TAHMO. (MAP FROM GOOGLE EARTH ENGINE)

5.1.3. UNKNOWN PRECIPITATION THRESHOLD FOR GRASS REGROWTH

In this research the model skill was determined for several thresholds (section 4.2.3 and Annex VI - ROC curves per threshold for March and April). However, when distributing this weather information, it is vital to obtain a better indication on what value for this rainfall threshold is the minimum required rainfall for enough grass regrowth. No values for grass regrowth precipitation thresholds in savanna ecosystems were found in literature during this research. According to (Nicholson, 2011) “the critical precipitation threshold […] varies as a result of differences in soil, nutrients, topography and runoff patterns” (p. 55). Therefore, obtaining a better impression of this threshold requires further research on the spatial variability of this threshold, which may result in a limited forecasts applicability to some areas within the fieldwork area. In addition to the potential spatial variability, grass regrowth depends on previous rainfall events (Nicholson, 2011). Therefore, further research should be conducted on the relationship between rainfall and grass regrowth. A suggestion is to include soil moisture as a variable, since it provides some information on environmental conditions prior to a rainfall event. Additionally, it gives a better understanding of the spatial distribution and intensity of rainfall events and may be a more accurate indicator for grass regrowth conditions. Finally, in addition to grass regrowth due to rainfall, the grass regrowth of some areas in Sinya is influenced by flooding. This adds yet another dimension to improving the predictability of grass regrowth in the area, which should be further researched.

On this topic, it is recommended to research whether there are other indicators which prove more predictable. Precipitation is a side-product of this model. This explains for example the numerical drizzle, a continuous precipitation signal, which is constantly present in the reanalysis and the larger-scale forecast data. If a direct model output such as wind strength and direction can be used to predict precipitation for the area, the accuracy may increase. However, the challenge with this is the often large scale of such variables. If the scale is too large, the forecast becomes impractical for the households in Sinya, as it often rains much more in areas around the study area, than in areas close to Sinya.

5.1.4. MODEL SKILL COMPARED TO GLOBAL ECMWF SKILL

The highest model skill over the fieldwork area resemble a ROC score of 0.78 (March) and 0.79 (April) and over the extended area 0.84 (March) and 0.76 (April). These scores are high compared to the global ROC score for the ECMWF monthly forecasts of below-average precipitation (Figure 24). Even when taking the spatial distribution of the ROC scores into account (Figure 25) the ROC scores of this study are high. However, it should be noted that the number of events which have occurred in this study are lower and that this research looks at a different, more specific variable. When bootstrapping the results, many of the ROC curves show a high point density in the outer areas of the graphs, representing the ‘always warning’ and ‘never warning’ situations (Annex VI - ROC curves per threshold for March and April). This is the case when the threshold is never exceeded as it is a high threshold (always warning, high point density in upper right corner), or when the threshold is always exceeded as it is a very low threshold (never warning, high point density in bottom left corner).

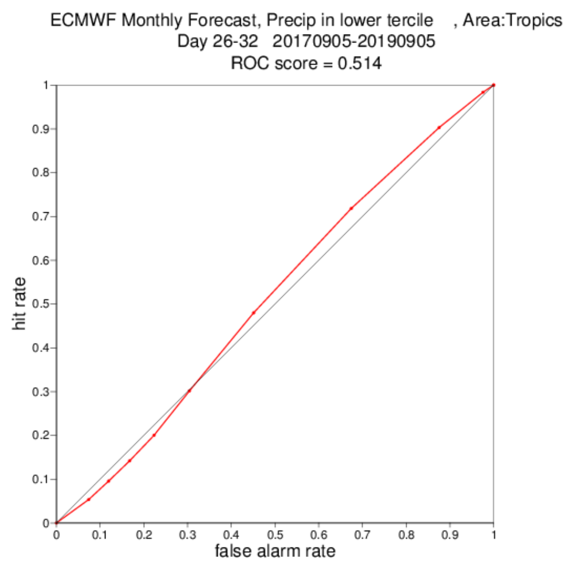

FIGURE 24 ROC CURVE FOR THE ECMWF MONTHLY FORECAST OF BELOW AVERAGE PRECIPITATION. THE PREDICTION IS MADE FOR PRECIPITATION UP TO A MONTH AHEAD (ECMWF, 2019)

It is recommended to test the skill of predicting the required weather information of different models, particularly those with a higher resolution as mount Kilimanjaro is bordering the study area. This includes testing the TMA model or other nested models for the area. Additionally, a multi-model approach can be tried or using the ERA5 land-dataset which is newly available since August 2019 and has a higher resolution. Moreover, it is recommended to assess whether assimilation of local weather observations improve the forecasts.

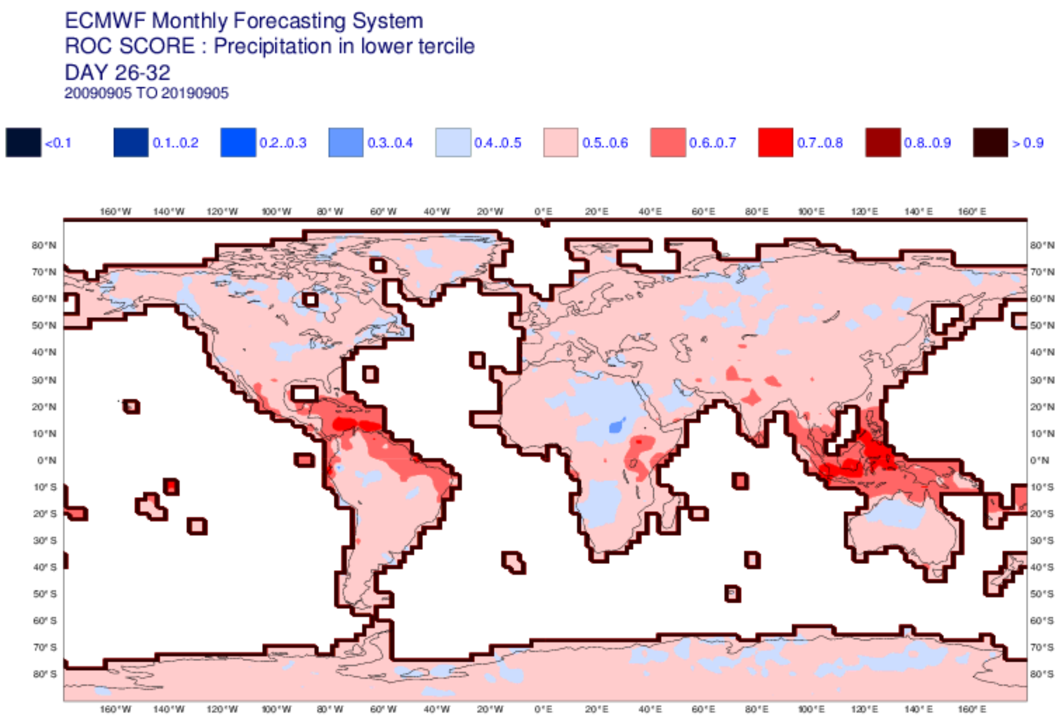

FIGURE 25 AN OVERVIEW OF THE SPATIAL DISTRIBUTION OF THE ROC SCORES FOR PREDICTING BELOW-AVERAGE PRECIPITATION UP TO A MONTH AHEAD. (ECMWF, 2019)

5.2. ADVERSE IMPACTS AND IMPLEMENTATION CONSIDERATIONS

Similar to the drought outlook systems (chapter 2), providing drought related weather predictions for *alamei* management, goes further than achieving a satisfactory model skill. Even if the model skill can be improved, several considerations should be made and adverse impacts should be kept in mind, when distributing this information. In section 5.2.1, recommendations and adverse impacts are discussed regarding the distribution of the weather information. In section 5.2.2 some final discussion points and recommendations are provided on the complexity of decision making within this topic.

5.2.1. IMPLEMENTATION RECOMMENDATIONS

Throughout this study it became evident that, at times, technological idealization or unclear communication of technological limitations, has led to the adaptation of technological 'solutions' as leading tool, which increased the adverse impacts. Therefore, how these technologies are used, should be considered carefully. With all the positive rhetoric and discourses surrounding new technology, the adverse impacts of adopting these new technologies are all too often ignored in much development policy and practice. *Alamei* management is a complex process which depends on many factors. Grass availability and depletion rates are examples of such factors, and the role of precipitation within grass regrowth is again an element of the grass availability and depletion rates. In such a complex system an outlook on precipitation should never be used as the only factor within *alamei* management decision making. The current strategies, social networks, and local knowledge should therefore be appreciated, and the *alamei*-related forecasts should thus be clearly communicated as one element of this complex decision-making system.

Within the careful consideration of the use of these weather predictions, several questions should be asked: When is the skill high enough; Who decides this; What happens when it turns out to be a false alarm; What happens when abundant rainfall is forecasted but does not occur? These are not questions that can be answered in this research, neither by scientists themselves. It is vital to include community members, key decision makers, and knowledgeable informants from the area in these discussions. In a group with these people and scientists, the adverse impacts and the potential consequences of the information distribution can be discussed thoroughly. As such, decisions can be made on when and how to communicate the forecasts. This process contributes to well-informed and well-thought through decisions by the people who are aimed to benefit from the weather information.

5.2.2. THE COMPLEXITY OF DECISIONS AND INDIVIDUALS

Decisions are made for a reason and may differ significantly per individual. In decision-based forecasting these points should continuously be kept in mind. For example, people have a reason not to sell livestock. Therefore, it is likely that in 'good conditions' it is more profitable to have livestock then to sell it. This means that if people sell their livestock due to a forecast of below-threshold rainfall and the rainfall actually does provide sufficient, this may lead to negative consequences for the household who sold more livestock than they usually would. However, what these adverse impacts are and whether they can be prevented is currently unclear. It is recommended to conduct more research on the reasons of why households do not continuously decide to take the actions which they would take if they know a bad *alamei* is coming. For instance, why do people only sell a limited amount of livestock; and what are the disadvantages of selling livestock? These, elements should be considered to avoid significant harm to the households who have, for example, sold much livestock when the prediction turned out to be a false alarm.

In this research, the inclusion of a large diversity of voices was a priority. However, to come to a wholesome conclusion on what weather information to predict, some of these voices may have been lost or generalized. Though the goal of spreading *alamei*-related weather information is to provide valuable predictions to contribute to *alamei* management for as many people as possible, it should not be forgotten that decision making and *alamei* management by individuals, groups, and communities are dynamic processes and can differ between individuals and groups. Therefore, feedback from a diverse number of voices over time remains essential to ensure the weather information continues to be relevant for the users.

Finally, it should be noted that this research has focused only on one key decision juncture in *alamei* management. If the provision of *alamei*-related weather information proves successful, it would be valuable to look into the second decision juncture (chapter 4.1.2), where potentially different weather information is considered useful.

6. CONCLUSIONS & RECOMMENDATIONS

From the fieldwork the following conclusions can be drawn. Firstly, the *alamei* management strategies differ between households and are not completely generalizable. The major factor which influences these differences is the availability of labour power to look after the cattle when they stay far away from home. However, for all the households who took part in this research, transhumance and selling some livestock to buy food, are the most prominent strategies in times of *alamei*. The decisions on moving and selling are influenced largely by grass availability, expected grass depletion rates and expected rains. However, these rains do not always arrive according to these expectations and the patterns have been highly unpredictable. Therefore, when the grasses are limited, and a decision on moving and selling needs to be made, it is considered valuable to receive a prediction on whether these rains will come and provide enough precipitation for the grasses to regrow. Though local knowledge exists on weather predictions, the ones who have this knowledge are often hesitant to share it and cannot predict with enough certainty to encourage action. Weather information from other sources such as the Tanzanian Meteorological Agency, do not provide the required information at a small enough scale. The forecasts are often incorrect for Sinya and, when available, the information is not received due to lack of internet, tv's and radios.

These findings resulted in the idea to provide *alamei*-related weather information during key decision junctures. This research is complementary to a lager system of *alamei* drivers and of knowledges on *alamei* management in Sinya. This study focusses on one specific decision juncture prior to the long rains in March and April. A second important decision period is between August and October, before the short rains in November and December. It is recommended to use a similar methodology as in this research to assess together with community members of Sinya, what type of weather information is valuable for this second decision period. For the first decision period two types of forecast information were considered important: (1) whether the expected long rains in March and April are predicted to arrive and (2) if predicted, will the rains provide enough precipitation for the grasses to regrow over an area the size of Enduimet Division (1282 km^2), which encompasses Sinya's core grazing areas. This can best be communicated through a group of trained volunteers through a meeting or a phone call chain, who learn how to communicate this information so that the uncertainties become clear.

The research analysed the skill of the ECMWF model to forecast the above dimensions. Though the forecasting skill of March was relatively high (ROC-score of 0.78), the skill of April over the fieldwork area was poor (0.59). A higher skill for April was found for using forecasts over a larger area (0.79). However, in both situations the reanalysis data provided too high values. Therefore, to ensure these forecasts are applicable in Sinya, it becomes vital to validate and correct the reanalysis values with ground values to ensure the forecast bias can be corrected using a trustworthy dataset. To improve the bias correction even further, an analysis should be conducted on whether the bias changes over time. This can be performed by plotting the forecast data against the reanalysis data as shown in the research. For an extended area, both the model skill and the reanalysis data values were relatively good (0.84 for March and 0.76 for April). However, this scale is too large to be applicable to *alamei* management strategies by the households in Sinya. In this extended area, different ecosystems and several large mountains are located. Obtaining one forecast over such a vast and diverse area thus gives very little information on what can be expected in Sinya.

It is recommended to use other weather models, amongst which the model which TMA uses, to assess whether a model exists which can predict the required information with enough skill. Moreover, it is recommended to look for models with a higher resolution, particularly because two high mountains (e.g. Kilimanjaro and Meru) are bordering the study area. Next, it is recommended to assess whether assimilation of local weather observations improve the forecasts. Additionally, it is recommended to research whether other variable which are easier to predict, can prove of similar use for the Maasai communities in Longido. For example, research can be conducted on grass dynamics to assess whether a predictable component can be identified. Another example is researching whether a variable, such as windspeed or wind direction, is easier to predict and can prove to be a strong indicator for high amounts of rainfall. However, for this to be useful for the households in Sinya, the scale has to be small enough and the amount of rainfall needs to be communicated in terms of 'enough for sufficient grass regrowth' or 'not enough for sufficient grass regrowth'.

Even if this information can be predicted with some skill, several important discussion points remain. First of all, the reanalysis dataset does not guarantee that it represents the actual situation on the ground. Therefore, before implementing anything, this dataset should be verified with ground truth data of Sinya and/or with data from surrounding weather stations. Another important thing to consider is that, currently, the precipitation threshold for grass regrowth in the area is unknown (e.g. how much rain is actually required over what time and space to ensure regrowth). Further research is required on this threshold and other potential factors which may play a role in grass regrowth. Finally, the role and adverse impacts of sharing this type of forecast information should be discussed with people from the study area, who have knowledge on the complexity of such information provision. This information is only one part of the complex system of managing *alamei* in Sinya and should therefore be treated and communicated as such. Too-often, as learned through this study, the adverse effects and limitations of such information is not given due consideration in development policy and practice.

From a larger perspective, the approach of this study can be applied to many different researches, whether it be in pastoral areas or elsewhere. The combination of ethnographic research with meteorological modelling can be valuable to other studies within for example climate change adaptation and mitigation fields. The end users, namely the community members, have a continuous voice throughout the process. They are the ones who explain what information is already there, what new information could potentially contribute, how this should be circulated, and what the adverse impacts may be. The technical angle, which is taken in the model assessment, provides an understanding on how realistic these ideas are and what needs to be adapted to make it more realistic. Additionally, this technical angle identifies the limitations which can then be discussed with the community members again. The feedback of the community can then improve the model use and the application in the targeted area. This circular process in which the community is continuously contributing, is vital to the success of the application of these technologies.

Reflecting on this research, it is one step in many to come. It is a step towards working with complexity and context specific weather information provision in remote pastoral areas. This research explores the opportunities and challenges of the contribution which technologies can provide to existing knowledges and strategies, to increase the chances of it being actually valuable for those who are expected to use it and to whom it may be a powerful addition to their livelihood strategies in a time of changing climate.

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APPENDIX

ANNEX I - INTERVIEW GUIDE

This annex provides an example of an interview guide which was used in an early stage of the research. The interview was conducted with a traditional leader.

General *alamei* info:

1. When was the last big *alamei*?
2. Which areas were affected? (e.g. how far did it reach)
3. What was the main cause & issue of those *alamei's*? (e.g. no rain, no water, no grass, herders from other areas coming in, disease)

***Alamei* prediction**

1. Do villagers in Sinya receive weather info?
   a. How, what, when, by whom?
   b. What scale?
   c. How access?
   d. What lead-time?
   e. How is it communicated?
2. If not,
   a. Do you have any ideas of how to communicate such information?
   b. Do you think it will be useful for households? (in *alamei* management?)
      i. What will households do to prepare?
   c. Do you foresee any adverse impacts on distributing such information?

Current *Alamei* Strategies

1. What do you do as traditional leader to prepare the community for an *alamei*?
   a. How do you decide when to open grass reserves?
2. What do you do as leader in times of *alamei*?
3. Are there parties which provide services to minimize the impact?
4. Are there any companies/organizations which monitor/predict water & grass availability?

Outlook System Role

1. If you (as a leader) know that there is a high likelihood that a big *alamei* is coming, what could you (as a leader) do to decrease its impact?
   a. What information & at what scale would you need to know, to achieve that?
   b. How much time would you need to prepare?
   c. According to you, to whom should this information be communicated? And in what way? (meeting, texting, etc.)
   d. Would you still take preventative *alamei* measures, even if it is a highly uncertain outlook?

ANNEX II - SEASONAL-OUTLOOK GAME

This annex explains the seasonal outlook game method of chapter 3.1.2. The seasonal outlook game used in this research (aka. The "*maharage* game" as called by some of the *moran* participants), is an adaptation of the Seasonal Forecast Game from the Red Cross Climate Centre (see https://www.climatecentre.org/resources-games/games/24/seasonal-forecast-game for more information). The main goal is to obtain a better understanding of how the participants respond to uncertain weather forecasts, and specifically to open up the discussion on the topic of using weather forecasts and their uncertainties.

Materials

- Half a kilo of uncooked beans (*maharage*)
- 20 blank cards
- A marker pen
- A piece of paper to keep the score
- 1 bag

Set-up

Each player is handed-out five uncooked beans (*maharage* in Kiswahili). These beans represent their livestock. The 'bank' has the remaining beans. On the cards, symbols are drawn to represent weather conditions. This can be filled out as the facilitator likes, depending of the objective of the research. For this research on 8 cards the symbols for "*kwa kawaida*" were drawn, which means "as usual" in Kiswahili and represents a "normal" season. 4 cards got a symbol representing a wetter season than usual, 4 a dryer season than usual and 2 an "*alamei sapuk*" (heavy drought). It is ensured prior to the start of the game that all participants recognize these symbols.

Rounds

The total duration of the game and discussion is between 1 to 1.5 hours. The game consists of several rounds. The number of rounds depends on the time available, how much time the participants take to make decisions, and how much time for discussion is desired in the end. During this research the number of rounds was determined along the way and were usually between 6 and 10.

- A round starts with the recording of all the capitals/beans. In the first round all participants have their beans in the form of "livestock".
- Next 10 cards are selected by the facilitator to represent the weather forecast. E.g. if 8 "normal" cards are selected 1 "rain" card and 1 "sun" card it means that the forecast states 80% chance of a "normal" season (for example dry season), 10% chance of a wetter dry season and 10% chance of a dryer dry season than usual. The cards are all shown and explained to the participants and put into the bag.

- Now, all participants need to decide whether they want to sell a bean (livestock) or keep it. If they decide to sell it, the money goes to the bank[7]. The bank/facilitator records this.
- Next, a volunteer from the participants picks a card from the bag without looking. This card represents the actual weather conditions of the season.
- The selected card determines what happens next.
  - If it is a wetter dry season than usual, the livestock at home is "happy" and "fat" and reproduces. This means that all the beans which the participants do not have on the bank are doubled. With the beans on the bank nothing happens.
  - If it is a dryer dry season than usual, one bean on the bank is spent on food/water for the livestock and leaves the game. If the participant has no beans on the bank, one animal (bean) dies, which means one of their livestock beans leaves the game.
  - If the season is an *alamei sapuk*, per livestock bean to save, one bean is used from the bank to pay for the food. For all the livestock beans of which there is no money bean on the bank, the livestock bean dies (leaves the game). If there is more money on the bank than livestock, the left-over money remains on the bank. For example:
    - One participant has 5 beans as livestock and 4 beans on the bank. The 4 beans on the bank are used to support 4 livestock beans and the remaining livestock bean 'dies'. The participant remains with 4 livestock beans and no money on the bank.
    - One participant has 1 livestock bean at home and 4 on the bank. He/she hands in one bean from the bank to buy food for that one livestock bean. The participant remains with 1 livestock bean and 3 beans on the bank.
  - If the season is a normal season, nothing happens.
- At the end of the round the new division of capital (beans) is recorded and a new combination of cards (weather forecast) is shown and put in the bag to start the next round. After the cards are put in the bag, but prior to the selection of the actual weather forecast, the participants can decide to buy livestock beans back from the bank or put more money beans on the bank.

End

The game ends when the facilitator decides it is time to move into the discussion. Prior to that the last two rounds are announced, to ensure the participants can adapt their decisions on it if they wish. If a participant runs out of beans, the facilitator may decide to provide "posho", support from the government, for example, and hand one bean to all participants to ensure the participant without beans can continue to participate.

Discussion

Some examples of discussion points which have been used in this research are:

- Is a weather forecast still useful, even though it is uncertain?
- Would you adapt your livestock management strategies, based on such weather forecasts?
  - Why? Why not? How?
- How should these uncertainties be communicated?

[7] Originally the game was set up as selling the livestock and buying food, based on one of the current *alamei* management strategies, but after a woman in one of the first games said she did not want to buy food but put the money on the bank, and the other women agreed with her, the game was adjusted. Interestingly, some of the participants in the remaining games (with the elders and the *morans*) emphasized how good idea they thought it was to put money on the bank. It should be noticed that this research concluded, that though the idea is supported, in practice very few people put money on the bank.

Comments and Recommendation

Obviously, this is a very simplified version of reality. In practice, people have many different strategies besides selling or not selling and passively waiting for livestock to die if they cannot buy food. However, this game is constructed to open up the discussion of uncertainty in weather forecasts and the role of weather forecasts in decision making in general.

An interesting addition to this game is to provide different type of beans to represent cows, goats, sheep, and donkeys. This would provide a more in-depth understanding on the role of livestock-types on the decisions.

ANNEX III - SEASONAL CALENDAR

This annex explains what the seasonal calendar method of chapter 3.1.2 entails. The seasonal calendar is created looking at three themes: Grass dynamics, rainfall dynamics and moving patterns of the herders to the temporary camps. These themes are described below.

Grass & Rainfall dynamics

The seasonal pattern of grass and rainfall are visualized by the participants in a line-graph. The x-axis of this graph represents the months, and the y-axis represents the amount e.g. maximum amount in the top of the axis, minimum amount in the origin. The discussion starts with visualizing a "normal" year. The creation of this graph roughly follows the following steps. Every step includes probing and a further discussion about the topic of that step.

1. First, the month(s) is identified in which it usually rains the most. It is verified whether this maximum rainfall occurs during the entire month or only for example in the beginning/end. A line is drawn horizontally at the top of the y-axis along the part of the x-axis which represents the indicated month.
2. Next, the month(s) is identified in which it usually does not rain at all. A line is drawn horizontally at the bottom of the y-axis, along the corresponding month(s).
3. Then the discussion goes month by month on whether it usually receives more or less rain than the month before/after and where the line should be drawn in the graph.
4. Step 1 up to including 3 are repeated for the grass availability.
5. Then, the discussion moves to the current situation. How much rain fell this year and when? This line is sketched in the graph too.
6. With this, the grass availability of the current year is discussed.

Moving pattern

To obtain a better understanding of the *alamei* management strategy of moving, the graphs of grass and rainfall dynamics are used to discuss the timing of moving with the cows away from home to stay in temporary camps. This movement occurs every year and is vital to livestock survival. The discussion on this topic is organized in the following way.

1. Two rows are drawn underneath the rainfall and grass availability graphs. One row represents cows coming home to the permanent home at night, the other row represents their presence at night in a temporary camp (or with relatives).
2. The location of the majority of the cows are marked in the corresponding row throughout the months of a normal year.
3. Next the current year is discussed. Where are the cows of the participants household now? And since when have they been there?

Finally, the discussion touches upon motivations of having the cows at home, or in a temporary camp. The participants are asked to come up with motivations in favour and against moving/staying at home.

ANNEX IV - PYTHON SCRIPT

This annex provides the python script which was used to determine the model skill of which the method is described in chapter 3.2 and the results are provided in chapter 4.2. Click on the image below to open the link to the python script.

Thesis_Esmee_Mulder

October 20, 2019

1 Script Thesis - Droughts and Decisions

NDVI & Precipitation plots and the ROC Diagram

1.1 Index

- Section 1.2
- Section 1.3
- Section 1.4
- Section 1.5
- Section 1.6
- Section 1.7
- Section 1.8
- Section 1.9

1.2 Import tools and Data

[1]:
```
%matplotlib inline
from netCDF4 import Dataset
import netCDF4
import xarray as xr
import numpy as np
import matplotlib.pyplot as plt
import glob, os
import regionmask
import rasterio
import fiona
from shapely.geometry import Polygon, MultiPolygon, shape, mapping
import datetime as dt
from datetime import date
import pandas as pd
from pandas import DataFrame
from scipy import stats
from sklearn.metrics import auc
import seaborn as sns
import scipy.interpolate as intp
```

1

https://github.com/e-mulder/Thesis_E_Mulder

ANNEX V – FIELDWORK REPORT

This Annex provides a detailed report on the fieldwork results. A summary of this report is presented in Chapter 4.1 of the main research report. This fieldwork report is structured as followed. First, the findings on the context are described (section 1). Next, in section 2 the results on the availability and content of weather information are discussed. In section 3 the *alamei* management strategies are shared. This section is followed by section 4 on decision making and the seasonal calendar. In section 5, a case study is shared of the *alamei* management strategies of one family which has been revisited over a period of 6 months. Next, in section 6 the findings are presented on the required weather information, and finally, in section 7 the feedback of the participants on these findings is discussed.

1. UNDERSTANDING THE CONTEXT

To understand how and what type of weather information can contribute to the *alamei*[8] management strategies of the Maasai in Sinya, a common understanding of the concept of drought, or *alamei*, should be obtained (section 1.1). Next, the context should be understood in which these forecasts would operate. Therefore, section 1.2 continues with a short overview of the water resources in the area and an explanation of the process of grass regrowth. Finally, section 1.3 is on what major recent *alamei's* have occurred in Sinya, what the impacts were, and what the current alamei looks like.

1.1. DEFINITION OF DROUGHT AND ALAMEI

Similar as to what (Goldman et al., 2016) found, the Kiswahili word for drought, *ukame*, often refers to dry season too. Likewise, the word for drought in Maa[9], *alamei*, is used both for drought and for dry season. The addition of the word *sapuk*, changes the meaning to a big alamei, a very dry dry-season, or drought as often referred to in English. However, in the focus group discussions and key informant interviews it became evident that the word *alamei* goes further than drought or dry season. As a young educated Maasai women described "Alamei is the time of suffering, lack of food" it is "dead time". In another key informant interview *alamei* was translated as "being hungry".

One key informant explained the concept in detail. He started by saying that if there are not enough grasses and water, there is *alamei*. It occurs every year. Even *alamei sapuk* occurs every year, though 2009 was the worse. He explained that if there is enough water but not enough grass, there is *alamei*. However, if there is enough grass but not enough water it is not *alamei*, then it is a water shortage. *Alamei* is usually caused by lack of rain. Even though *alamei* mainly refers to dry season and grass shortage, there can also be "*alamei* of the people", he explained. This is when there is not enough food, for example when the food prices on the market are so high that people cannot or can barely afford it. The other *alamei*, e.g. the grass shortage *alamei*, is according to him "*alamei* of the cows". He concluded by saying that if cows are sick but there are enough grasses, we do not call it *alamei*.

In the focus groups and key informant interviews, *alamei* was used in reference to "*alamei* of the cows". It represents periods when, according to focus group participants: "there is no more grass"; "when livestock dies due to the lack of grass"; "the period after the rains end"; "no food for people and animals"; and "a period in which cows have to be moved in order to find food". In contrast to how droughts are often referred to in English, during the focus groups *alamei* was only in two groups explained as "the water is far", but in all groups the main focus was on grass shortage. Similarly, in key interviews the issue of grass shortage

[8] The term for drought (amongst other definitions) in Maa, the language of the Maasai
[9] The language of the Maasai

came up far more often and more prominently than water shortage or water being far away, when discussing *alamei*. This issue of grass shortage is therefore the main further focus of this research.

1.2. NATURAL RESOURCES OF SINYA

In this section two natural resources, grass and water, are discussed. Additionally, the findings on the process of grass regrowth are shared. These resources and grass regrowth play an important role in *alamei* management in Sinya.

1.2.1. WATER RESOURCES

Water in Sinya is mainly accessed through community-built rainwater dams, community-dug groundwater wells and more recently, as of 2017, World Bank-constructed groundwater taps. The rainwater dams ensure water is available close to the homesteads after the rain season has ended, but they usually eventually dry up during the dry season. The community-dug well, which is used mostly in the fieldwork area, is the *Iujoroi* well. Both the women and the men focus groups claimed that this water never runs out. This claim was supported by statements such as "we make the well deeper once the water is finished" and "the well has never run dry" both statements were from women groups, who are responsible for the household water supply. One of the men focus groups discussed that in the 2009 *alamei* "there was still water at the *Iujoroi* well in Sinya, but only a little, and it came out slowly". Even though some water is available year-round, this water is not enough for all livestock to drink from. Therefore, though participants shared that mobility is mainly driven by grass shortage, finding water for livestock is still an important factor of mobility.

1.2.2. GRASS REGROWTH

Rains were indicated to be the main cause of grasses to regrow and the lack of rain was often correlated by the focus group participants and key informants to the lack of grass. As explained, when discussing *alamei*, the timing of the dry season, and *alamei sapuk*, the focus group participants of all groups discussed when "the grasses were finished" and never when the water was finished. For *alamei* management strategies, hearing where it has rained, or where and when it will rain, were considered to be of major importance and a contribution to finding grasses. This topic is further discussed in Section 6 - *Required forecast information.* However, when explicitly asking whether rainfall always leads to grass regrowth the answer from several men was no, sometimes it has rained but there are no grasses. An elder shared that at those times the "sun has burned the earth". When the soil stays moist for several days, the grasses will regrow according to these men. How many days the soil has to remain moist was not agreed upon specifically. Some claimed a day or two, others estimated 4 to 5 days. However, all men agreed that it takes less than a week for grasses to regrow when the earth is wet.

1.3. ALAMEI IN SIANYA

This section is on *alamei's* in Sinya. First, previous *alamei's* are discussed after which the impacts of these *alamei's* on the livelihood of the participants are shared. Finally, the 'current' *alamei* is discussed, which addresses the issues related to the lack of rainfall during the fieldwork period of February 2019 - August 2019.

1.3.1. PREVIOUS ALAMEI'S

The largest alamei was in 2009. One informant shared, that in 2009 his household had about 100 cows, but almost all died due to the *alamei* and only 4 remained. Another participant shared that the furthest he has ever moved with his cows was in the 2009 *alamei*. In that year he moved to Serengeti, a 10-day walk from his village. However, it is not a 10-day direct walk as the herders and cows stop along the way, so they are away from home for several months in total. In 2009, the government supported the community members of Sinya by providing "*posho*", help, in the form of food such as maize. Other major recent *alamei* years which were mentioned in the various discussions are 2007 and 2017.

1.3.2.ALAMEI IMPACTS

A major impact of *alamei sapuk*, mentioned especially in the male focus groups, is livestock loss. During severe *alamei* periods, livestock at times die on the way when walking large distances to find grass and water. Additionally, some die when not moving during an *alamei*. According to an elder in a focus group "In June [the 2009 *alamei*] people started moving with their livestock. In August no one remained. Those who did, their livestock died." Another impact of *alamei* is the decrease of livestock health and thus the decrease in monetary value of livestock. This makes it challenging and less advantageous to sell livestock on the markets during a severe *alamei.* An impact of *alamei* observed by mainly the women is the lack of milk for the family. According to some of the women, this results into a decrease in child health. According to the women of one family, the only food available in the heaviest months of the 2009 *alamei* was water-based porridge.

1.3.3.CURRENT ALAMEI (2019)

During the period in which the field research was conducted, February – April 2019 and the first week of August 2019, the long rains ceased to arrive in Oldonyo Mali, one of the villages of Sinya. Only May received a little bit of rain, causing many households in the area to bring their cows back home for a month until the grasses were finished in mid-June. In August, a women's group discussed that, it rained a little bit in nearby villages, namely Oltepesi, Leremetta and Enkusero, but not in Oldonyo Mali (all villages of Sinya). A traditional leader shared that the dry season grazing areas (DSGA's) which received some rain were opened a month early, on the 1st of August. However, some DSGA are still open in August 2019 since last year September, since no rain has fallen. A flood area a few hours walking distance from Sinya called Orkishinki, has received some water through wadi's coming from areas which have received a bit of rainfall. Therefore, in August several households were grazing their cows there. The elders shared that the grass in most DSGA's was finished around June and July. One elder said that "this year, we were not even at home since June". According to these elders and the *morans* (male youth) of the focus groups, the majority is currently (August 2019) staying with relatives or friends on the western slopes of Kilimanjaro in Olmolog, Elerei, Boma Ng'ombe, and across the border in Kenya in Namanga, Oloitokitok, and Matopato. One key informant mentioned that luckily the south has received quite some rain, so those herders are currently not moving up north towards Sinya, which makes the grass depletion go less fast. He continued by saying that if the rains come around mid-October, which would be considered normal, he will only loose a few cows out of the approximately 1000 which he has[10]. However, he mentioned that if those short rains come late, "there will be a big problem". These mobility and grazing strategies are discussed in more detail in section 3 - *Alamei Management Strategies*. One family has been followed during this *alamei* to understand their decisions and strategies in managing these conditions. These findings will be described in detail in section 5 - *Case study Family.*

2. WEATHER INFORMATION

In this section an overview is provided on the weather information, which is available in Tanzania and more specifically, in Sinya. First, the local knowledge on weather is discussed in section 2.1 after which the information provided by the Tanzania Meteorological Agency (TMA) is shared (section 2.2).

2.1. LOCAL KNOWLEDGE

Though no evidence has been found of a clear infrastructure for sharing weather information, some key informants shared that many people in Sinya use their knowledge on the environment and make phone calls

[10] It should be noted that this number may be an exaggeration, as owning a large number of livestock is looked up upon. Additionally, this number is not just of one man but of the entire family. However, either way, this number is very high as in Longido District, on average one household owns 51 Tropical livestock units (TLU) (SD = ±99; range 0-830), with 4.2 TLU per adult (SD = ±6; range 0-41) (Trench et al., 2009). Of which 1 cow = 1 TLU.

with relatives and friends, to gain information on the weather. This type of information is usually obtained through observations of rainfall and clouds. Besides such direct observations, some people indicated to have faith in the local knowledge of some elders. One key informant even claimed that some of these elders are more correct than TMA, however he added that "wise men look at many things, […] but they don't share". The informants discussed various indicators which the elders use to forecast the weather, namely the clouds, winds, stars, and animal observations. These observation elements and the overall use of this local knowledge is discussed below.

2.1.1. CLOUD AND RAINFALL OBSERVATION

A leader shared that when he was traveling to Ngasorai, he observed some rainfall. He shared that simple observations like that can be good indicators on where grasses may regrow if the rainfall continues. He explained he will look at the clouds to see if it continues to rain in that specific area. If so, he will discuss with the other men in the homestead to visit that place to check whether there are grasses available. The vast, relatively flat landscape of Sinya area, makes it possible to observe cloud formations in many different surrounding villages.

2.1.2. WINDS

An example of using wind as a forecasting indicator is the observation of wind direction, the strength of the winds, and the timing of these winds (e.g. which month do they start/end). According to a key informant, these wind conditions provide information on whether the rains will come early or late. These signs can usually be seen one or two months in advance before the rain season is supposed to start. An example is that long rains come from the ocean and short rains usually come with strong winds from the south. The winds are usually strong and regular in August until mid-October. Then in mid-October they usually change direction, coming from the south. However, if this does not happen, the short rains will be late. Additionally, the informant mentioned that since it is still raining, through very little, right now in August (2019), the short rains will likely come late. However, he mentioned that he does not want to share these ideas with other people, in case he is wrong.

2.1.3. STARS

A tradition leader shared that at times he asks elders to interpret the stars. In those situations, he collects money with several other community members and sends someone to Ngaraneibur (a village 40-50km away from Sinya) to talk to an elder about the weather. He explained that some elders are right, but some are wrong. The one in Ngaraneibur has so far never disappointed him. When visiting an elder in Ngaraneibur, who is known for his weather predictions, this elder shared how he reads the stars. The position of the stars shows whether the rain is coming or not. He shared an example: "when I just moved here, I told my daughters to prepare the field to grow maize. But then I saw certain stars and asked them to stop, because there is no more rain coming". He saw those stars in January which indicated the rain would stop. On 10 April 2019 he said, "it will rain this month, because in May and June, those stars [referring to the constellation which looks like a homestead according to him] will go down, which means it will not rain again, but now they are up so it will rain." He shared that unfortunately he cannot see in the stars whether an *alamei sapuk* is coming. A long time ago people knew about that, he claimed, but not anymore.

Another elder explained a different way of reading the stars. He explained that there are two "rivers" in the sky. The first river is present from January up to March. When the river disappears, it is "empty", and no more rains are coming. After March a second river appears, which indicates new rains are coming. These rivers look like patches of milky way. Besides the "rivers", there are 5 stars [which look like a magic wand]. According to the elder, when they are high up in the sky it is going to rain, and when it moves down towards the horizon, it will not rain anymore.

2.1.4. ANIMALS

Various animals are used as indicators of rain. For example, various key informants shared that the presence of many scorpions and frogs indicate rains are coming. Another key informant claimed to follow the elephants, "the elephants are the sign of the rain". Since the elephants are in Sinya in April during this conversation, he has hope that it will rain. Additionally, various signs in livestock behaviour are interpreted to indicate rains are coming. For example, whether a cow sleeps with stretched or bent legs, whether they give birth, or whether the excrete faeces at night.

2.1.5. CURRENT USE AND COMMUNICATION OF LOCAL KNOWLEDGE ON THE WEATHER

The elder in Ngaraneibur shared that news on for instance the weather travels from person to person, for example through visits. He never shares predictions on the weather through a meeting, because in a meeting people will not believe it and if it is wrong, their trust is broken. The elder explained that it is not a family tradition to learn about the weather, there is not any official institution for example. He believes that only when children are interested, they will learn from elders.

He continued by sharing that people used to come from, for example Monduli, to ask him about the weather. However, according to him nowadays some people do not believe information coming from "people". They believe information coming from the tv and radio. He said that he believes weather forecast on tv and radio too, but he does not have a tv and town in too far, so he looks at the clouds and the stars.

In the focus groups it became evident that many do not consult these elders for weather predictions. This is mainly due to lack of faith in the outcome. When asking the women of a focus group whether there are Maasai individuals who can predict the weather the response is "No. [laughing] No. Only God can predict."

2.2. TMA WEATHER INFORMATION

This section is on the weather forecasts which are provided by TMA. In the first part is explained what the TMA forecasts entail and how they match the observations in Sinya and Longido. The second part is on the accessibility of these forecasts in Sinya.

2.2.1. THE TMA FORECASTS

The Tanzania Meteorological Agency (TMA) provides daily, 10-daily, and seasonal weather outlooks on their website which includes drought and rainfall information. On their website TMA shares that they "reconstructed rainfall and temperature data over land areas on a 0.0375˚ x 0.0375˚ lat/lon grid (about 4 km of resolution). The rainfall time series (1983 to 2014) were created by combining quality-controlled station observations with satellite rainfall estimates. Minimum and maximum temperature time series (1961 to 2013) were generated by combining quality-controlled station observations with downscaled reanalysis product" (TMA, n.d.). When following the weather reports during the fieldwork period, several observations were made.

On the smallest scale, the daily level, there is one prediction per region (Figure 26). The region of Arusha in which Sinya, Longido and Arusha city are located, is roughly 90% of the size of the Netherlands. During the example of Figure 26, it was cloudy in Longido on Monday but no rain, only a slight drizzle at night of which the drops could be counted. On Tuesday during fieldwork in Sinya, no rain was observed. Wednesday provided a slight drizzle in Sinya of which the raindrops could be counted on the dusty earth. Thursday was a rain-free day in Sinya, and Friday provided no rain in Sinya nor in Longido. It is clear that the predictions did not match the actual situation in Longido and Sinya, however in some weeks when this was the case, it did actually rain in Arusha city. All these locations are in Arusha region and the patchiness of the rainfall shows how challenging one prediction over an entire region is.

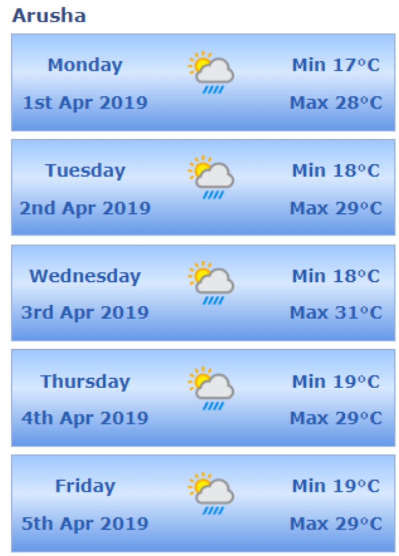

FIGURE 26 AN EXAMPLE OF A TMA FORECAST ON THEIR WEBSITE FOR ARUSHA REGION (TMA, N.D.)

The next temporal scale is the 10-daily forecasts. The detail in these forecasts is limited and one forecast covers the regions of Arusha, Manyara and Kilimanjaro, a total area of more than 95,000km^2 which is more than twice the size of the Netherlands. These forecasts are often available on the TMA website on the first day or second day of the 10-day period. An example of such a forecast for the 1st of March till the 10th is the following: For Arusha, Manyara and Kilimanjaro region "Rain showers over few areas" (TMA, n.d.).

TMA also provides monthly outlooks. These outlooks are in a report format. An example is the following outlook for March: "Occasional periods of rains are expected over few areas during the first week of March, 2019. There is elevated chance of enhanced rainfall activities over most areas during the second and third weeks of March, 2019 that could lead to various impacts associated with excessive rainfall. […] Rains are expected to commence during the fourth week of February, 2019 and are likely to be above normal to normal over most of Kilimanjaro, Arusha and northern areas of Manyara regions. […] In areas expected to receive above normal to normal rains, particularly those in the north-eastern highlands (Arusha and Kilimanjaro regions), the rains are expected to favour production of crops which are adaptive to excessive soil moisture. On the other hand, sufficient pasture and water for livestock keeping is expected. […] Sufficient water availability is likely, especially in areas expected to receive above normal to normal rains. Water levels over the dams and rivers are likely to significantly improve. However, negative impact on water resource infrastructure may occur."(TMA, n.d.) Unfortunately, in Longido and Sinya this predicted rainfall did not arrive.

The largest temporal scale on which TMA provides forecasts is in the form of seasonal outlooks. The report for March till May 2019 was created on the 5th of September 2018, according to the report itself. The report shared the following relevant information for the study area: Above average rain is predicted in Kilimanjaro, Arusha, and northern Manyara regions. This is expected to start around the 4th week of February (which turned out to be correct, though quite limited in Longido and around Sinya, and not in Oldonyo Mali village in Sinya). The report includes a warning for potential flooding in Kilimanjaro and Arusha and damage to houses, infrastructure and property. Sufficient water availability is expected and sufficient pasture and water for livestock (TMA, n.d.). Unfortunately, in Longido and Sinya this prediction did not represent the actual situation, namely a rain season with very little rain.

Overall, the forecasts and outlooks provided by TMA are on a large scale when considering the patchiness of the rainfall in the area. This is understandable from a technological and data-availability perspective but makes it very inaccurate for the fieldwork area. The seasonal outlook and monthly forecast for March have turned out to be incorrect for the fieldwork area, predicting higher than usual rainfall and potential flooding instead of the absence of rainfall, which was the case for Oldonyo Mali village in Sinya for the entire month of March. However, it should be noted that the forecast was only followed for one season and can thus not conclude anything on the overall skill of the TMA forecasts.

2.2.2.ACCESSIBILITY AND AWARENESS IN SINYA

Overall it can be concluded that there is very little awareness on and access to the TMA weather forecasts, neither to any other technology-driven forecasts. Only one village leader owns a tv, one government official reads the newspaper from time to time or TMA forecasts on the internet, and only one *moran* claims to have access to a radio. All the other key informants and focus group participants claimed not to have access to any of these information sources, neither to a smartphone. When asking whether the government provides weather information, most participants laughed and said the government does not do anything. A key informant who does have access is very sceptical about TMA. He claimed that TMA has been there a long time, but that no one listens. People come in to try to work with what meteorologists say, but nothing really happens, he shared. The leader with the tv said that he does not always believe the news on tv because "people are not God'. However, several participants stated that they do receive some weather information through relatives in cities who listen to the news. This is for instance how the forecast of last-years flood was received by some people. This alternative source of information was mainly brought up by the *morans* in the focus groups. Several elderly men and some women shared that they have heard some news on the weather through these routes but stated that they usually do not believe it is true.

Believing these information sources, differs from person to person and often depends on what their experiences were. For example, a *moran* said that some youth working in the cities heard about the 2009 drought on the news and shared it with family, while an elder shared that someone showed him a newspaper last year stating a heavy drought was coming. However, instead of a drought, it rained excessively resulting into flooding. Yet, the ward executive mentioned that he heard that these floods were coming one month in advance, through the newspaper.

3. ALAMEI MANAGEMENT STRATEGIES

During the discussions and interviews, two main *alamei* coping strategies came up. The first one, which is a prominent strategy of the Maasai livelihood, is transhumance. The decisions related to the strategy and the land management practices which shape this mobility is discussed below (section 3.1). The second major strategy, which is often combined with the first, is selling livestock. This approach to *alamei* management is discussed in section 3.2.

3.1. MOBILITY

When the grasses are finished, herders move their cows to a place where there are still grasses available. At times, when the grass is far, herders settle in temporary camps. Since goats and sheep can eat from shrubs and eat seeds from trees, resources which are available for a longer period that grasses, they usually stay overnight in the main homestead and graze close to home. The cows are herded by *morans* and *lioni* (young boys). The women usually stay behind with the children, the elderly men, the goats and sheep. When shrubs and seeds are not available anymore, which happens during a bad *alamei*, some women go to a temporary camp with the goats and sheep. These temporary camps are built in the dry season grazing areas (DSGA). It is prohibited to live in a DSGA permanently. Each family has a temporary camp in each DSGA around their village. These DSGA are areas designated for grazing only in specifically identified months. Several villages may share DSGA's and will decide together with the traditional leaders on when to open and close these areas. Usually the DSGA's open the first of September and close the end of March. However, when no rain has fallen in a DSGA, the area is not closed since there is no grass to preserve. As a traditional leader explained, talking about the year 2019: “We usually close the DSGA, so that there are resources to use later, but now there is nothing. […] Usually we close in March, but this year it is different because we closed some parts. Not everywhere was closed.” As explained, the areas which were closed in March 2019, because they have received some rain or water from temporary rivers, were opened on the 1st of August 2019. This is one month earlier than usual as there was only very limited grass available in the surrounding areas.

Temporary camps are not prohibited to be built outside of these DSGA’s. If there is no grass available in the DSGA’s anymore, nor close to home, families may decide to move their cows to a homestead of a relative or friends. This usually requires some negotiation and providing the host family with a bit of money. This money is paid in advance. According to the head of a household this is, “because people are in competition. […] You just give him some money so that he cannot give your place to anyone else anymore. […] Most of the people, from where you are from, go to the same place”. Moving to relatives or friends can be a costly operation. Besides providing money to the host, participants and key informants explained that they pay money for food, for fines, and across the border in Kenya for water too. Paying for food and water is mainly required in Kenya, where most of the land has been privatized. However, some households may decide to bring their livestock to agro-pastoral communities on the western slopes of Kilimanjaro, such as Elerai, Leremetta, Olmolog, or Boma Ng’ombe, where they can buy food from farmers from the agricultural waste products. Fines are mainly an issue when moving to such farm areas. As an elder described, “we get fines because we are passing roads, particularly to Boma Ng’ombe, where there are so many farms, […] the cows can enter the farm”. Herders get sent to the police station when this happens and “to get out, it is so costly”, he explained. Buying food from farmers while keeping the cows at home is not an option for most participants and key informants “because it is far away, and we don’t have a vehicle which can bring grass here at home”. An elder explained that it is not possible to simply buy food for all of his cows, it would be too costly. He would have to sell several cows and then there is a chance the food is not enough, and he would lose even more cows.

The relationship that the people from the low-laying Sinya area have with the highland communities on the slopes of Kilimanjaro, is mutually beneficial. While the Sinya herders go uphill in rough dry seasons, some highland herders come down to Sinya area during the rainy season to graze. A *moran* from the highlands explained that he moves the cows to the lowlands because there are salts in those areas, which are good for livestock health. Larangwa a village on the western slopes of Kilimanjaro, where he is from, does not have those salts according to him.

A final resource area for grazing in case all the grasses in the area are depleted, are national parks. However, grazing in these parks is prohibited. Therefore, a traditional leader together with other leaders, has to negotiate with the government on whether they can get an exception. According to a traditional leader, such an exception will only be granted in years of extreme droughts. He claimed to have moved his cows all the way to Serengeti in 2009, the year of a very extreme *alamei*.

In order to know where to go and where grasses are available, regular communication with friends and relatives is crucial. Additionally, observations of clouds and rainfall can give an indication of which area may potentially have some grasses available, as explained in section 2 - *Weather information*. Once an idea is obtained of where there might be grasses, a herder is sent out to scout whether the grasses are indeed there. If there is grass in an area with a temporary camp, the movement to that area can take place is a short period of time, for example the next day. However, when moving to relatives or friends, the negotiations require a bit more time and plans are created sometimes a few weeks in advance.

However, moving is not an option for everyone. As a woman described in a focus group: “The main reason is labour […] when you have boys to look after the cows in a temporary camp, you can shift them, but if you have no people to look after the cows away from home, the herders go herding during the day and return in the evening”. The lack of labour force came up in every focus group and interview, when discussing reasons why people do not move. An elderly man shared: “The problem is manpower; some people may lack manpower. You might have two boys. One looks after the goats, the other looks after the cows. So, it is impossible for the one who is looking after the cows to stay at the temporary camp by himself, since it is difficult to manage by one person.” A leader explained that if you want to shift your cows to a temporary boma, you need about three men: “one looks after cattle and looks for grass during the daytime, the other looks after calves near the camp, the other might be sent home to get food or collect water”. He shared that in most families these days only *morans* do these tasks “because now *lioni* are going to school”. The issue of limited workforce because boys are in school was shared by participants and key informants of all other discussion groups too. The hope is that these boys will eventually bring money to the family once they get a good job. This money can then potentially be used to buy food for livestock if necessary or pay for other daily needs. Others hope that once the boys are finished with school, they can come back home to help with herding.

Another argument against moving is the risk of losing livestock along the way or in the new area because of the change in environment. A leader explained that if you stay at home, your cows can become weak slowly, but if you leave, they can die suddenly. He said, because he leaves his cows at home, there is less chance his cows catch a “bad disease”. Additionally, the high costs of moving, as explained above, makes some people hesitant to go, especially across the border, to relatives, and to agricultural areas. An argument of staying at home for two leaders was their role in the village. One explained he “cannot be away from the village”, because he has many responsibilities and is needed in the village. According to several participants, a final argument against moving is that when the cows are at home, the whole family has easy access to their milk, and the cows can be monitored which makes it easier to sell the best one in case that is required.

3.2. SELLING LIVESTOCK

Selling livestock is not only a strategy in times of *alamei*, but also in good times. A joke which is made often is that, a livestock herd is like “a walking ATM”. “There goes the Maasai ATM” some colleagues would say. When school fees need to be paid or food from the market needs to be bought, a goat, sheep or in more expensive cases a cow, can be sold on the market. However, when an *alamei sapuk* hits, the family might decide to sell more livestock. The money is sometimes used to buy food for the livestock. As explained previously, in normal years, it is not financially attractive, or for many households not feasible to do so. However, in extreme *alamei’s* this decision might be made to at least save part of the herd. An example of such a situation is when there is no more grass in the DSGA’s and people move their livestock to Kenya or relatives living in farm areas, as explained above. Additionally, some more wealthy people may use the money to pay for transport to move their livestock to further areas. However, this is only done in *alamei sapuk* and the only person who claimed he did so in the study area was the ward executive.

The money which is earned when selling livestock is rarely put into a bank account. As a traditional leader explained: “When you put money in the bank there is no protection. When I sell livestock, I buy everything that I want, I buy food for the children, food for the cows.” The closest bank is in Namanga which is approximately a 40 km walk away. However, there are a few individuals who do have a bank account. A leader estimated this is no more than 20 people. According to him they all work for the government, because their salaries get paid to a bank account. He is one of these individuals and shared that he sold 12 bulls, stored money on the bank, and used it for his business and for building a house in 2015-2017. He explained that he can use the money on his bank account to rebuy cows, when the rains come.

As part of a governmental climate change adaptation project in collaboration with IIED, a storage house for food was built in Sinya in the end of 2017. The idea behind it was that people can store food in it to use in times of drought. Each household pays 1000 Tanzanian Shillings (approximately €0,40) per bag of food. The ward executive explained that it is best to sell when a cow is fat since you get more money for it than in the middle of the drought when it is thin. Additionally, the food is cheaper when there is no drought. He shared that people store their food in the storage house, because it is safer. If the rains come, it will not get wet, there will not be any insects or other animals eating from it, and the government put some “medicine” in it to destroy the insects and animals. A traditional leader explained that his family keeps food for the family at home, but that it is easier to store food for cows in the storage house, because it is close to the market and they do not have a motorbike to bring the food to the house. However, even though the leaders all agreed that it is a great idea, it is unclear whether people really use it. This may be the case since no large *alamei* has hit the area since it was built. Yet, even in August, when there was barely enough grass in the area and it was only the beginning of the dry season, the traditional leader had no food stored there. His main argument for this was the challenge of bringing the food to the storage house and from the storage house to the homestead.

4. RAIN/GRASS DYNAMICS AND DECISION MAKING

The decision to sell livestock is made throughout the year, depending on when money is required. This decision is usually made by the head of the household. The decisions on moving with the cows to temporary camps or relatives, is related to grass availability. Usually the head of the household decides where and when to move to, together with the other men in the household. This decision is strongly dependent on whether the DSGA’s are open or not. This decision is made by the traditional leaders and village members who live in the bordering villages. Due to the dependency on grass availability and rainfall, a general seasonal pattern can be found related to such decisions. However, it should be kept in mind that due to changing patterns in rainfall, the exact timing of such decisions may differ strongly in dry years.

In focus groups with *morans,* women, and elderly men, the grass availability, rainfall patterns, and moving timings were sketched out for a ‘normal’ year in Sinya. A ‘normal’ year in these discussions relates to rainfall arriving in the expected months, and grass growing to the expected amounts in those months. Three of these focus group sketches are shown in Figure 27.

All groups agreed that the long rains usually start in March, quite abruptly, and end around mid-June with a slow decline. April was considered to be the wettest month by all groups and both the men groups argued that March is similarly wet. The groups agreed that early or mid-October the short rains start and that they are much smaller than the April rains. There was a consensus that there is usually no rain at all in January, February, July, August and September.

All focus groups argued that the grass availability usually shows a delayed response compared to the first rainfall in March and October. According to the women and the elders, the grass is most abundant in April and May. The *morans* believed the grass is most abundant around May and June. The elders and women agreed that the grass turns yellow around June, while the morans said it is more around July that the grasses turn yellow. All agreed that the grasses available after and throughout the short rains, is much fewer than the availability in the long rain season. The months of September and February were generally considered the months with no grass at all, and the women even argued there are no grasses starting from mid-July.

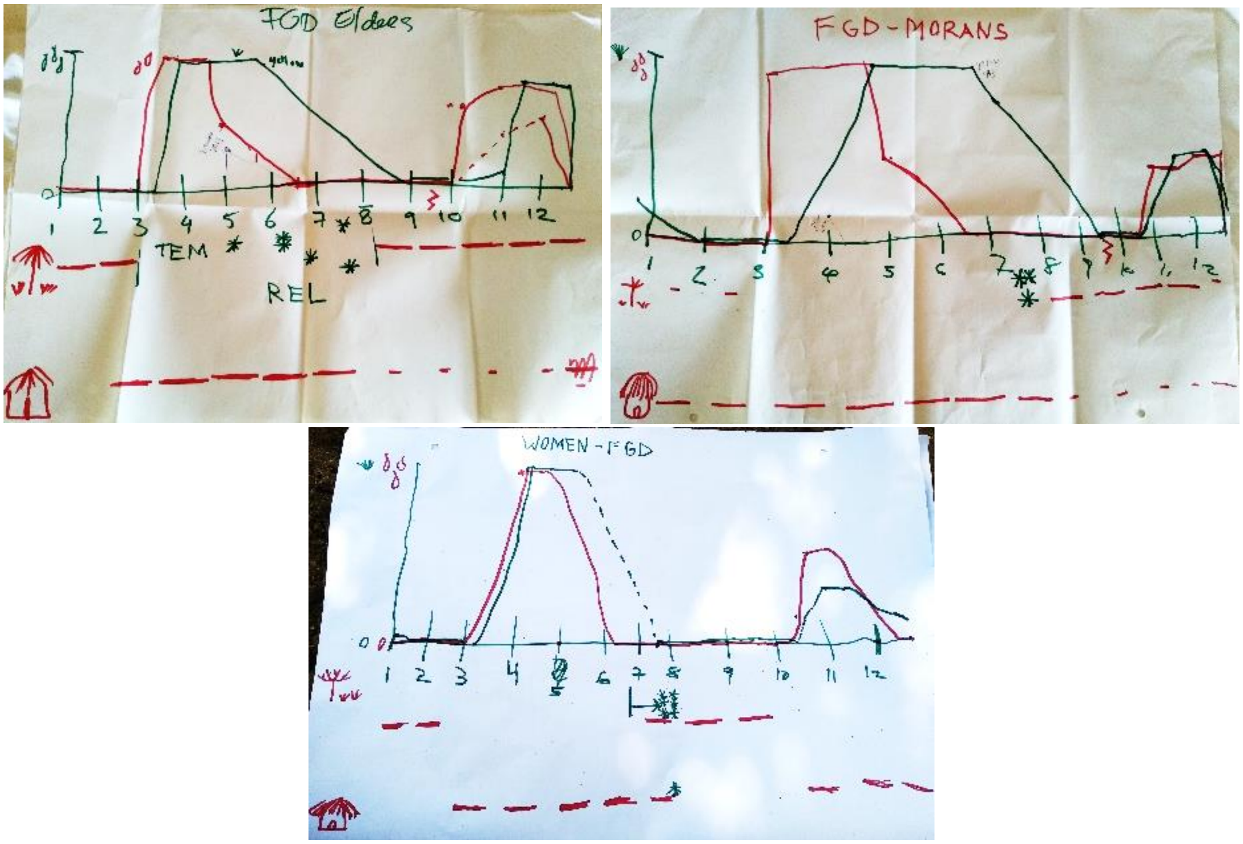

Figure 27 Graphs of rainfall, grass availability, and livestock locations (temporary camp or at home) for a 'normal' year in Oldonyo Mali village in Sinya. The results are from focus group discussions with seven Elderly Men, Women, and Morans. The red lines in the graphs represent the rainfall pattern over time in a normal year, the green line represents the grass availability, and the red lines below the graph represent whether most households have their cows in a temporary camps or at home, of which the top dashed line indicates the months in which most cows are in temporary camps and the bottom dashed-lines the months they are usually at home. The stars represent where the cows of the participants are at the moment, it should be noted that two stars are missing in the poster of the elders, for which the cows are currently at home. Finally, there is a small line drawn with pen in the Moran and Elders sheet for the month of May. This is according to them the relative amount of rainfall which fell during that month in 2019.

There was a general agreement that in a 'normal' year, all families have their cows at home from March till July. The month of July itself was debated by the women, who claimed that some already start moving then, but all the men groups argued that the cows are then still at home. Though the women argued that most families bring their cows home in the short-rain season, the two male groups claimed that most are usually still in the temporary camps around that time. As an elderly man argued, many stay in temporary camps even in the short rains, to ensure their cows recover well. He said, by staying in the temporary camps with grass abundance, the cows can recover and "bulls start to reproduce there". He added that "only goats can be at home in December […], only goats and people, but no cows". Either way, all participants emphasized that it is dependent on grass availability. The movement towards temporary camps was also highly dependent on when the DSGA's are opened, and on whether there is enough manpower in the household to help out as discussed above. In the three groups a consensus was reached that the majority of the households stay in a temporary camp when the DSGA's are opened, rather than going back and forth every day.

The year 2019, however, was according to all participants a "strange", or "bad" year. Due to lack of rainfall there was no grass in Oldonyo Mali in March and April. Therefore, for many households, the cows were in a temporary camp around that time, or they went back and forth every day to these DSGA's which were still open. The elderly men shared that in May there was some rain in Oldonyo Mali, resulting in most cows to come home. However, one participant of this group explained he shifted the cows to relatives already in May. The other participants did the same throughout June and July. On the first of August, all elderly participants, apart from one, had their cows with relatives. One man explained this is because "the places in which the temporary camps are located, did not receive any rainfall". The *morans* shared that half of them had cows at relatives, one in a temporary camp, and the others at home because they did not have enough men to move. The elders shared that it is not normal to have the cows with relatives around this time of year. Every year people go to the temporary camps, but they only go to relatives when it is a bad year, according to them.

5. Case study Family

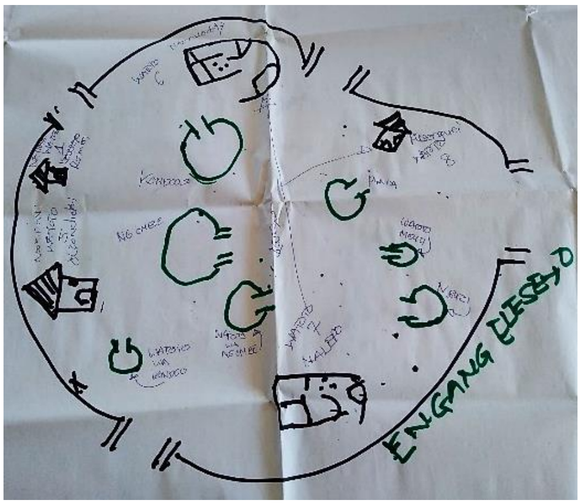

Figure 28 A sketch by the women of the homestead structure

Figure 29 A discussion with the head of the household

The family was visited in March, April and in the first week of August (Figure 29). These visits were conducted to obtain an in-depth understanding of how one family makes its decisions related to grazing and what information these decisions are based on. The women explained that the household consist of three husbands, 5 wives, and 27 children. The oldest man, the head of the household, has three wives: one wife has 8 children, one wife has 6 children and the last one has 7 children. The two other men who live in the homestead, are his sons who each have one wife. One has 5 children and the other has one child. Besides the houses of the women, the homestead consists of designated areas surrounded by fences of thorny branches for the sheep, goats, calves, lams and kids. The cows occupy the large area around these smaller designated areas, which in its turn is surrounded by the houses and an outer fence, which is also constructed of thorny branches to keep the wildlife out (Figure 28). When visiting the family, in the end of March, the rains had been very poor, and the grass availability was limited. This is quite unusual for that time of year. Throughout 4 visits, discussion with the men took place about their decisions in livestock management throughout the months. The conversations with the women in the household were part of the general focus groups in this research. The results of those group conversations are included in the results sections 1, 2, and 3 of this report.

The men of the family explained that in bad *alamei's* they go to areas across the border in Kenya, such as Namanga and Oloitokitok (both locations are around 40-50km away) or move to the highlands on the slopes of Kilimanjaro. They explained that due to the land subdivision and land privatization in Kenya, crossing the border for grazing is "difficult". They claimed that sometimes they need to pay for using the resources, for example they might need to buy grass. Going to Kenya for grazing is "expensive". They said that if you go to Kenya, you need to sell a cow to pay for the resources which you use and then when the grass is finished in that place, you need to sell another cow to pay for the fees of the new place. In Kenya "we even buy water for the cows". The amount of days of which the cows have drunk from the water source are counted and it is expected that this fee is paid after a few days. They continued by saying, when you go there, even if the well is broken, you need to pay to fix it. "If we have a big problem, like a big *alamei*, we go to Kenya, but if the situation is not very bad, then we don't go to Kenya." The last time they went to Kenya was in 2017.

On 27 March 2019 the men of the family decided to split the cows into two groups: the young cows with their mothers in one group, and the stronger cows in the other group. The first group moved to Sirol; an area of 2 hours walk away where some grasses were still available. The men knew that this place usually receives quite some water and thus hoped there would be grasses there too. The site was first inspected by the *morans* to see whether there were indeed grasses. When they found what they were looking for they renovated their temporary camp in Sirol the same day, 26 March 2019, and the next day took the cows with them. The men alternated days of watering and feeding the cows. The drinking places and grazing locations are separated traditionally. The explanation behind this separation of resource areas is that grasses around watering holes will be depleted fast, since around watering holes livestock stay for many hours in the same small area and the water source attracts wildlife too. Thus, if the areas are not separated the density of animals on the grasses around the watering hole is too high and not enough grass would be available. Instead the grazing areas are away from watering holes, ensuring a more equal grazing distribution and thus a higher abundance of grasses.

The second group was brought to Amboseli, a 2-hour walk in an area in Tanzania which is part of the Amboseli ecosystem. On the 26th of March 2019 the stronger cows were drinking in that area. Similarly, as for the Sirol group, for the Amboseli group the men decided to use the temporary camp in the grazing area and send the stronger cows there. A donkey joined to assist with carrying food and water. In the Amboseli area there was less water than in Sirol, so it was not suitable for the younger calves who need water regularly. However, when asking why they did not simply go with one group to Sirol instead, the response was that if they would all go to Sirol together the group would be too big. On market day (Tuesday 6 days later), the father would sell some livestock to buy food for the family and the herders in Sirol and Amboseli. Prior to this visit, the head of the household explained that the money will be used to buy food straight away and no money will be stored.

When asking what is next, where they will move to next, the answer was that it "depends on rain and grasses; if grasses are finished there, then we listen to the news to see where there is rain and grasses". This news is received through relatives and friends by phone. After such a phone call some herders will go to the area to confirm there is indeed grass and water, before moving the cows. On the 4th of April, the flood plains were still open (since September 2018) for consumption because no rain had come. In April the men explained that if it stays like this till May "the cows can die because there is no grass, not within the dry season grazing area and not outside of it." On this day there was still enough grasses in Sirol and Amboseli to survive, so the cows were still there.

Several months later on the 1st of August 2019, the family was visited again, to understand how they have coped with the little rainfall and what management strategies they used to ensure the survival of their livestock. The head of the household explained that the Amboseli group went towards Kitenden (20-30 km away) in April, but they did not reach Kitenden since they heard there were not enough rainfall there. Instead, they went to the dry season grazing area near Kibo Lodge (10 km away). The Sirol group with the young calves went back home and grazed in the flood area. These areas had received some water through temporary rivers, which transported water from areas close by which had received a bit of rainfall. The head of the household explained again why they split the cows in two groups. The first reason corresponded with his explanation in March, that not all cows are strong enough to travel far and there is too little grass for all cows to graze in one area. However, this time he added a second reason. He explained that this strategy is used to spread the risk; it is a "matter of probability".

All cows came back home in May, when a small amount of rain fell in the area, and they stayed home for the entire month. In mid-July they left the homestead with all their cows and went back to the temporary camp in Amboseli area. The temporary camp belongs to other people, but the elder explained that they were not there so his cows could stay there. They went with all their cows this time, because they did not find any other places where they could bring cows to. Amboseli area was their only option. The cows were still there during the last visit on the 1st of August. As usual, they went by foot to the area in advance to scout for grass. Only *morans* and *lioni* moved with the cows. The women and children stayed at home. However, he shared that sometimes, if the season is "too harsh", the goats are taken to temporary camp in dry season grazing areas. He continued that even now (1 August 2019), some goats and women have moved to a temporary camp near Kibo Lodge. Sometimes they ask an elder who has a good relationship with the Kibo staff, to ask Kibo if they are allowed to graze in that area. However, their temporary camp is outside of the Kibo area and thus no permission was required for this movement in August. The women who stayed behind in the regular homestead looked after a few goats, so that they would have some milk available at home. Additionally, from time to time the men sold a goat so that the women could buy food.

The head of the household continued his story by explaining that the grass availability in the Amboseli area where the cows are, is very little, but just enough for now. On the 1st of August, it was not yet necessary for the family to buy food for the cows. However, he shared that this might be necessary soon, which means they would have to shift. Since the dry season will continue, "the *alamei* is still too long", they have to consider carefully where to shift to. The elder shared that he is considering two options: going to Kenya or to Boma Ng'ombe (an agricultural town 60km away). They usually go to Boma Ng'ombe to buy the maize cultivation waste products off the farmers as food for their cows. When they stay in Boma Ng'ombe they stay at "other people's homes". These people are not relatives, but family connections. Their cows may graze in Boma Ng'ombe a little bit, but not far from the host families homestead since they mainly buy food for the cows. The second option, Kenya, entails buying food for the cows too "and even water". It is prohibited to build a temporary camp in Kenya, so they stay in other people's homesteads.

The decision to move to Boma Ng'ombe or to Kenya in the next few weeks after the visit of the 1st of August, depends on long-term food availability. The head of the household explained, they use their "imagination" to find out "which place is more satisfactory for the cows for a certain period of time". They want to find out for how long food will be available for the cows. The men research this by talking to farmers before shifting to see how much food for the cows they can buy from them; "can I get enough food to survive the whole dry season?". Additionally, they look at "the cost of the food" and "the cost of the fines", because "you can get so many fines". Another factor which plays a role in the decision making for this family is "discrimination". He says that in Kenya there is much discrimination towards Tanzanians "[they would say], you Tanzanian, you just go". Sometimes, "you have no option and then you go to Kenya".

At the time of the visit, the head of the boma was leading more towards going to Kenya, than to Boma Ng'ombe, because in Boma Ng'ombe "grass can finish quickly". The final decision on where to go will be made "until there is no more grass left where the cows are currently grazing".

6. Required forecast information

After having discussed *alamei* management strategies and the availably of information on weather forecasts, the discussions moved towards designing an ideal weather forecast system. In this design process participants shared what type of weather information is required to contribute to *alamei* management strategies (section 6.1), what area should be covered for these forecast (section 6.2), how far in advance such forecasts need to be communicated in order for the community members to take timely actions (section 6.3), how these forecasts should be communicated to assure as many people as possible in Sinya will receive it (section 6.4), and finally what *alamei* management actions can be taken based on the forecast information (section 6.5). In the final focus groups, the topic of uncertainty was discussed through a seasonal outlook game (section 6.6). The results of these various discussions are described below.

6.1. WHAT

When discussing what forecast information is required to contribute to *alamei* management, all focus group participants, and key informants unanimously agreed. In summary, they would like to know when it will rain, where it will rain, and how much it will rain; more specifically, will it rain enough for grasses to regrow.

Within this, if it is not going to rain, the participants are interested in knowing how long it will not rain, where it will rain and when. The *morans* specifically indicate they find it useful to know whether the rains will come late. A leader explains that he believes it will be convenient to know what comes after a drought, for example, it there enough water and grass coming. Finally, several *morans* and the ward executive express their interest in knowing whether a flood is coming, like last year.

6.2. WHERE

The main areas which were mentioned to which herders move to graze their livestock, are the DSGA's, the western slopes of Kilimanjaro, Manyara Region, Longido District and southern parts of Kenya. A rough indication of all the mentioned areas is visualized in Figure 30.

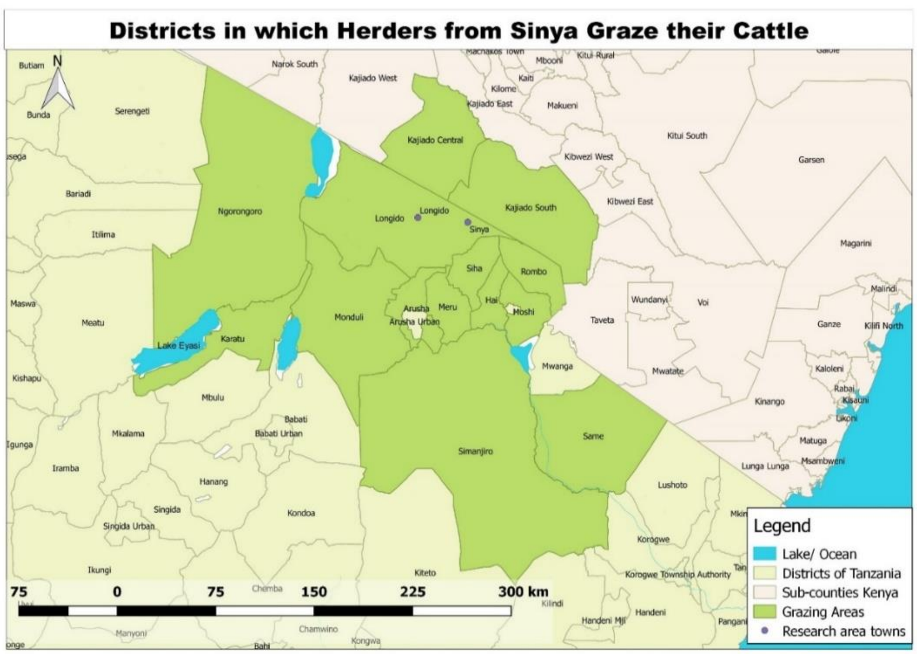

FIGURE 30 CATTLE GRAZING AREAS INDICATED BY THE FOCUS GROUP PARTICIPANTS AND KEY INFORMANTS IN SINYA. IT SHOULD BE NOTED THAT GRAZING IN A REGULAR ALAMEI IS USUALLY ONLY IN THE AREA AROUND THE VILLAGE. HOWEVER, IN AN ALAMEI SAPUK, THE FURTHER AREAS ARE USED FOR GRAZING TOO.

6.3. WHEN

Since droughts are a slow process, obtaining consensus on a specific lead time was challenging. When asking what lead-time would be best, the responses ranged between one week to two months in advance. An elder shared that he will need to know whether a large *alamei* is coming 2 months in advance to prepare. In those months, he said he will choose cows of good health to sell and get the most money. He would only sell cows. Goats can be sold any time before an *alamei* to get money, he explained. One of the *moran* groups and one women group agreed with 2 months required for such *alamei* preparation. However, the other elder, moran and women groups agreed that one-week lead-time is enough. An elder explained that in that week they can sell livestock, buy some food and move.

When following the decisions made by the case study household, the orientation on where to move to once the grasses finish started a few weeks prior to moving. The scouting for grass and moving itself was a matter of days. Therefore, for mobility purposes, a lead time of a month should be enough. The more targeted orientation on where to move, only starts when the grasses in the current grazing area are about to run out, or if the consumptions rate is very high and thus the threat of it running out soon is high. Additionally, for the orientation of when and where to move, it is important to know where it actually has rained, or in an ideal world where there is a highly accurate prediction on where it is going to rain. Therefore, concerning decision making on livestock moving, no evidence has been found on a required lead-time of several months or longer.

However, when considering selling strong livestock prior to a large *alamei* hitting the area, it can be argued that a longer lead-time is useful. A lead time of two months as the three focus groups argued, can ensure enough cow strength. Nevertheless, it is essential that this forecast is highly accurate for households to make such a decision.

6.4. HOW

No consensus arose on how best to communicate these forecasts. When posing the question on means of communication to the focus groups, the radio and tv were mentioned. However, when continuing on that topic all participants agreed that only a few individuals have access to these technologies and that another way of communication would be more effective to ensure as many people as possible in Sinya hear the forecasts. Communicating through the internet is no option either, since only very few people have smartphones or access to internet. If feasible, SMS messages might be another option according to all participants. Almost all households in Sinya had access to a non-smartphone which can receive texts. However, not everyone could read, Maa is not a written language, and Kiswahili is not spoken by all. Yet, on a household level, there was usually someone who can read and understand such messages. Sharing information on village markets was also probed. However, though all participants agreed it is possible, two male participants worried that people are busier with other things on market days, and thus will unlikely be listening to the weather forecast.

In all focus groups a meeting in which the forecast is shared, was considered the best option. All participants agreed that these meetings should be on village, or ideally on sub-village, level. One group of *morans* argued that only *morans* should be invited to this meeting as they are the ones who need to move the cows, but the other groups all agreed that everyone should be invited, men, women, young and old. However, in a focus group with the women it came up that only educated people will see the relevance of such meetings and thus many people will not come. A key informant explained that, one person of a household is sent to such meetings to share the information with the rest of the household. This is done to ensure the other household members can continue their daily duties. In all focus groups the participants concluded that such meetings should be held approximately twice per month.

The next question though, is who should share the forecast at such a meeting. A *moran* group nominated Maasai leaders to do this. A key informant shared that this type of information should be transmitted through a neutral system, not through village leaders. He took the Enduimet Wildlife Management Area as an example, but later threw that example out as it has become "political" too. He argued that traditional leaders might be a good way to communicate through. However, when discussing this with a village leader and a traditional leader, they were both against this idea. Both argued that if they share this news and it is wrong, their word will not be trusted in the community anymore. A key informant responded to this interview by suggesting taking the individual out of the information. He said, "I am hesitant actually in believing or in telling people information that I don't believe myself". However, if it can be communicated clearly that the information comes from an external source and insight on the limitations and accuracy is shared, it should be fine he believes.

An NGO staff member shared that based on his experience, meetings will not work. He said that with the meetings of one of his projects, he can see that the participants have many other things to discuss in addition to what the project is about and sees that as a sign that they do not regularly meet up in groups at village level. He shared that he thinks very few people will attend such a meeting and is not sure whether everyone will know about it either, since he doubts that the leaders communicate these things to everyone. Another NGO staff member suggested forming a group of volunteers, to which an NGO for example makes phone calls sharing weather information. These volunteers then become responsible for the communication to other village members. This system of calling is according to him how most of the information is communicated these days in Sinya anyway, and in which he has most faith that it will reach the largest amount of people. After proposing this idea to the key informant, who was proposing a more "neutral" system, the informant agreed and believed it has potential.

6.5. ACTIONS

Most of the actions which households can take to manage an upcoming *alamei* based on the forecasts are selling livestock and orienting on where to move, as mentioned when discussing the lead time. However, though all focus groups initially concluded they can move earlier if they hear an *alamei* is coming, an elder explained most people will still wait for the grass availability to decrease around home before moving. Apart from the advantages and disadvantages moving, which are discussed in section 3.1 - *Mobility*, he shared: "You cannot just move from home to anywhere. You will look like a crazy person. Because there are grasses here, why would you move?". However, a key informant argued that if a forecast is accurate enough, households will start to orient themselves earlier on the moving options.

A leader shared that if the forecast is accurate enough, he will sell some cows when they are still fat and buy the food when it is not too expensive. Another leader said that if he would know a drought is coming, he would sell some livestock and use the money to invest in a house or something else. Interestingly, when discussing the option of selling livestock, the majority of participants and key informants, especially in the focus groups, only referred to selling a few and buying food for their remaining herd. The option to sell many and put the money on the bank if an *alamei* is coming and using the money to buy cows after the alamei, was not considered apart from a few individuals. The reason why this was not considered remains unclear. However, when playing the seasonal outlook game, a woman from a focus group came up with the idea of selling livestock based on an *alamei* forecast and rebuying it after the event. When using this option in the games with the other focus groups some of the elderly men and morans were excited about the idea.

6.6. UNCERTAINTIES

The role of uncertainties in the forecast has been an underlying topic throughout many discussions. To get an impression of how people would deal with such uncertainties and to start the discussion on this topic, a seasonal outlook game was played with the focus groups (see *Annex II - Seasonal-Outlook Game* of the main report for more information). Some participants, especially those who followed education in all women, *moran*, and elderly male groups, played safe and always kept about half of their 'livestock' on the 'bank'. In one *moran* group and in the elder groups, there were a few participants who stuck to the strategy to have most if not all their 'livestock' with them, so not on the 'bank'. These two groups roughly represented half of the participants. However, the other halve, especially in one of the women groups, adapted their strategies, based on the provided 'weather forecast'. Quite often this forecast did not turn out to be true. When discussing these prediction results with all the groups after the game finished, the response was in several groups that only God knows these things, or "no one is God", as one of the participants put it.

The uncertainty of the forecasts did not seem to play as big of a role in the game, as in the responses to the real-life situation. As discussed only very few people trust the weather information which they receive, since it often does not correspond to the actual situation. However, one of the leaders shared that, though he does not always believe what he hears on his tv about the weather, he does listen and keep it in mind. When asking the groups and key informants directly whether a forecast is useful, even if it is not certain, the responses were: "Yes we should still have a meeting [to share this information], even if it is unsure" (elder); "We will prepare earlier if we hear the forecast, even if it is not sure" (*moran*); "we will fight for our future, so yes, we will listen to the forecast [even if it is unsure] and move earlier" (*moran*); "Yes, that is the problem. But still, even if it is not as bad as predicted, people will be warned and can at least make sure they have an alternative option to livestock" (key informant). A leader explained that "Even people I listen to are wrong sometimes, but you follow them the first time, and if it is wrong, you know not to follow them next time".

7. FEEDBACK ON PROPOSED FORECAST INFORMATION

From the above results the conclusion was drawn that a general drought-early-warning system may not be suitable in Sinya. However, the idea arose that if in March an accurate prediction can be made on whether it will rain (enough) in April, this might contribute more substantially to the current drought management strategies and the pastoral livelihood. In August, these ideas where discussed with some community members to generate their feedback. This discussion was conducted in 3 focus groups of 6 to 8 participants, one group of elders, one of women, and one of *morans*. Additionally, several key informant interviews were conducted with a traditional leader, a village leader, a rangeland ecologist and with the head of the household of the case study family.

Generally, people were enthusiastic about the idea. A leader's response was the following: "It is helpful, because if we know it is going to rain or not rain in April, we can do something because we can move to some places where it is raining. For example, yesterday there was a thunderstorm near Elerei and Longido with a little bit of rain and herders followed with their cows to drink there, but we don't know, we are not sure, if it is continuous or not". He said that, if they know that it is not going to rain, they may move faster or orient faster on where to move. Another informant shared that "It is good to warn people on disasters. People have the right to be informed." He continued by saying if people would receive this information they would "move livestock, and in time". According to him, people want to move, but have to always send a scout and by the time such a scout comes back, the grasses may have already almost finished. One of the leaders shared his thoughts, "if we get something that can predict the weather correctly, people can either wait if it is going to rain, or they can go if there is no rain at all. When it is accurately predicted that there is no rain, those who normally move, they move to places where there is rain, and those who don't move, they can sell most of the cows and do other activities or put it into an account, and then when the rain comes, they start to buy other cows." He continued by saying, if you know it is going to rain "you try to do what you can do to maintain the stability of the cows up until that time, so you can get into costs, but you know you will get something for it later”. To ensure this “stability” he would spend some money to buy food for the cows to ensure they stay healthy. If it is not known that the rains will come, he may not spend that money to be safe and the cows will become weaker slowly.

However, this perspective on moving earlier or selling cows was not shared by everyone. According to a key informant, “we won’t wait for rains to come”. If there are grasses somewhere and not at home “we go”. In the focus group with the women it was discussed that if they are back home because there was a little rain in March and some grasses, but there is no rain after, they can wait for the whole month of April. But if any rain falls somewhere else in the meantime, they shift.

The rangeland ecologist summarized the different views in the following way. He explained that the rural pastoral communities will be sceptical about these forecasts. It will take time before they will listen to them and believe them. For that to happen the forecasts need to be correct. However, once this is the case for a few years, he thinks they eventually will respond. When verifying this statement with other leaders and key informants, all agree. However, this dependency on high accuracy is a crucial part of the potential effectiveness of the forecast. According to one key informant “it will help, if at all it is true, it will help”. Another informant states that “technology for weather forecasts has to be improved and refined, otherwise, it is a waste of time”.

Besides worries about the accuracy, in the discussions and interviews one thing continued to come up: It is not only useful to hear if it is not going to rain (enough), but also where it actually *will* rain. It helps the most “if we know where it is raining, because if we know where it is raining, we know where to go”. However, when proposing this might be step 2 in a research and asking whether step 1 is still useful if step 2 does not exist (yet), the answer was unanimously that it is still useful to know if it will or will not rain in the month of April over Sinya area.

Furthermore, the topic of adverse impacts was discussed. The conclusion in all cases was the importance of clear communication to avoid false expectations and misinterpretations. However, one worry which came up in a few key informant interviews was the potential risk of many people going to the same place and causing the grasses to finish in that place very quickly. However, this would only be relevant if the predictions would include where it *will* rain, which is currently not the case. Nevertheless, it may happen the other way around, that if only for Sinya it is know that it will rain, herders from other areas could potentially all come to Sinya. Whether this is likely should further be explored.

A final point which came up in several interviews is the scale of the predictions: “pastoral livestock land use is much more diverse than just between Mount Kilimanjaro, Mount Longido and Mount Meru.” This ties into the comment on knowing where it will rain. The discussion with the rangeland ecologist led to new ideas of future research to expand the analysis by conducting it over various sections, to increase the scale, but keep the detail. However, first there is a need to find out whether the current technologies are even capable of forecasting this information for one area, and exactly that analysis is what this research is about.

ANNEX VI - ROC CURVES PER THRESHOLD FOR MARCH AND APRIL

This annex shows the ROC curves for March (Figure 31) and April (Figure 32), with the bootstrapped density points for different thresholds for the various thresholds explained in chapter 4.2.

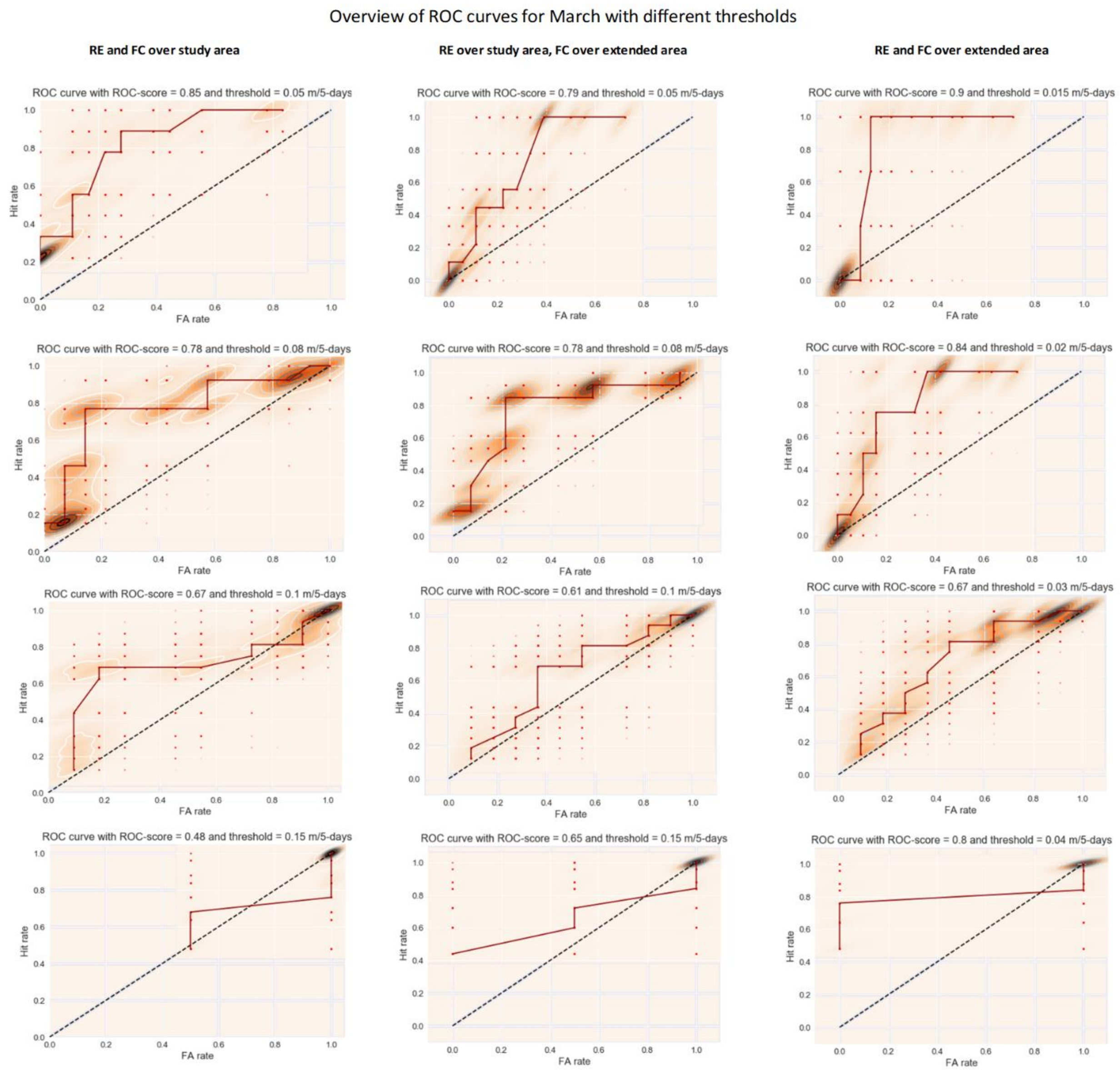

FIGURE 31 THIS FIGURE PROVIDES AN OVERVIEW OF THE ROC CURVES FOR NON-EXCEEDANCE OF DIFFERENT THRESHOLDS FOR MARCH FOR THE VARIOUS SCENARIOS. THE BLACK LINE INDICATES THE 'RANDOM' FORECAST SKILL. IF THE ROC CURVE IS ON THIS LINE, THE CHANCE OF A FORECAST BEING CORRECT IS 50/50. ANYTHING BELOW THE LINE INDICATES THAT THE FORECAST IS MORE OFTEN INCORRECT THAN CORRECT, AND THE CURVE ABOVE THE GRAPH SHOWS THAT THE MODEL HAS SOME SKILL. IN THE BACKGROUND CONTOUR LINES OF THE POINT DENSITY OF THE BOOTSTRAPPED DATA ARE PLOTTED. THE DARKER THE AREA WITHIN THESE CONTOUR LINES, THE HIGHER THE NUMBER OF POINTS WITHIN THIS AREA. THE RED DOTS SHOW ALL THE LOCATIONS OF THE BOOTSTRAPPED POINTS. THE LOWER THRESHOLDS SHOW A HIGH CONCENTRATION OF 'NO ALARMS' (BOOTSTRAPPED POINTS IN BOTTOM LEFT CORNER) THE HIGHER THRESHOLDS SHOW A HIGH POINT DENSITY FOR 'ALWAYS ALARM' (UPPER RIGHT CORNER). THIS SHOWS THAT OVERALL THE FORECAST DATA VALUES ARE LOWER THAN THE REANALYSIS DATA VALUES.

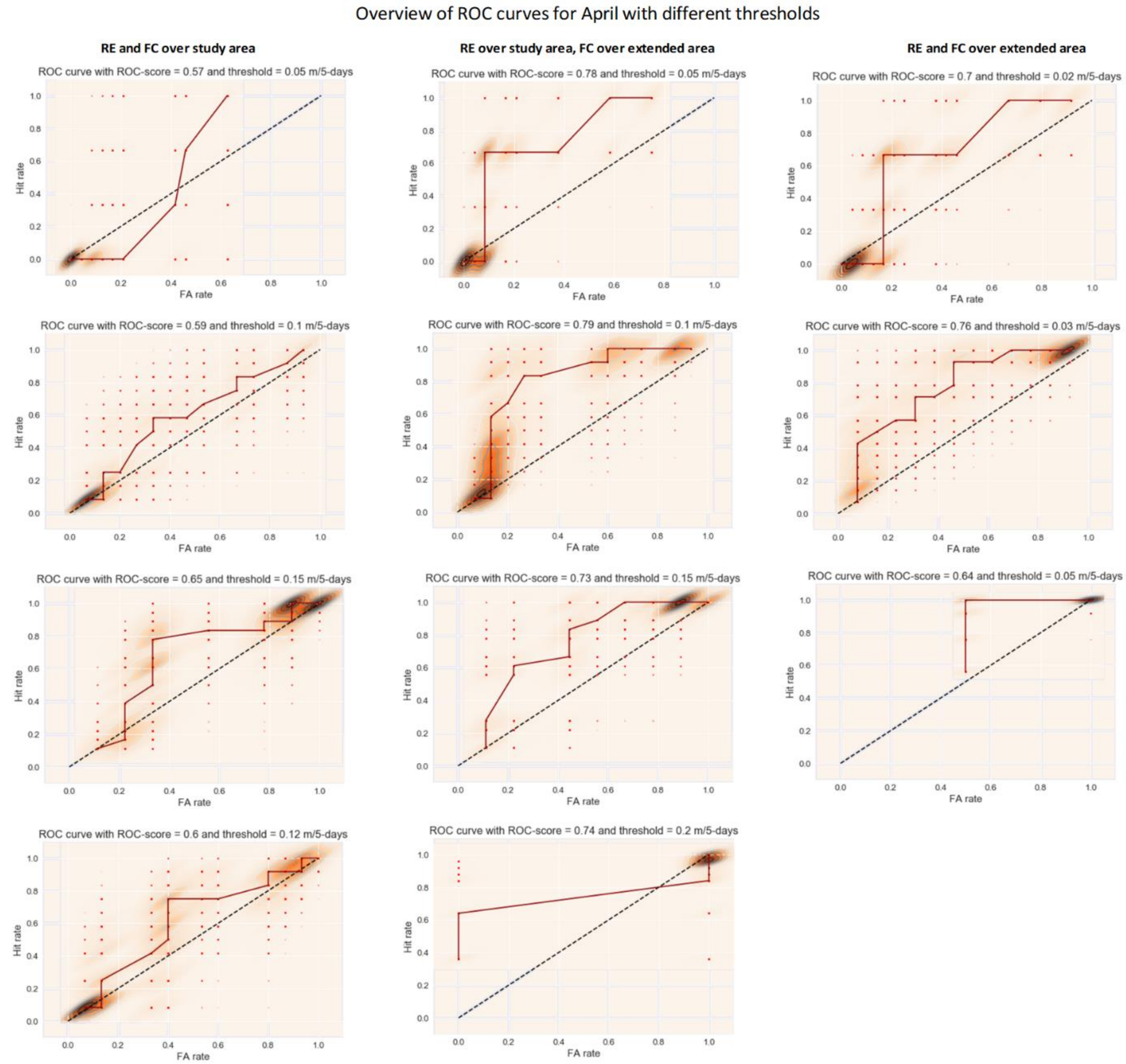

FIGURE 32 THIS FIGURE PROVIDES AN OVERVIEW OF THE ROC CURVES FOR NON-EXCEEDANCE OF DIFFERENT THRESHOLDS FOR APRIL FOR THE VARIOUS SCENARIOS. THE BLACK LINE INDICATES THE 'RANDOM' FORECAST SKILL. IF THE ROC CURVE IS ON THIS LINE, THE CHANCE OF A FORECAST BEING CORRECT IS 50/50. ANYTHING BELOW THE LINE INDICATES THAT THE FORECAST IS MORE OFTEN INCORRECT THAN CORRECT, AND THE CURVE ABOVE THE GRAPH SHOWS THAT THE MODEL HAS SOME SKILL. IN THE BACKGROUND CONTOUR LINES OF THE POINT DENSITY OF THE BOOTSTRAPPED DATA ARE PLOTTED. THE DARKER THE AREA WITHIN THESE CONTOUR LINES, THE HIGHER THE NUMBER OF POINTS WITHIN THIS AREA. THE RED DOTS SHOW ALL THE LOCATIONS OF THE BOOTSTRAPPED POINTS. THE LOWER THRESHOLDS SHOW A HIGH CONCENTRATION OF 'NO ALARMS' (BOOTSTRAPPED POINTS IN BOTTOM LEFT CORNER) THE HIGHER THRESHOLDS SHOW A HIGH POINT DENSITY FOR 'ALWAYS ALARM' (UPPER RIGHT CORNER). THIS SHOWS THAT OVERALL THE FORECAST DATA VALUES ARE LOWER THAN THE REANALYSIS DATA VALUES.