AN INTERACTIVE NEAR REAL-TIME EARLY WARNING AGRICULTURAL SYSTEM FOR NORTHERN FARMERS IN NAMIBIA

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN INFORMATION TECHNOLOGY

OF

THE UNIVERSITY OF NAMIBIA

BY

WILLBARD KOTOKENI KAMATI

201402279

OCTOBER 2024

MAIN SUPERVISOR: DR. VALERIANUS HASHIYANA (UNIVERSITY OF NAMIBIA)

CO-SUPERVISOR: DR. ELIAKIM HAMUNYELA (UNIVERSITY OF NAMIBIA)

ABSTRACT

Preparedness is a vital aspect of disaster mitigation, management, and recovery, especially in agriculture. However, it is quite challenging to prepare for unforeseeable disasters without adequate information on the nature of the disasters, their probable start, and their cessation. In the absence of sufficient disaster predictions and early notices, a community's readiness is at its lowest. This makes that community extremely vulnerable to the losses associated with the disasters. Meanwhile, agriculture is one of the sectors that has been exposed to different inevitable climatic threats over the years in Namibia. Inconsistencies in broadcasting weather information and early disaster warnings are some of the factors that hinder farmers' preparedness and mitigation of climatic disasters. Therefore, this study intended to explore the development and use of an early warning agricultural system to contribute to resilience and preparedness for hazards and threats by generating comprehensive and timely warnings for farmers in northern Namibia. The study started with a review of existing early warning agricultural systems in the northern regions of Namibia. Subsequently, a mixed research method was employed to conduct a survey in Outapi and Anamulenge constituencies to get 15 commercial and 73 communal farmers' past experiences with disasters, information sharing, their expectations, and readiness to adopt the system in mitigating the impact of disasters. Lastly, area-specific historic and near real-time data streams from Namibia Meteorological Service were obtained, and a near real-time interactive early warning agricultural system was ultimately developed using the prototype software development methodology. The study revealed that the use of early warning agricultural systems among Namibian farmers in mitigating agricultural losses is open for exploration, with a high possibility of feasibility to a portion of farmers that has technical resources and skills to adopt the system. However, it may come with limitations to the other portion of farmers with limited access to resources and skills.

Keywords: Agriculture, Disasters, Early Warnings, Mitigation, Namibia

LIST OF PUBLICATIONS/JOURNAL ARTICLES

Kamati, W., Hashiyana, V., & Mutuku, J. (2024). Development of a Near Real-Time Early Warning Agricultural System for Disaster Prediction. *Malaysian Journal of Computing, 9*(1), 1706-1721.

TABLE OF CONTENTS

LIST OF TABLES

TABLE OF FIGURES

LIST OF ABBREVIATIONS

CRUD	Create, Read, Update & Delete
CSV	Comma Separated Values
EWAS	Early Warning Agricultural System
GDP	Gross Domestic Product
GIS	Geographical Information System
GPS	Global Positioning System
ICT	Information Communication Technology
IoT	Internet of Things
NDVI	Normalised Difference Vegetation Index
NMS	Namibia Meteorological Service
UNAM	University of Namibia
UNFCCC	United Nations Framework Convention on Climate Change

ACKNOWLEDGEMENT

Firstly, I would humbly thank God for giving me all the strength, focus, and courage I needed to complete this research project, and most importantly, for granting me the opportunity to do this research project.

Secondly, I acknowledge that the success of this project would not have been possible without the guidance and support of my supervisor, Dr. Valerianus Hashiyana, and co-supervisor, Dr. Eliakim Hamunyela. I would like to extend my sincere gratitude and deep appreciation for their valuable input, endless support, and guidance throughout this project.

Lastly, I would like to pay tribute to the people of Outapi and Anumulenge constituencies for their unforgettable contributions to this project. Their involvement and cooperation were instrumental in its completion and success. I would also like to express my deepest appreciation to the Namibia Meteorological Service (NMS) for their important role in this project.

DEDICATION

I would like to dedicate this thesis to my entire family, the Kamati family, which provided me with all the unwavering support that I needed to conduct this study. The thesis is further dedicated to the entire farming community in Namibia which is working tirelessly to provide food to all Namibians and grow the country economically against all odds.

DECLARATION

I, Willbard Kamati, hereby declare that this research project titled "An Interactive Near Real-Time Early Warning Agricultural System for Northern Farmers in Namibia," submitted to the Faculty of Agriculture, Engineering & Natural Science, University of Namibia, is my original work done under the supervision of Dr. Valerianus Hashiyana and co-supervision of Dr. Eliakim Hamunyela. I confirm that I have not previously submitted it to any other university or higher education institution for the award of a degree.

Willbard Kotokeni Kamati	....	October 2024
Name of Student	Signature	Date

Chapter 1: Introduction

This chapter highlights the background of the study, the problem statement, research objectives, the significance of the study, limitations, and delimitations of the study.

1.1 Background of the Study

Internet of Things (IoT) and digitalization have tremendously transformed the world into a global village by connecting people from different corners of the world and improving the means of information sharing. This combination of technologies has created a paradigm shift in the way information is spread and accessed, enabling a network of interconnected devices and platforms. A notable application of this pivotal improvement in technology is the development of web-based early disaster warning systems. These systems are designed as a means for proactive disaster management and resilience-building within interconnected communities in the face of forthcoming disasters.

Meanwhile, Namibia has a rich history of farming despite unpredictable climate-related threats. Climatic threats include drastic changes in the weather within a specific region for a particular period (Oluyemi, 2015). Normally, when changes in weather parameters occur around their normal averages, they are regarded as normal. However, it becomes a matter of concern when they fluctuate significantly from their normal averages. The expected impacts of climatic disasters include a decline in water availability and rising temperatures due to higher evapotranspiration and changing rainfall patterns (Amadhila et al., 2013).

The northern region of Namibia is particularly one of the areas that is heavily invested in subsistence farming. Although this part of the country only covers 10% of the country's land, it is home to roughly half of Namibia's population (Wilhelm, 2012). In the same vein, Namibia is the most arid country in southern Africa, and only 2% of its land receives sufficient rainfall for production (Mbeeli, 2019). It is anticipated that extreme meteorological and climatological events, such as excessive rainfall, increasing heatwaves and droughts, would continue increasing in intensity, interval and occurrence in Namibia (UNDP, 2020). Therefore, the agricultural sector in Namibia continues to be subjected to poor production due to extreme weather events, as well as the underutilization of land and water resources. Limited access to skills and information is partly to blame for poor agricultural practices (Mtega, 2017). This poses a threat to food and water security in the country, while also affecting the Gross Domestic Product (GDP).

Meanwhile, an early warning system contains the essential technologies necessary for generating and disseminating prompt cautionary information. This empowers individuals, communities, and organizations confronting potential risks by enabling them to put necessary preparatory measures in place and respond appropriately to mitigate damage or losses (Magomelo et al., 2014). With regards to disasters, early disaster warning systems consist of a set of computer systems, tools, and processes capable of alerting people when a disaster is awaiting, which empowers individuals to take appropriate actions in sufficient time (Magomelo et al., 2014).

Early warning systems consist of key components such as risk understanding, risk monitoring, forecasting, warning dissemination, and response capabilities. Typically, these systems heavily rely on numerical models for forecasts beyond the immediate timescales (Somses et al., 2020). The significance of effective early warning systems extends beyond supporting agricultural production, it also plays a crucial role in safeguarding the livelihoods of communities and even saving lives (Magomelo et al., 2014). As a result, the adoption of early warning systems could be a viable approach to addressing both climate change and the climatic disasters associated with it in Namibia.

Methods of disseminating early disaster warning information include sirens, alarms, door-to-door alerts, internet, radio, television and so on. This information should be accessible, credible, suitable, actionable, and in time and space dimensions that allow for preventative measures (UNDP, 2020). However, in numerous communities struggling with natural disasters like floods and droughts, effective disaster early warning systems are either not available, highly ineffective or break down at critical points, thereby jeopardizing lives, and leading to destruction (Magomelo et al., 2014).

Early warning systems would face limitations without the integration of critical knowledge about different environmental and societal factors. Therefore, they must be comprehensible and inspire trust within the communities they serve (Magomelo et al., 2014). Furthermore, warnings hold minimal value if they don't prioritize or reach the individuals most vulnerable to risks, who should be educated to respond effectively to approaching hazards. Therefore, an early disaster warning is only useful if communicated effectively (Niipare et al., 2020).

While weather and climate modelling activities have seen extensive improvements in developed countries, progress has been slower in Africa due to limited access to supercomputing and other necessary technical resources required for running these models (Somses et al., 2020). One notable challenge in the effectiveness of internationally standardized early warning systems when implemented in rural settings is the oversight of community dynamics, which leads to system failure, inadequate preparedness, and subpar emergency responses to disasters (Moises & Kunguma, 2023). Therefore, most societies in Africa still rely on indigenous knowledge as a basis for assessing weather patterns, counting on their observation, experience, and cumulative knowledge to foresee natural disasters (Mbewe et al., 2019).

Research studies laid out areas that need special focus and improvement as listed below (UNDP, 2020):

- Adopting relevant technologies and suitable mediums of communication.
- Establishing shared databases and fostering community cooperation and engagement.
- Incorporating communities in systems design, operations and maintenance.
- Promoting information sharing and ensuring data quality, reporting frequencies, and effective dissemination channels.
- Building of affordable community-based weather stations.
- Encouraging public-private partnerships in building weather stations and distribution of weather forecasts.
- Digitizing historical weather records.

It is against this background that this study aimed to contribute to the mitigation of climate-related risks by developing a near real-time interactive agricultural early warning system as a complementary system and extension of the existing systems. The system would provide spatial-explicit information on crop and rangeland conditions. Historic and near real-time data from weather agencies' datasets would be processed and stored in the PostgreSQL spatial database, managed through Structured Query Language (SQL), mapped with the GeoServer, supported by Apache web server, and visualised and presented on a web-based system developed with PHP.

The information would be displayed in the form of comparable vegetation imagery using the OpenLayers mapping library, making it easier to comprehend, navigate, and identify patterns. Lastly, the system would have an interactive community forum through which farmers can send location-specific warnings to each other. This feature aims to improve community collaborations in various aspects, including risk detection, disaster monitoring, dissemination of early warnings, disaster mitigation, improving emergency responses, and improving information sharing among farmers.

1.2 Statement of the Problem

Namibia has a landscape that consists largely of five distinct geographical areas, each exhibiting unique environmental conditions and vegetation. These are the Namib Desert, the Great Escarpment, the Bushveld, and the Kalahari Desert (Steyn, 2021). Additionally, Namibia is made up of different climatic regions, namely the tropical, semiarid, and desert regions. Most of these regions are not favourable for managing agricultural activities due to changing weather patterns and extreme weather events associated with them (Awala et al., 2019). In addition, there has been an increasing occurrence of extreme weather patterns, including floods and prolonged droughts in recent years (Shikangalah, 2020). These patterns have had a significant impact on the availability of both surface and groundwater, as well as on rangeland and agricultural productivity (Awala et al., 2019). Furthermore, they have led to challenges in terms of food security and have aggravated land degradation issues like bush encroachment and soil erosion (Wilhelm, 2012). Meanwhile, timely weather estimates are hardly available to help farmers plan and foresee climatic misfortunes due to the low density of weather stations in the country (Awala et al., 2019). Furthermore, accessing most historic rainfall estimates is often difficult as they are only accessible through meteorological and hydrological agencies that are not easily accessible. Lastly, studies have proven the presence of early warning and disaster prediction systems, including the CEOS system, the TIGER-NET system, and the Namibia Meteorological Service weather forecasting systems, each with its own challenges and limitations.

1.3 Research Objectives

The main objective of the study was to develop a near real-time interactive early warning agricultural system to contribute to the mitigation of climatic disasters that hinder agricultural production in northern Namibia.

The sub-objectives of the study were defined as follows:

a) Determine existing early warning agricultural systems and disaster mitigation practices in northern Namibia.

b) Develop a near real-time interactive early warning agricultural system.

c) Evaluate the performance and usability of the developed near real-time interactive early warning agricultural system.

1.4 Research Questions

The main question of the study was:

How does the development of a near real-time interactive early warning agricultural system contribute to the mitigation of climatic disasters that hinder agricultural production in northern Namibia?

The sub-questions of the study were as follows:

a) What are the existing early warning agricultural systems and disaster mitigation practices in northern Namibia?

b) How can a near real-time interactive early warning agricultural system be developed?

c) How effective and usable is the developed near real-time interactive early warning agricultural system?

1.5 Significance of the Study

This research is significant as it serves as an educational tool and provides valuable documentation of poorly documented traditional disaster mitigation practices, as well as efforts to adopt newer technologies. Furthermore, it increases awareness and understanding of climate-related risks among farmers, promoting proactive disaster management strategies. The study further may serve as a blueprint for developing policies that support technological advancements and infrastructure improvements in rural farming communities.

1.6 Justification of the Study

This research shed more light on the potential of ICT to improve farming and strive towards smart farming in Namibia, especially for farmers in rural areas, and potentially bridge the gap between communal and commercial farmers in terms of skills and practices.

1.7 Limitation

This research was hindered by the lack of smart devices and computer literacy skills among some of its potential users, as well as poor network coverage in some areas.

1.8 Delimitation

This research was only limited to two constituencies within the Omusati Region, namely Outapi and Anamulenge constituency. This decision was made to reduce travelling costs, considering that the researcher was based in Outapi constituency, which is adjacent to Anamulenge constituency. Furthermore, it made it easier for the researcher to reach these areas. Additionally, selecting only two constituencies was convenient and time-saving.

Lastly, disaster prediction and early warning systems cover a wide range of components that cannot all be addressed in one research project. Hence, this research project focused only on analysing spatial data of two hydrological disasters, namely floods and droughts. However, warnings about other types of disasters can be communicated in the farmers' forum on the developed system.

1.9 Summary

This chapter has provided an overview of the study. It outlined the study's background, highlighting the difficulties faced by farmers due to extreme weather events and the lack of timely weather information. It emphasized the importance of early disaster warning systems. The chapter presented the problem statement, objectives, significance, justification, limitations, and delimitations. Overall, this chapter sets the stage for exploring technology in addressing issues related to climatic disasters in Namibia's agricultural sector, ultimately enhancing food security and sustainable agriculture.

Chapter 2: Literature Review

This chapter presents the state of agriculture, disasters, vulnerabilities, and disaster management in Namibia. Additionally, it compares indigenous and scientific weather forecasting. The chapter further extensively examines the use of early warning systems in Namibia.

2.1 Agriculture in Namibia

Namibia, like many other countries in southern Africa, faces continuous and increasing pressure on land resources to increase food production and reduce poverty, particularly in rural areas (Taapopi et al., 2018). Meanwhile, the majority of Namibians, approximately 60% of the population, live in rural areas and rely mainly on agriculture for subsistence (Wilhelm, 2012).

Additionally, the agricultural sector remains one of the prominent employers in Namibia, employing about 31% of the population (Mubita, 2019). As a result, the agricultural sector could make a significant contribution to poverty alleviation, income generation, and reducing food shortages in many parts of the country. Moreover, Namibia has a potential for economic transformation through agriculture, to achieve value addition, job creation, and improved living standards, thanks to its abundance of natural resources such as land and water (Mubita, 2019). This makes agriculture, including cereals and horticulture production, one of the sectors in Namibia with great potential for growth.

In 2000, agriculture contributed 5.6% to Namibia's Gross Domestic Product (GDP), with almost 90% of that coming from the production of cattle and small stock (Wilhelm, 2012). The key agricultural production subdivision in Namibia is cattle production, which generates an annual value of approximately N$900 million (Akashambatwa et al., 2017). From 2007 to 2016, the agricultural sector contributed around 4.2% to the GDP (Mubita, 2019). Despite facing numerous challenges, agriculture remains crucial to the livelihoods of most Namibians and continues to be a significant driver of the country's national GDP.

While business-driven and income-generating activities have gained momentum in many parts of the world, the majority of the population in northern and northern central Namibia still engage in subsistence crop farming, mainly focusing on pearl millet (Pennisetum glaucum), and livestock husbandry (Bloemertz et al., 2018). Pearl millet, commonly referred to as *"Omahangu"* in the local vernacular, constitutes the primary ingredient of staple diets and beverages for inhabitants residing in the northern and northern central regions of Namibia (Spear & Chappel, 2018).

Most small-scale subsistence farmers in north-central Namibia face numerous challenges, ranging from low crop yields and high rainfall variability to land degradation, which threaten the long-term productivity of the land (Bloemertz et al., 2018). The average grain yield in communal areas has been estimated to be around 0.5 - 0.55 tonnes per hectare (Montle, 2016). However, cereal production in Namibia has drastically dropped to 68,000 tonnes in 2015, compared to an average yield of 113,000 tonnes for the period between 2011 and 2015 (Bloemertz et al., 2018). This represents an average of 7% of the country's total agricultural production (Montle, 2016). This decline could be attributed to the sensitivity of cereal production to climate change (Montle, 2016), which affects food security in these regions and the entire country at large.

Assessing the state of agriculture in Namibia is crucial for a study such as this to understand its significance to the citizens in the regions and the country as a whole. Similarly, it is important to clearly identify areas that need special attention and evaluate the resources available when intending to create an early warning system.

2.2 Disasters

A disaster is defined as a disruption in the functioning of a society or community that results in environmental, economic, material, and human losses, often exceeding the capacity of the affected society or community to cope (Muvhali, 2013). It can be characterised as either human-induced or natural, localised or widespread, and sudden or progressive, causing damage to infrastructure, the environment, properties, and leading to loss of lives (Muvhali, 2013).

Similarly, a hazard refers to the probability of an event of a certain intensity occurring at a specific location during a defined period of exposure (Musungu, 2012). Hazards are further defined as dangerous substances, human conditions, or activities that can result in injury, property damage, loss of life, environmental harm, economic and social disruption, as well as the loss of services and livelihoods. Hazards also have a significant impact on agricultural production (Amadhila et al., 2013).

Hazards can be categorised into three main types: natural hazards, environmental hazards, and anthropogenic hazards (Gill & Malamud, 2014). Natural hazards encompass natural processes or phenomena occurring in the biosphere that have the potential to cause significant damage, such as earthquakes and volcanoes (Muvhali, 2013). Environmental hazards involve processes that damage or alter ecosystems or natural processes influenced by human behaviour or activities, such as climate change and deforestation (Muvhali, 2013). Lastly, anthropogenic hazards originate from industrial conditions, infrastructure failures, and technological conditions (Gill & Malamud, 2014).

On the other hand, risk is defined as the combination of the probability of a specific event occurring and the impact it would have if it occured (Musungu, 2012). It comprises two components: the chance or probability of an event happening and the consequences associated with that event (Musungu, 2012). In other words, risk refers to the expected losses, such as loss of life, injuries, property damage, and economic disruption, resulting from a specific hazard in a given area.

The evaluation of risks is crucial for appropriate planning and the design of interventions aimed at future risk mitigation (Muvhali, 2013). The consequences of a risk can be either desirable or undesirable, and risks can vary in magnitude from low to high (Musungu, 2012). Mathematically, risk is the product of hazard and vulnerability (Musungu, 2012):

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability}$$

On the other hand, preparedness is an ongoing process that involves the efforts of government, the private sector, and non-governmental organisations at all levels to identify threats, assess vulnerabilities, identify necessary resources, formulate and implement solutions (Musungu, 2012). Building resilience through preparedness interventions focuses on utilizing local knowledge, informed by predictions of possible climate changes, and shifting community behaviour in response to hazards (Amadhila et al., 2013). Therefore, preparedness should encompass various activities, including developing flexible response plans, training and equipping responders, and conducting thorough assessments of community vulnerability (Musungu, 2012).

Studying the dynamics of disasters, hazards, and risk evaluation was crucial in this study. This is because it paints a clear picture of the distinctions between them and how to tackle each one effectively when developing disaster mitigation strategies, such as an early warning system.

2.3 Vulnerability

Disasters are inherently discriminatory (Amadhila et al., 2013). Wherever they strike, pre-existing structures and social conditions determine that some members of the community would be less affected, while others would pay a higher price (Amadhila et al., 2013). Generally, vulnerability refers to the level at which the environment, community, individual, industry, infrastructure, property, and resources can be negatively affected by hazards (Muvhali, 2013). Additionally, vulnerability is widely regarded as the characteristics of a group or a person in terms of their capacity to cope, resist, and recover from the impacts of natural hazards (Muvhali, 2013).

Factors that determine one's vulnerability include geographical proximity to hazards, livelihood circumstances, social protection, and self-protection (Muvhali, 2013). Therefore, adaptation aims to improve a society's ability to cope with changes in climatic conditions (Wilhelm, 2012). Moreover, the ability of a group of individuals or society to provide support and protect themselves from harm is known as social protection (Muvhali, 2013). This includes technical knowledge and resources, access to information, knowledge, and materials (Muvhali, 2013). Therefore, one's vulnerability is worsened by a lack of adaptation strategies, especially in rural areas in Namibia.

Additionally, more factors have been identified that indicate when people are more likely to be at risk from the impacts of natural disasters. These factors include being a marginalised or disadvantaged individual (Muvhali, 2013). People are often disadvantaged and marginalised due to their social class, ethnicity, age, gender, and lack of resources or capacity. Consequently, they lack the ability to mobilise or protect themselves against hazards. Namibia's rural communities and impoverished populations throughout the country are particularly vulnerable to the adverse effects of climate change (Wilhelm, 2012). Studies conducted among rural communities in northern central Namibia have observed insufficient adaptive capacity to cope with the impacts of climate change (Kaundjua et al., 2012).

Natural hazards such as floods, droughts, and storms affect millions of people in Africa every year, often with devastating consequences (Amadhila et al., 2013). Namibia's economy heavily relies on its natural resources, thus making the country vulnerable to climate change and associated hazards, which can significantly impact its economy (Wilhelm, 2012). The vegetation in the Omusati Region consists mainly of mopane trees and thorny bushes, and much of the land is sparsely covered (Wilhelm, 2012). As a result, the land is vulnerable to flooding and soil erosion during the rainy season.

Climate change is predicted to cause significant spatial changes in vegetation structure (Wilhelm, 2012). Due to hotter and drier conditions, drier vegetation is projected to dominate over the grassy savannah (Wilhelm, 2012), which would impact livestock production and wild fauna. Namibia is highly vulnerable to the effects of climate change due to existing evidence of desertification, such as land degradation and bush encroachment, as well as recurrent droughts.

Studies conducted in the northern and central regions of Namibia have seen a later arrival and earlier cessation of rains, resulting in shorter seasons in most areas (Wilhelm, 2012). The country sometimes experiences an early, low-intensity rainy season starting in September and October, with the main rainy season typically lasting from January to March and occasionally extending to May (Kaundjua et al., 2012). Notable impacts of climate change include water scarcity, outbreaks of pests, and diseases (Kaundjua et al., 2012). The United Nations Framework Convention on Climate Change (UNFCCC) has identified responses to climate change, which include adapting to its impacts through community engagement in coping mechanisms and preparedness measures (Kaundjua et al., 2012).

With emphasis on Namibia's exposure to different disasters, it is equally important to understand the extent to which Namibians are vulnerable to these disasters and hazards. Furthermore, one needs to understand the circumstances that make these individuals vulnerable to these disasters to improve these circumstances and reduce the people's vulnerability.

2.4. Disaster Management

Disaster management is a continuous and multidisciplinary process of implementation and planning of measures which aim to reduce or prevent the risk of a disaster (Muvhali, 2013). It mitigates the consequences or the severity of a disaster by implementing effective and rapid responses to a disaster and restoration after a disaster. Disaster risk reduction is defined as a systematic approach to identifying, assessing, and reducing the risks of disasters (Amadhila et al., 2013). It seeks to reduce socio-economic vulnerabilities to all kinds of disasters, as well as deal with the environmental factors and other hazards that trigger them.

An effective disaster management system covers the following aspects: risk identification, emergency preparedness, capacity building, and risk mitigation (Amadhila et al., 2013). To tackle various disasters such as floods, research indicates the need for enhancing national and regional institutional capacity for early warning, response coordination, contingency planning, and integrating disaster risk management into development planning (Licke, 2023). This makes disaster management a broad and complex process that needs commitment and collaboration from private and government institutions, and the affected communities.

Amongst other government disaster management initiatives, the Disaster Risk Management Policy was launched in 2009 and later adopted in October 2010 (Tshilunga, 2014). It specifically aimed to reduce the impact of natural disasters and increase people's resilience to natural hazards and disasters in a way that aligns with other international policies. Their responses include the temporary relocation of people seasonally to dry land, and allocation of food parcels and shelter (Tshilunga, 2014). A similar initiative, the Flood Risk Management Plan, was launched in 2011 to guide local stakeholders in coordinating their efforts to manage natural hazards and incorporate these considerations into sustainable development decisions (Licke, 2023).

Another disaster management intervention in Namibia is the National Emergency Management System which aims to put the nation at the highest level of preparedness for natural disasters (Amadhila et al., 2013). It aims to not only react to emergencies, but also to reduce the risks. For this reason, there could be a need to have more than one competing intervention. On the other hand, the Disaster Risk Management Act highlights the responsibilities of local authorities and regional councils in developing and implementing strategies to build a resilient society against hazards (Licke, 2023). Therefore, it has also been noted that the Namibian government provides resources such as sand to create embankments to prevent water from entering and destroying properties, but with limited success (Amadhila et al., 2013). Reports have also reported on a government initiative that aimed to provide affected communities with food during and after flood and drought seasons.

Equally important, studies have shown that communities have insufficient coping or adaptive capacity to deal with major disasters and long-term climate risks (Steyn, 2021). However, not all strategies that are currently being practised by most communities are sustainable, nor are they capable of providing long-term solutions to these vulnerabilities. For instance, the evacuation of informal settlements may lead to community dependency on government relief, health risks associated with overcrowding, loss of economy and businesses, disruption of social structures, and lack of human dignity (Kaundjua et al., 2012).

Studies have further found that most local communities find it difficult to adapt to climate change and disasters linked to it, and therefore there is a need to (Kaundjua et al., 2012):

- Spread awareness on climate change, enhance coping strategies, and support the social mobilization of community members to help themselves.
- Ensure clean water provision during flood periods and emphasise on rainwater harvesting for agricultural irrigation, livestock and fish farming.
- Build earth dams for water harvesting.
- For engineers to design adaptive drainage systems.

In conclusion, despite the tremendous impact of disasters, they cannot entirely be controlled. Instead, they could be managed to lessen the damage they could cause. For example, an ideal disaster management strategy should incorporate the following components (Dambe, 2020):

- Investing in building water reservoirs, water channels, and drainage systems.
- Implementation of flood mapping, and land use planning.
- Immediate rescue and relief efforts to the sufferers in the form of food provision, shelter, sanitation, and long-term reconstruction.
- Accepting the losses.

When planning a new disaster management strategy, it is essential to review existing practices, assess their effectiveness, identify their shortcomings, and consider the desired standards. This process helps determine what to incorporate into the proposed strategy and what to avoid.

2.5 Indigenous Weather Forecasting

Before modern meteorological instruments, many traditional societies in Africa depended on indigenous knowledge to forecast the weather (Mbewe et al., 2019). Most communities have developed the art of assessing weather conditions using their experience, observation, and cumulative knowledge from generations (Muzuwa, 2017). It stems from various elements such as historical experiences, plants, insects, genetics, relationships, rituals, faith, and intuition (Mbewe et al., 2019). In other words, it is largely based on keen observation of various systems including the nature of clouds, fauna, flora, sun, moon, wind, migration patterns of birds, and other physical changes in their environments that precede or accompany meteorological phenomena.

Indigenous knowledge originates locally, naturally and/or spontaneously, and it is normally unique to a given community (Muzuwa, 2017). Hence, it is also known as local knowledge, traditional knowledge, indigenous technical knowledge, rural knowledge, and ethno-science which is significant for preparedness. Despite these advances, indigenous knowledge has not been well studied to determine its effectiveness (Muzuwa, 2017).

The indigenous indicators for weather prediction do not significantly differ amongst communities (Mbewe et al., 2019). They are broadly classified as meteorological (moon, stars and sun behaviour), biological (tree flowering and fruiting, tree leaves, bird and insect behaviour) and geographical (temperature and wind movements) (Muzuwa, 2017). Short-term indicators could be used to predict events within 24 hours or 2 to 10-day period (Mbewe et al., 2019). While, long-term or seasonal indicators could be used to predict weather events months before the events could unfold (Mbewe et al., 2019).

Although most local communities historically relied on indigenous knowledge to understand weather and climate patterns, the extent to which indigenous knowledge was used and the accuracy of indigenous knowledge in forecasting weather have not been adequately studied and documented (Mbewe et al., 2019). Therefore, lack of documentation results in a lack of understanding and ownership of knowledge of local farmers and communities. It is therefore important that local communities and the traditional leadership consolidate, document, and utilise indigenous knowledge in weather prediction for planning their livelihood activities such as farming.

Furthermore, studies have demonstrated the importance of indigenous knowledge and how it could still be employed in weather forecasting and wonderfully contribute to disaster risk reduction and saving of human life and agricultural production (Mbewe et al., 2019). There are still aspects of indigenous knowledge that remain relevant and critical to the weather forecasting system to date. Therefore, efforts could be made to integrate indigenous knowledge into modern weather forecasting systems to strengthen weather forecasting.

2.6 Scientific Weather Forecasting

Science is a process through which natural phenomena, problems, and questions are identified, defined, and solutions are proposed, tested or validated (Muzuwa, 2017). This means that scientific knowledge has been invented in attempts to interpret and explain theories generated through extensive enquiries and teachings that are tested and validated.

The scientific weather forecasts carry more specific information and accurate risk assessment to generate warnings for those at risk so that they can prepare adequately for the possibilities (Mbewe et al., 2019). Climate forecasts also help farmers reduce their vulnerability to extreme weather, while also allowing them to maximise opportunities when favourable rainfall conditions are anticipated (Mbewe et al., 2019).

Coincidentally, both indigenous knowledge and scientific knowledge are based on keen observation of one’s surroundings. Indigenous knowledge comes from a longer term of spontaneous observation while scientific knowledge usually relies on a shorter term of observation to produce scientific-driven outcomes (Muzuwa, 2017). Therefore, they could both be important factors to consider when developing an early warning system.

2.7 Flood Prediction

A flood is defined as the presence of excess water in an area that is known to be usually dry. The University of Wisconsin established characteristics of floods which include high water velocity, increased water depth, and increased rate of rise, i.e., the rate at which water depth increases (Dambe, 2020). Floods are associated with different impacts.

The impact of floods can be both positive and negative. The negative impacts of floods include the damages that floods cause to people and the environment as a result of the uncontrollable movement of water that immerses and washes away trees, agricultural land, properties, and infrastructure, among others (Dambe, 2020). On the brighter side, floods come with fertile soil in floodplains, water for domestic purposes, and flat plains conducive for settlement (Dambe, 2020).

Studies have estimated that on a global scale, there were 539 811 fatalities, 361 974 injuries, and 2 821 895 000 people were displaced as a result of floods between 1980 and 2009 (Dambe, 2020). Based on a global analysis of floods, an amount of US$ 24 billion was spent annually specifically on floods from 2001 to 2011 (Dambe, 2020).

Locally, between 2008 and 2009, Namibia experienced heavy rains in the north and north-eastern parts of Namibia, which resulted in severe flooding (Amadhila et al., 2013). The heavy rains were worsened by the rainfall received in the neighbouring countries, i.e., Angola and Zambia (Amadhila et al., 2013). Prior to that, Namibia experienced a number of hazards between 2004 and 2009 in the south, north and northeast (Amadhila et al., 2013). Additionally, from 1982 to 2008, the country had close to 19 events of natural disasters including floods, which affected about 884 953 people (Amadhila et al., 2013). The floods caused tremendous destruction to infrastructure, homes and property, loss of agricultural production and lives.

On the other hand, hydro-meteorological records in the past were scarce and limited to a 30-year timeframe (Dambe, 2020). However, recent developments have facilitated the utilization of sophisticated computers with high processing power and speed, enabling the employment of numerical models for making predictions. The modelling processes are either hydrological or hydraulic modelling. Hydrological modelling plays a crucial role in flood management as it seeks to answer the question of "how much water is there?" (Dambe, 2020). While hydraulic modelling is relevant in addressing the question of "where will the water go?" (Dambe, 2020).

Fortunately, the limited access to quality real-time and lengthy data has been overcome by the availability of new types of remote sensing techniques like satellites, and the standardization of data through international and interdisciplinary data sharing and open-source data (Dambe, 2020). Floods can now be predicted with high accuracy because more real-time and historic data about rainfall is now available through the abovementioned technologies (Muvhali, 2013).

Additionally, recent advances in climate modelling have resulted in an increased ability to predict rainfall in many parts of the world with a lead time ranging from a few days to a few months, by using dynamical forecasts or statistical methods (Mbewe et al., 2019). While these sophisticated scientific models are better at forecasting the weather, it is also vital to realise that indigenous knowledge should not be relegated to the background. Integration of indigenous knowledge and meteorological forecasts could be useful in effective rainfall forecasting and decision-making at the village level (Muzuwa, 2017).

Therefore, this study intends to document the different methods used in flood prediction. Additionally, it aims to demonstrate that if new and old methods of disaster mitigation are combined, the resilience of communities vulnerable would be immensely enhanced.

2.8 Drought Prediction

Drought is a persistent climatic process that occurs with uneven temporal and spatial characteristics over broad areas for an extended period of time (Wyss et al., 2022). Drought is characterised by precipitation deficiency in terms of amount, intensity, and timing. High temperatures, high velocity winds and less cloud coverage are some of the signs that are associated with droughts (Wyss et al., 2022). Drought prediction is one of the methods used to predict the likelihood of upcoming droughts. This is mostly done by assessing rainfall patterns from the previous months to generate drought warnings to warn farmers and other concerned parties.

Locally, between 2000 and 2007, Namibia experienced at least five crippling droughts which affected between 300 000 to 700 000 people in all 13 regions (Amadhila et al., 2013). It is further predicted that there would be droughts in the coming years (Angombe, 2012). Hence, it is important for affected communities to take necessary precautionary measures once they receive a warning. Furthermore, proper planning and research on near real-time data could curb the devastating environmental and socio-economic impacts of drought.

In addition, drought warnings are also needed by government agencies and other organisations with keen national interests and responsibilities (Angombe, 2012). Hence, drought assessment helps the government assess the state of the drought to implement drought relief programs and other mitigation measures, and is important for people living in the affected areas.

Accuracy of drought warnings is the primary goal when it comes to drought prediction. While it is frustrating and costly to give disaster warnings that never materialise, it makes the users lose faith in the effectiveness of early warning systems. Therefore, detecting drought onsets and ends as well as assessing drought severity is essential as it generates reliable warnings. Considering these factors would be beneficial for the proposed system.

2.9 Early Warning System in Namibia

An early warning system is a set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organisations threatened by hazards to prepare and act appropriately in a timely manner to reduce the possibility of harm or loss (Department of Environmental Affairs, 2016). The early warning system includes three components: a process to monitor weather indicators, a contextualised analysis of these indicators and trends, and the means to communicate findings (IFRC et al., 2014). The aim of early warning is to empower individuals and communities, predisposed to hazards, to act in reducing personal injuries, deaths, and damage to properties, or surrounding environments. Forecasts and warnings should aim to provide key information to users on which they can base their decisions on.

Early warning systems are designed to provide services that include short to medium-term weather forecasts, prediction of the onset and cessation of a rainy season, prediction of wet and dry seasons, climatic forecasts and soil moisture monitoring, and drought predictions. Such systems can be based on local observations, or a highly technical approach based on analysis of remote sensing data (IFRC et al., 2014).

Characteristics of effective early warning systems include (IFRC et al., 2014):

- **Trusted:** The information and analysis it provides must have the confidence of its users.

- **Accountable and transparent:** They should be held accountable for the predictions they produce, and each system should be judged in terms of its prediction capability.
- **Have a clear mandate:** Early warning systems should have a clear set of functionalities.
- **Communicate effectively:** The outputs of an early warning system must recognise the diversity of the audience and be appropriate to that audience. They should include a clear indication of the severity, and timing (IFRC et al., 2014).

Additionally, in order for early warning systems to be effective they should address four key elements as defined by the United Nations International Strategy for Disaster Risk Reduction (UNISDR): 1) risk identification, 2) monitoring, 3) warning dissemination, and 4) response actions (Department of Environmental Affairs, 2016).

Furthermore, the effectiveness of the early warning systems depends not only on technical capabilities but also on the preparedness of decision-makers and their immediate response. Therefore, the effectiveness of an early warning is assessed on how early the warnings are disseminated, whether the early warnings align with other credible forecasts, the kind of information incorporated in the early warning, and whether the early warnings are accepted or ignored by the local communities. If ignored, what the reasons were. Moreover, the warning messages must be simple, understandable and should have instructions on how to react while the timeliness of the message dissemination has to be highly respected.

It is encouraged to develop early warning systems that are people-centred. They should directly reach the affected population through accessible media and platforms. Early warning alerts and messages mostly have a specific and wide potential audience, hence the specific audience needs to be taken into account when considering the language, complexity and medium of each communication (Department of Environmental Affairs, 2016).

Although there is strong evidence that early warning systems can and do provide sufficient warning for governments, other development partners and humanitarian entities are further encouraged to take actions in protecting lives and livelihoods, and strengthen resilience (IFRC et al., 2014). This includes addressing challenges around warnings interpretation and translation of climate information at the local level.

Several existing early warning systems in Namibia were reviewed. The first system was the CEOS Project, which is an experimental project in which a Namibian early flood warning system was piloted under the Ministry of Agriculture, Water, and Forestry (MAWF) (Mandl et al., 2012). The project aimed to promote the adoption of satellite sensor data in early warning systems. Making use of NASA's SensorWeb technology, the project integrated data from satellites with ground sensors like river gauges in Namibia. Furthermore, the project also experimented with the Open Cloud Consortium's (OCC) cloud computing services to manage and distribute large datasets of rainfall data. This combination of technologies was used in Namibia to create a Flood SensorWeb system that aimed to form a flood monitoring and early warning decision support system tailored to local needs in the Zambezi region (Frye et al., 2013). During the pilot, several performance challenges were identified, including incorporating large size of datasets, security issues, and network bottlenecks hindering the presentation of maps on the dashboard. Additionally, the flood dashboard, designed to provide a visual interface for data mashup and visualization to support decision-making, faced display challenges, especially with iPads, and interoperability issues (Mandl et al., 2012).

The second system reviewed was the TIGER-NET project, which involves operational probabilistic hydrological modeling and river discharge forecasting, using a hydrologic–hydrodynamic modeling system and data assimilation approach to inform forecasts with all available in situ and remote sensing observations and meet the demand for free, up-to-date, and spatially resolved water information, and capacity-building across the African continent (A.Walli et al., 2013). Reliable forecasts of river discharge are essential for flood and drought management. Among the partner institutions involved in the TIGER-NET project is the European Space Agency (ESA) and the Ministry of Agriculture, Water, and Forestry, which is has interest in forecasting the discharge of the Kavango River. The entire system has been developed as an open-source, robust, and simple probabilistic river discharge forecasting system for poorly gauged river basins, based solely on open-source software and public data (A.Walli et al., 2013). Challenges identified during the piloting process on the Kavango River include the absence of an operational data set of in situ precipitation observations, due to a limited number of operational meteorological and river discharge stations in this part of the country. Additionally, the spatial resolution of forecasts is reduced by a factor of two for forecasting horizons beyond one week (Bauer-Gottwein et al., 2015).

Lastly, the Namibia Meteorological Service is a renowned institution in Namibia that operates an extensive network of both manual weather stations and automatic weather forecasting systems (Strohbach, 2014). The Namibia Meteorological Service is dedicated to applying meteorology, acquiring and preserving Namibia's national climate data, ensuring that quality weather and climate services are accessible to vital economic sectors including aviation, water resources, agriculture, energy, tourism, and the environment, all of which are vital to the national economy. The dissemination of seasonal climate forecasts often reaches farmers through televisions and radio broadcasts (Strohbach, 2014). However, despite the wide availability of these forecasts, some farmers, particularly in northern Namibia, do not utilize this valuable information (Davies et al., 2019). The reasons include challenges with downscaling the forecasts to relevant communities, limited capacity among farmers to understand and interpret the forecast data, and mismatches between the provided information and what farmers perceive as practically useful (Davies et al., 2019). Hence, this information is often too broad and general to be used in decision-making and preparation processes by conservative farmers.

Therefore, the reviews above justify the need to create a farmer-centric early warning agricultural system to enhance disaster preparedness and mitigate the impacts of floods and droughts, particularly in vulnerable regions. Key features to incorporate in such a system include robust infrastructure for quality weather data management, high interoperability with various technologies, user-friendly graphical interfaces, and addressing security concerns. Additionally, optimizing network performance is vital to ensure reliable and timely information dissemination to decision-makers and affected communities.

2.10 Gaps in Current Early Warning Systems

Some of the gaps in current early warning systems include (Council for Scientific and Industrial Research, 2014):

- Dissemination of warnings to all levels of society remains a challenge.

- Lack of awareness in communities.
- Poor participation of communities and other key stakeholders in disaster management.
- Lack of funding or limited institutional knowledge on how to secure funds.
- The acceptance of early warning systems remains slow.

Further weaknesses and challenges in the use of early warning systems include (UNDP, 2020):

- There is often insufficient data, and the data quality is poor.
- Inadequate data sharing from agencies and governments, and a high cost of data
- Early warning systems are sometimes not user-friendly, and users are not trained on the application of early warnings in decision-making.
- Lack of the ability of disaster monitoring systems to fully understand disaster magnitudes.
- Issues of inaccessibility, underutilization, and general unacceptance.
- Sometimes information delivered through early warning systems is too technical, such that its interpretation and comprehension to the ordinary community member is limited, resulting in little or no action.
- Lack of political will and government endorsement.
- Non-existent correlation between traditional systems and formal early warning systems.

The gaps identified in the current early warning systems serve as crucial reference points in designing a new improved system. These shortcomings can also be used as guidelines for defining the requirements of the new system.

2.11 Conclusion

It is highly recommended that weather agencies move from reactive disaster management to proactive disaster management approaches (Council for Scientific and Industrial Research, 2014). These approaches should align with the international best practices and maintain the standards of the World Meteorological Organization and International Weather Services (Department of Environmental Affairs, 2016). These practices include the use of multiple monitoring systems, meteorological, hydrological and climate information to prepare for and respond to hazards (Department of Environmental Affairs, 2016). Furthermore, the disaster warnings could be broadcasted to the affected communities through the media, i.e., printed, electronic media platforms, the internet, and cellular services.

Locally, the number of Namibian internet users has skyrocketed to approximately 1,347,418 by December 2020, representing a 4,391 percent growth from 2000 to 2021 (Nawa, 2021). The internet could be a convenient platform to deploy early warning systems in Namibia. This is because Namibia has a good number of internet users and farmers would not have much trouble using the same medium to receive clear, understandable, area-specific, and action-provoking early warnings through the internet.

2.12 Summary

This chapter discussed the state of agriculture, disasters, vulnerabilities, and disaster management in Namibia. It also compared indigenous and scientific weather forecasting. Additionally, it thoroughly explored the use of early warning systems in southern Africa.

Chapter 3: Research Methodology

This chapter presents the research methodology used in the study which entails the research design, participants, sampling, data collection, research procedure, data analysis, ethics, and the processes involved in transforming the system requirements into a fully functional system.

3.1 Introduction

Researchers employ a combination of different techniques to help discover new knowledge and understanding. In this study, to achieve the initial research objectives, specific methodologies and methods were selected and applied. A methodology refers to a guideline followed to achieve the objectives of a study (Lameck, 2016). A method, on the other hand, is a sequence of activities applied to achieve the methodology, which is specific to the nature of the problem (Lameck, 2016). They are all however essential for guiding researchers and ensuring that the problem at hand is eventually resolved.

3.2 Research Paradigm

This study embraced the pragmatic paradigm, a practical and action-oriented approach to addressing the research questions and achieving the study objectives, regardless of whether they are traditionally qualitative or quantitative. It best suited the descriptive nature of this study as it is flexible and adaptive in selecting the most appropriate techniques for data collection and analysis.

3.3 Research Design

This study adopted a descriptive research design. The descriptive research design helps in describing the characteristics of a population or phenomenon being studied. Therefore, the descriptive research design was chosen to provide detailed and comprehensive descriptions of the current state of early warning systems, and disaster mitigation practices, and identify areas that require improvement. This ultimately contributes to the development of effective strategies for mitigating weather-related risks in the study area. Additionally, it enabled the collection of both qualitative and quantitative data, facilitating a thorough and holistic investigation of the research problem. This aligns with the study's objective of using a mixed research approach.

3.4 Method

It is essential for a researcher to have clear strategies required for the process of transforming a general plan into well-articulated ideas for data gathering, and addressing the research problem at hand successfully (Nashandi, 2020). Hence, this research adopted the mixed research approach to jointly incorporate the qualitative and quantitative methods to accomplish the defined objectives, mainly, Objective a), which was about closely exploring the extent to which early warning systems are currently utilised, reviewing current disaster mitigation practices, and expose areas that could be improved.

A mixed research approach involves studying and interpreting quantitative and qualitative data in a series of studies that investigate a common underlying problem. Furthermore, a mixed research approach seeks validation, elaboration, discovering inconsistencies, and widening the range of research by using diverse methods. Hence, this method was suitable for this study, particularly because the use of GIS in early warning systems has not been fully explored in Namibia. Thus, this study needed to discover an in-depth and holistic understanding of the best ways to implement it while mitigating weather-related risks at hand.

3.5 Study Area

The area chosen for this study was Outapi and Anamulenge constituencies in Omusati region. These neighbouring constituencies are located along the Namibia and Angola border, in the northern central region of Namibia. According to the 2011 census, the northern and northern central regions alone (Ohangwena, Oshana, Omusati, and Oshikoto region), which are further subdivided into 41 constituencies, account for a combined population of 847,259. Specifically, there are 245,446 people in Ohangwena, 243,166 in Omusati, 176,674 in Oshana, and 181,973 in Oshikoto region (Shifidi, 2014). With their rich history of subsistence agro-silvo-pastoralism, it has been reported that about 25% of cattle, 43% of goats, and 70% of donkeys in Namibia are found in the northern central regions (Wilhelm, 2012).

The Omusati Region alone has a total area of 26,551 km², which is further divided into 12 constituencies, including Anamulenge and Outapi (Taapopi et al., 2018). This region is one of the most densely populated regions in Namibia, with a population of 243,166. Over 90 percent of the total population in the Omusati Region lives in rural areas. The population density is twelve (12) people per km², which is almost five times higher than the national population density average (Wilhelm, 2012).

Geographically, the Omusati Region is located in the Cuvelai River Basin, an ephemeral river system that carries excess rainwater from southern Angola during the rainy season to the Etosha Pan in northern Namibia (Shaamhula & Rooy, 2019). The Cuvelai-Etosha River Basin is also characterised by an interconnection of trivial water courses, known as *'iishana'* in *Oshiwambo* (Shaamhula & Rooy, 2019). The Omusati Region receives an annual average rainfall between 300-400 mm, which falls seasonally between October and April. The region's topology is mostly flat, with arid sandy soils. This makes Omusati Region farmers extremely vulnerable to several climatic disasters and other effects of climate variability.

The Anamulenge and Outapi constituencies cover an area of 353 km² and 4,178 km² respectively. They have a total population of 50,500 and 9,500 households, most of which have farming fields according to the 2011 census. The reason for opting for these constituencies is that they are located in one of the regions that experience an increase in water scarcity and extensive flooding regularly. Additionally, agricultural production in Omusati Region is anticipated to become extremely unstable, leading to severe food insecurity (Amadhila et al., 2013).

3.6 Population

Generally, a research population is a group of individual persons, objects, or items from which samples are taken for measurement (Nashandi, 2020). Therefore, the population for this study was the farmers within Outapi and Anamulenge constituencies in Omusati region. However, it was initially challenging to determine the precise size of the targeted population because the statistics could not be obtained. As a result, the total number of households in the two constituencies, i.e., 9 500, was used as the estimated population size. This approach was taken since over 90 percent of the total population in the Omusati Region resides in rural areas, and the majority of households in these areas have farming fields according to the 2011 census. This method was employed to arrive at an estimated population size within an acceptable margin of error.

3.7 Sample

It is not practical or feasible to study the entire research population. Therefore, a sample was selected to participate in the study. This is a set of participants selected from a larger population for the purpose of a survey (Nashandi, 2020). The stratified sampling method was employed in this study. The stratified sampling method is a method for achieving a greater degree of representativeness and for reducing the degree of sampling error (Nawa, 2021). For this study, farmers were grouped into 2 strata, namely, communal and commercial farmers. Communal farmers were persons who evidently conducted farming activities within their traditional residences, while commercial farmers were individuals who owned small to medium-sized farming operations, primarily along the Calueque-Oshakati water canal. Subsequently, random sampling was done in each stratum based on their accessibility, availability and interest. The sample size was initially 20 commercial farmers and 80 communal farmers. However, the response rate was 75% for commercial farmers and 91% for communal farmers.

3.8 Data Collection

Given the nature of this research, both qualitative and quantitative data collection methods were used. Therefore, semi-structured face-to-face interviews and questionnaires were used as research instruments to collect qualitative and quantitative data respectively. The qualitative data was centred around the farmers' past experiences with disasters and information sharing, their expectations and readiness to adopt the proposed system for mitigating the impact of disasters. While the quantitative data was about the farmers' farming experience, it also addressed the frequencies at which they attempted to use early warning and information sharing systems. The data collection efforts aimed to reach Objective a).

3.8.1 Semi-structured Interviews

Generally, interviews involve an interviewer, who facilitates the conversation and asks questions, and an interviewee, who responds to these questions (Sheya, 2019). However, a semi-structured interview allows an interviewer to probe in a non-standardised manner as much as they can until they obtain answers relevant to the study (Nawa, 2021). This gives the researcher an opportunity to give further explanations or rephrase questions for participants, should they be unclear.

For this study, not all questions were pre-written before the interviews, some of them were prompted by the open and flexible conversation the researcher had with the farmers. This gave the researcher an opportunity to give clarification on the concept of early warning agricultural systems.

3.8.2 Mixed Questionnaires

The mixed questionnaire comprised both open questions and closed-ended questions, i.e., scales, dichotomous, and multiple choices. Questionnaires were one of the best instruments for this study because they could collect a large amount of data in the limited time that was allocated for data collection for this study. Before the questionnaires were handed to respondents, the researcher gave an introduction to the survey and its purpose. This is due to the fact that the concept of early warning systems was new to most respondents.

Before the actual data collection process, the questionnaire was piloted to ensure that the questionnaire's content, layout, and wording were appealing, clear, and understandable to the potential respondents. For this study, four farmers were involved in this exercise. It took each farmer approximately 12 minutes to grasp the concept of early warning systems and how they could impact their lives. One farmer was satisfied with the questionnaire, while the other three suggested that more clarity should be provided on early warning systems and how they work before the questionnaires are handed over to any respondents. As a result, more explanations were included in the questionnaires and more effort was put into clearly introducing the study before the questionnaires were given to respondents.

3.9 Procedure

Firstly, the researcher obtained a permission letter as approval from the main supervisor of the research from the University of Namibia to proceed with data collection. The letter was presented to potential respondents to demonstrate the legitimacy of the study. Extensive literature reviews, complemented by questionnaires and interviews, explored the effectiveness of existing early warning systems, and disaster mitigation measures as well as their shortcomings in northern Namibia. This was done to achieve Objective a).

Interviews were conducted at the respondents' respective farms. Most interviews were conducted in Oshiwambo, which is the native language spoken by the majority of people in the Omusati region. Afterwards, the findings were translated into English by the researcher. Similarly, questionnaires were handed over to farmers at their farms and farming projects. They were filled out in the researcher's presence, allowing for additional explanations and addressing any queries from the farmers. The majority of the clarifications were provided in Oshiwambo. Each respondent spent roughly 20 to 50 minutes to complete a questionnaire.

Subsequently, a fraction of farmers was shown prototypes for further enhancements until all desired features were integrated. Thereafter, the development of a near real-time interactive early warning agricultural system was begun to achieve Objective b). Lastly, area-specific historic and near real-time weather data was acquired from the meteorological agency i.e., Namibia Meteorological Service (NMS), to evaluate the performance of the system, and users were allowed to test the usability of the system, hence achieving Objective c).

Table 3.1 below summarises the research objectives and procedures that were followed to achieve them.

Research objectives	**Procedures**
a) Determine existing early warning agricultural systems and disaster mitigation practices in northern Namibia.	Questionnaires, and semi-structured interviews were employed to accomplish the objective.
b) Develop a near real-time interactive early warning agricultural system.	Results from Objective a) incorporated into the design and development of a desirable early warning system for agricultural purposes.
c) Evaluate the performance and usability of the system.	Historic and near-time data obtained from the Namibia Meteorological Service were imported into the system to evaluate its performance and usability. Furthermore, questionnaires were used to gather the users' evaluation feedback.

Table 3.1: Research Procedure Source: Willbard Kamati

3.10 Data Analysis

Fundamentally, data analysis is the process of summarizing, grouping, and categorizing non-standardised and complex collected data to become meaningful information (Nawa, 2021). It involved sorting, organizing, storing, processing, analysing, and studying collected data to discover new knowledge and understanding. The content analysis technique was used to analyse and interpret the data collected from farmers through semi-structured interviews and questionnaires. It involved thorough data interpretation, and pattern identification to successfully review existing early warning agricultural systems and disaster mitigation practices in northern Namibia. Thereafter, the outcome assisted in pinpointing factors and attributes to be integrated into the developed system to contribute to the mitigation of manageable disasters facing the agricultural fraternity, hence attaining the main objective.

3.11 Research Ethics

Research ethics ensure that researchers follow the ethical standards and policies of the institution they are representing when conducting data collection (Mutelo, 2019). Ethical standards endorse collaborative work, trust, accountability, mutual respect, and fairness (Mutelo, 2019). Ethical clearance was obtained from the Decentralised Ethics Committee (DEC), and research permission was obtained from the Centre for Research Services of the University of Namibia (UNAM) prior to engaging farmers.

Additionally, farmers were given a detailed presentation on the purpose of the research, and what information being collected would be used for. Furthermore, the researcher ensured farmers that no harm would be exposed to them. The researcher also ensured that participants understood that their participation was voluntary, and that they could withdraw at any given time. Permission was given by participants to take notes, and their identities were protected throughout the data collection exercise.

3.12 Software Development Methodology

After data collection, prototype software development methodology was applied to ensure that the development of the system only commenced once a percentage of farmers had approved the prototype. This is a software development model that allows a developer to create a prototype of the solution to demonstrate to the clients for modifications before developing the actual application (Munywoki, 2020). It gives a client a clear understanding of the complete concept of the application and reduces the risk of failure since potential risks can be identified in the early stages and rectified (Munywoki, 2020). The prototype software development methodology was employed to attain Objective b) and the main objective of the study.

Additionally, the collaborative relationship between the farmers and the researcher made the development goal centred and user centred which also helped with gathering requirements. The prototype software development methodology allowed farmers and the researcher to come up with the final requirements for the system before the actual system development began.

Figure 3.1 shows a graphical representation of the prototype software development methodology:

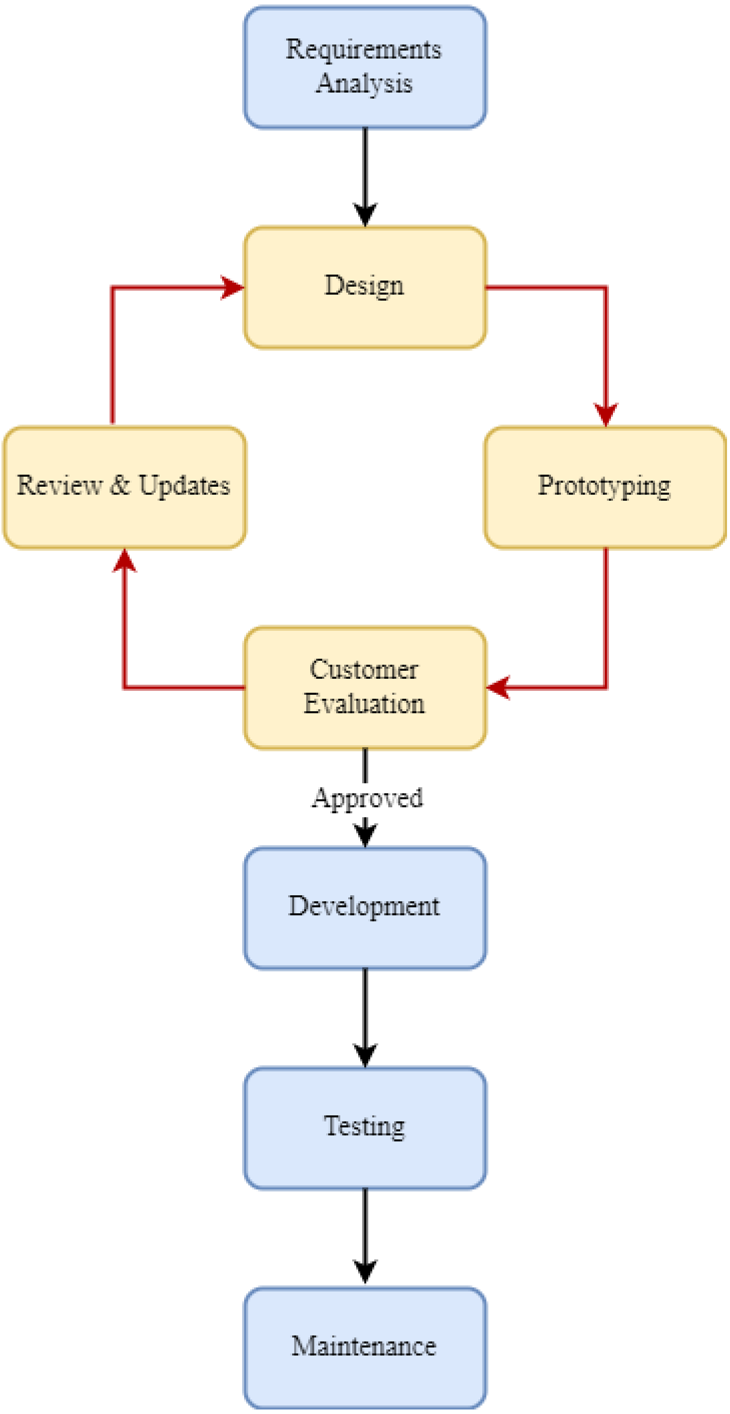


Figure 3.1: Prototype Software Development Methodology *Source: Willbard Kamati*

3.13 System Implementation

Several steps were involved in the software development process of the EWAS. These were requirement analysis, system design, prototyping, the actual system development and system testing.

3.13.1 Requirements Analysis

Requirement analysis involves defining the purpose of the proposed application, the services the system would provide, how the system would react to particular inputs and situations, and defining how the system would meet the users' needs. It is an essential part of software development which determines the success or failure of the application. The success of an application is based on whether the defined requirements were met or not. Software requirements are further classified into two categories, i.e., functional, and non-functional requirements. These requirements were informed and shaped by the respondents' expectations and attitude towards the system.

3.13.1.1 Functional Requirements

The functional requirements entail the functionalities an application would perform. These are the services that the application would offer to its users. The early warning agricultural system for northern farmers has the following functional requirements or capabilities:

- Compare weather data - Historic and near real-time data is visualised and presented on a web-based system in the form of comparable vegetation imagery, which makes it easier to comprehend, navigate, and identify patterns.
- Navigate the map - the users are able to navigate selected areas, zoom in and zoom out, using the map to pinpoint hazardous areas.

- Receive warning notifications - the system analyses the historic and near-real time data, picks up patterns, and signs of upcoming disasters, and the system would present these warning notifications on the map.
- Send warnings - through the interactive farmers' map-based forum, farmers are able to send alerts, i.e., detailed geotagged warnings to other farmers.
- Receive warnings - similarly, through the interactive farmers' map-based forum, farmers are able to receive messages, i.e., detailed geotagged warnings as communications from other farmers.

Figure 3.2 below shows the use cases of the EWAS. The use case is essential for requirement analysis as it defines the specific interactions between users and the system, providing a clear understanding of how the system should operate to meet user needs.

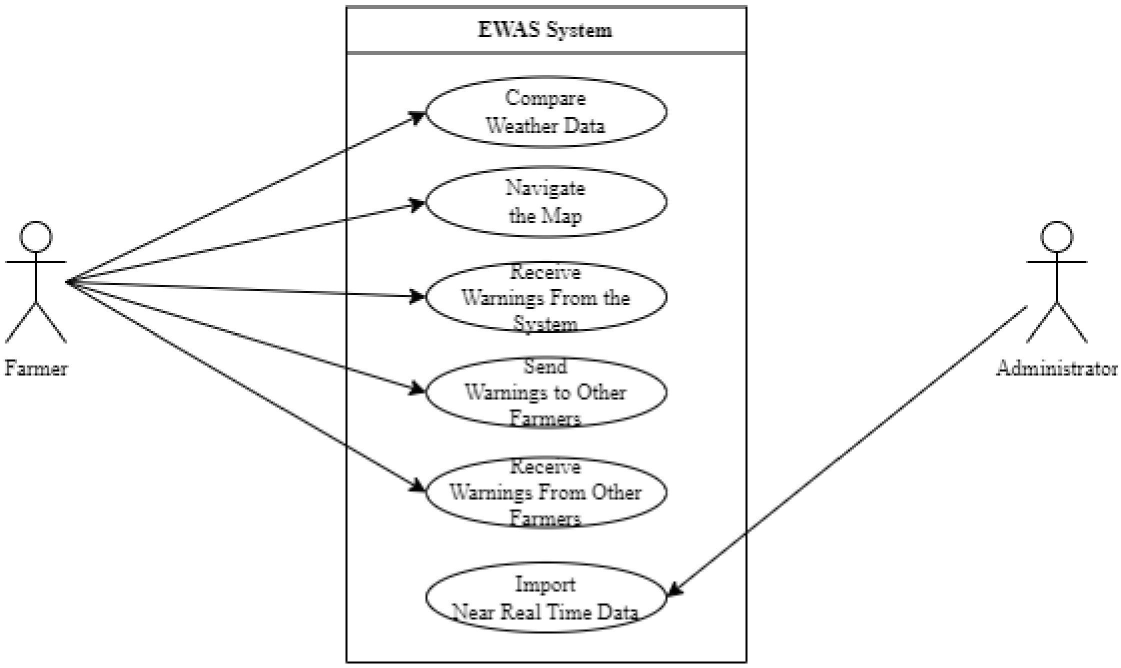


Figure 3.2: Use Cases *Source: Willbard Kamati*

3.13.1.2 Non-functional Requirements

The non-functional requirements are focused on attributes and constraints that might prevent the system from functioning effectively. Although an application can be executed without meeting certain functional requirements, an application which does not satisfy all the required non-functional requirements is considered not useful (Nashandi, 2020).

The early warning agricultural system for northern farmers has the following non-functional requirements:

- Openness - It allows the system to be flexible in a way that farmers and other interested users can navigate the application without restrictions. This is achieved by not imposing limitations on the system controls.
- Security - This system avoids storing farmers' sensitive data to prevent data leakage.
- Scalability - The web-based system is able to cater for a varying number of farmers without affecting its overall performance. This is ensured by hosting the application with a reliable provider that supports optimal scalability
- Availability - Keeping the system up and running every time farmers want to access its services is the ultimate goal. This is achieved by using a reliable hosting service with a 99.9% uptime assurance.
- Interoperability - Ability to interoperate with other technologies that farmers and other stakeholders may opt to use, e.g., their operating systems and browsers. This is achieved by using the technologies that make a website responsive across various platforms.

- Maintainability - System improvements can be done without having to build a new system from scratch. Equally, the administrator of the system is able to update the data anytime without restrictions. This is because the codes are readable, reusable and upgradable.

3.13.1.3 Hardware Requirements

The hardware requirements are meant to ensure that the system can perform its functions effectively, including data analysis, visualization, and user interaction, while remaining accessible to users with varying hardware capability. These are the physical hardware prerequisites for the EWAS to reach its optimum performance:

a) Front-end:
   - Desktop computer, Personal computer, tablet or mobile phone
   - Read Access Memory: 512 MB
   - Hard Disk Drive: 2 GB

b) Back-end:
   - Web server
   - Read Access Memory: 4 GB
   - Storage: 32 GB

3.13.1.4 Software Requirements

The front-end requirements would ensure broad accessibility and usability across different devices, while the back-end requirements would ensure a stable and secure environment for processing and storing data, essential for the system's critical functions. By meeting these requirements, the system would be able to provide seamless user experience. These are prerequisites that should be satisfied for the EWAS:

a) Front-end:
   - Web Browser, i.e., Microsoft Edge, Chrome, Mozilla Firefox, or Internet Explorer
   - Operating System, i.e., Windows or Android operating system

b) Back-end:
   - Operating System, i.e., a Windows operating system
   - Database storage

3.13.1.5 Network Requirements

These are prerequisites that should be satisfied for the EWAS to reach its optimum performance:

- A front-end bandwidth of at least 1 Mbps per user for smooth navigation of the web-based system and timely reception of warning notifications, and a back-end bandwidth of at least 50 Mbps for high availability and ensuring scalability during peak usage times.
- Ensure a minimum network uptime of 99.9% to match the availability requirement of the hosting service. This is crucial for providing uninterrupted access to the EWAS.
- Use SSL/TLS encryption for data in transit to protect against interception and ensure secure communication between front-end users and the back-end servers.

3.13.2 System Design

System design is the process of designing the elements of a system such as the architecture, system components, graphic interfaces, and database structure (Nashandi, 2020). In other words, the overall objective of the system design is to create a graphical replica of the system that can be transformed into a functional system during the development phase (Nashandi, 2020). It involves architectural designing, interface designing, and component designing.

The system design process aimed to produce a design system with the following qualities:

- Usefulness: the system should enable farmers to explore all functionalities of the system as may desire.
- Effectiveness: the system should prioritise being able to meet the user's expectations.
- Efficiency: the system should adequately make use of all resources to accomplish the user's goals with a high level of accuracy and completeness.
- Satisfaction: the users' comfort and positive attitudes towards the use of the system should be prioritised.
- Learnability: this is how easy it is for farmers to learn how to use the system. To achieve this, the system's controls or components needed to match their actions, and system controls needed to give a farmer or any other possible user a clue of how they should be used. Lastly, errors needed to be prevented by putting limits on the farmers' actions when they are more likely to make mistakes.

- Memorability: this is how easy it is for farmers to remember how to use the system. Components of the system were made visible, so farmers did not have to wonder where to find a certain control. Furthermore, the system had to respond to the farmers’ actions accordingly in the form of writing or animations. This makes the farmers feel in control, and they would not wonder if an action they tried to perform has been completed or not.

3.13.2.1 System Prototype

An extensive literature review on existing early warning systems in southern Africa was used to inform the first prototype of the proposed early warning agricultural system.

Figure 3.3 shows one of the earliest prototypes:

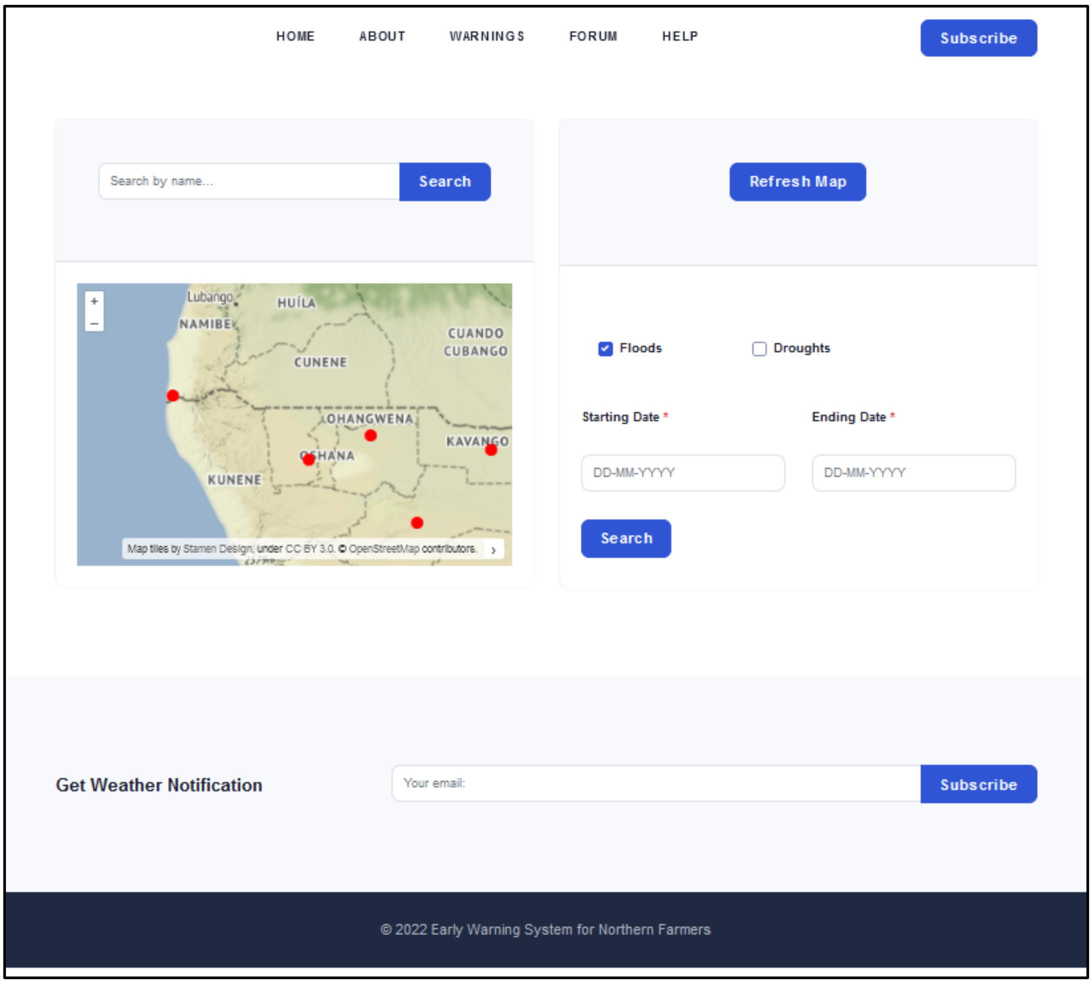


Figure 3.3: First System Prototype *Source: EWAS Prototype Screenshot*

The first system prototype accompanied some questionnaires which enabled a percentage of farmers to assess it and give their input. The purpose of the study was thoroughly explained before the prototype was presented to the farmers. Thereafter, the farmers' reactions were noted down and used to further improve the prototype system. After constant engagement with some farmers, their input was used to build the final prototype. Figure 3.4 shows the final prototype:

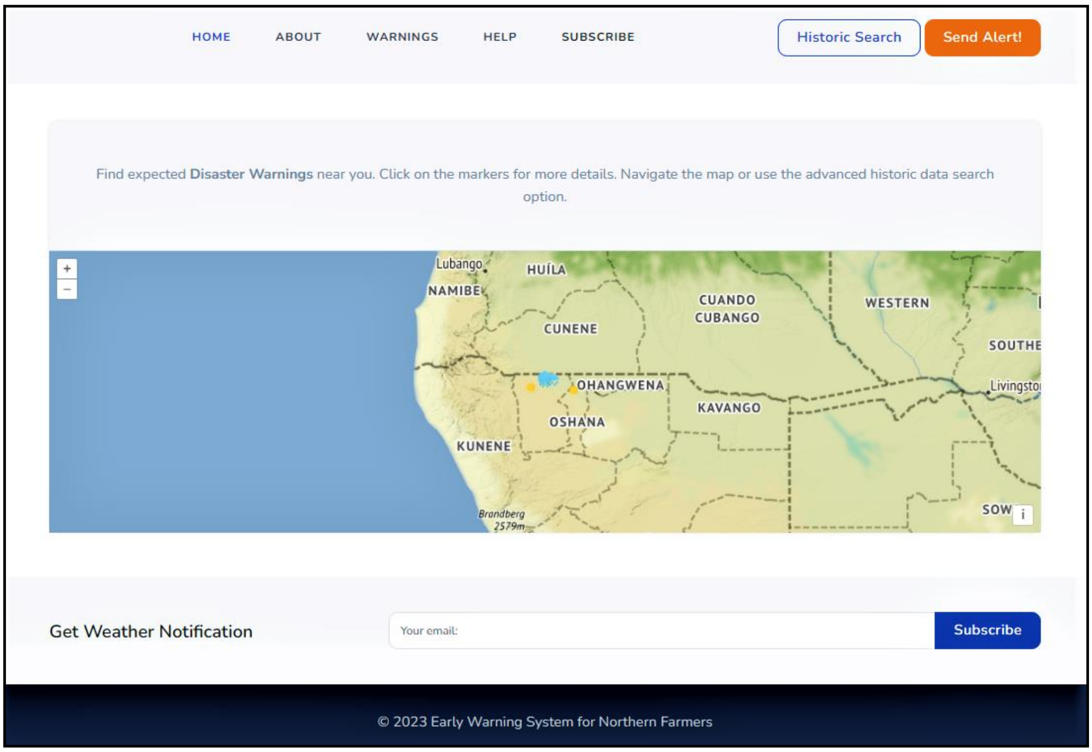


Figure 3.4: Final Prototype *Source: EWAS Prototype Screenshot*

3.13.2.2 System Architecture

The system consists of a combination of technologies and components that enable it to be a functional system. These are illustrated in Figure 3.5. Similarly, the system Context Level Diagram and Data Flow Diagram are displayed in Figure 3.6 and Figure 3.7 respectively:

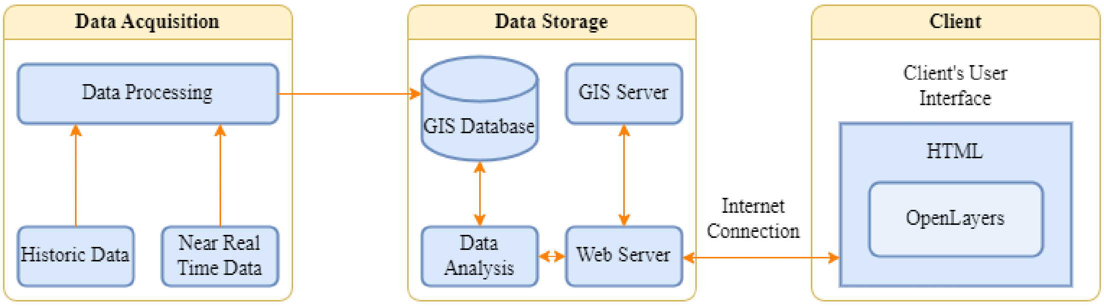


Figure 3.5: System Architecture *Source: Willbard Kamati*

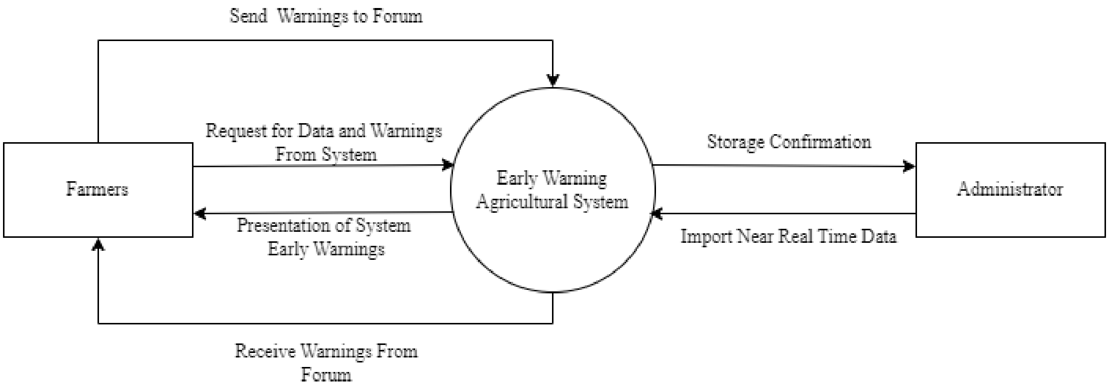


Figure 3.6: Context Level Diagram (Level 0) *Source: Willbard Kamati*

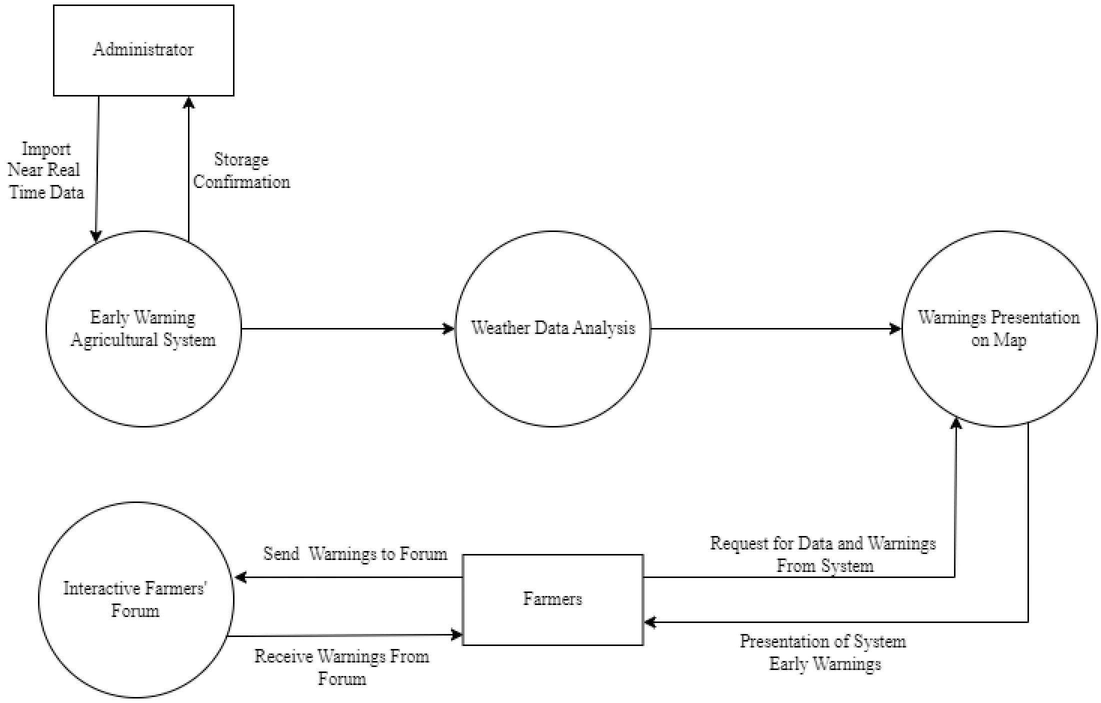


Figure 3.7: Data Flow Diagram (Level 1) *Source: Willbard Kamati*

The components that form the system architecture illustrated in Figure 3.5 are explained in detail as follows:

3.13.2.2.1 Client

A client device is a device that a client uses to connect to the web server through the internet and access the services that the system offers. This could be any device that supports web browsers like Google Chrome, Mozilla Firefox, Microsoft Edge, etc. For this early warning system, the client's web interface is a terminal through which a farmer is able to explore the early warnings and other system functionalities. Hypertext Markup Language (HTML) together with OpenLayers was utilised to visualise warnings and maps.

3.13.2.2.2 OpenLayers

OpenLayers is a pure JavaScript library for displaying maps in modern web browsers with no server-side dependencies, which uses JavaScript API to build rich web-based geographic applications (Mukumbira, 2012). Furthermore, OpenLayers supports the development of interactive interfaces used to present and interact with spatial data through the Map server with the support of the Web server.

3.13.2.2.3 Internet Connection

An internet connection connects the client to the web server. It is a medium that handles queries from users and returns a web page (Munywoki, 2020).

3.13.2.2.4 Web Server

A web server is a computer that handles access to centralised resources through the web (Munywoki, 2020). It handles queries from the clients using Hypertext Transfer Protocol (HTTP), stores and retrieves web pages to clients' devices.

3.13.2.2.5 GIS Database

A GIS database, also known as a geodatabase, is a collection of structured and related data containing locations that is stored electronically on a computer system (Munywoki, 2020). It is a central location where data is retrieved, stored, managed, and manipulated (Adeleke, 2018). It houses data pertaining to the spatial locations and the geometry of geographical features, which are stored as areas, lines, points, or pixels. Just like many other databases, it allows users to Create, Retrieve, Update, and Delete (CRUD) information in a database. The use of spatial databases aligned with this project because the system was meant to manage geographic and spatial data for effective indexing. PostGIS and PostgreSQL were used for creating and storing the data and providing the necessary storage support for geospatial data. Figure 3.8 shows a glimpse of the PostgreSQL database:

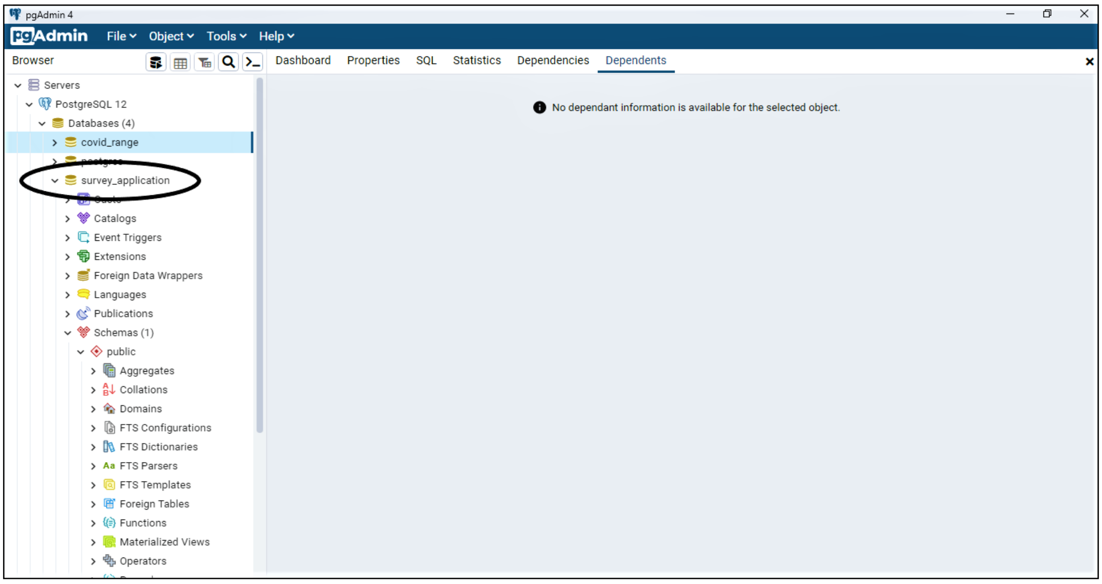


Figure 3.8: PostgreSQL Database *Source: PostgreSQL Screenshot*

Similarly, Figure 3.9 shows a PostGIS Shapefile Import/Export Manager:

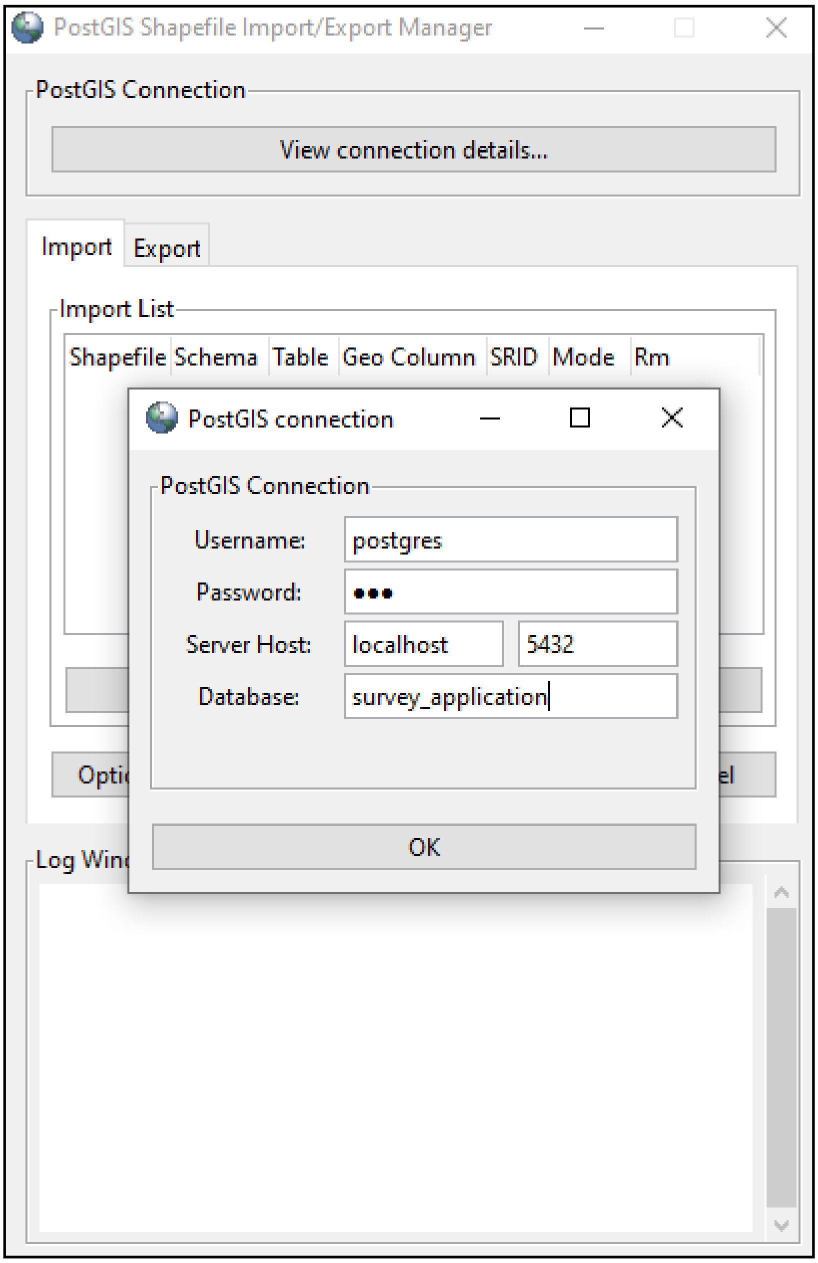


Figure 3.9: PostGIS Manager *Source: PostGIS Manager Screenshot*

3.13.2.2.6 GIS Server

A GIS server, or map server is an open-source platform for publishing spatial data and interactive mapping applications on the web (Munywoki, 2020). It is the engine that supports the display of maps on the system. It creates a linkage between the web server and a GIS database and generates appropriate imagery by assembling geospatial data from the geodatabase, also known as the GIS database. Figure 3.10 shows the GIS server configuration used for this project:

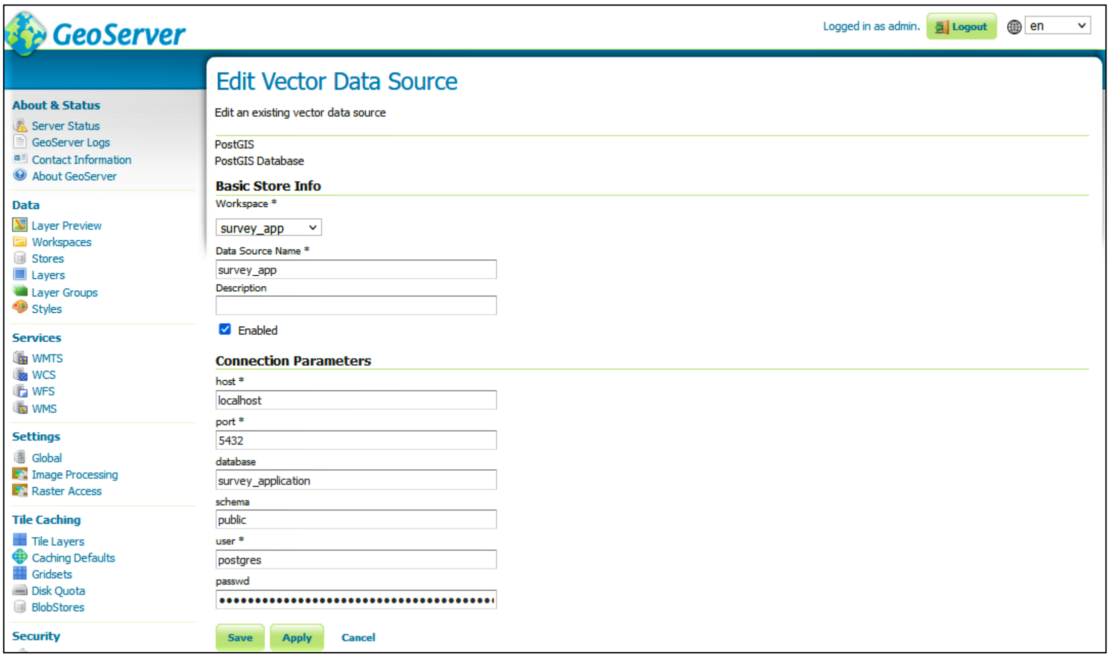


Figure 3.10: GeoServer Configuration *Source: GeoServer Screenshot*

3.13.2.2.7 Data Acquisition

Acquisition of GIS data is not only very time-consuming, but also very expensive (Adeleke, 2018). Therefore, it is best to use data already generated by a third party, such as government municipalities, parastatals, or international agencies. In Namibia, historic daily rainfall data was requested and obtained from the Namibia Meteorological Service (NMS) which has the largest and oldest rainfall database in Namibia from multiple weather stations in all corners of the country.

3.13.2.2.8 Data Processing

Data processing is centred around encoding the acquired GIS data into a format that can then be read by GIS applications (Adeleke, 2018). Data processing involves data verification, data integration, and editing (Adeleke, 2018). Data verification is the most important aspect of data processing, as it ensures that the acquired data meets the desired format. The data from the Namibia Meteorological Service (NMS) was converted to the Comma Separated Values (CSV) format before getting imported into the GIS database. Figure 3.11 illustrates a sample of the CSV data ready to be loaded into the PostgreSQL database:

A1 | StationID

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	StationID	Station_Name	Code	Lat	Lon	Elev	Year	Month	1	2	3	4	5	6	7	8
2	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2016	2	5	6	0	0	0	25	0	0
3	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2016	3	34	0	7	0	0	14	3.5	0
4	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2016	4	0	0	0	0	0	0	0	0
5	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2017	3	49.5	0	20	23	2.5	0	0	10.5
6	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2017	4	0	0	5.5	0	0	0	0	0
7	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2017	12	0	0	0	0	5.5	0	0	18
8	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2018	1	0	0	0	0	0	0	0	0
9	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2018	2	0	0	0	0	0	14	6	0
10	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2018	3	0	0	0	12.5	18.5	22	0	0
11	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2018	4	0	0	23.5	0	0	0	0	0
12	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2018	10	0	0	0	0	0	0	0	0
13	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2019	2	12.5	10	0	4	0	0	0	0
14	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2019	3	0	0	0	0	0	0	0	0
15	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2019	4	9	0	0	0	0	0	0	0
16	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2019	10	0	0	0	0	5	0	0	0
17	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2019	11	0	0	0	3	0	0	0	1.5
18	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2019	12	0	5	0	0	28.5	0	0	0
19	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2020	1	0	0	30.5	0	56	24	0	0
20	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2020	2	0	0	2	0	11	0	0	0
21	1148594A	Onaanda ADC	5	-17.91	15.35	1097	2020	12	0	0	30.5	0	56	24	0	0
22	1198644A	Tsandi ADC	5	-17.74	14.88	1110	2011	1	0	0	0	0	0	0	0	0
23	1198644A	Tsandi ADC	5	-17.74	14.88	1110	2011	2	0	0	0	0	0	0	0	0

data_products

Figure 3.11: Input Data Sample *Source: MS Excel Screenshot*

3.13.2.3 Database Design

The database designing process involved analysing the storage requirements, conceptualising database solutions, and outlining the structure of the database.

Figure 3.12 illustrates the graphical representation of the database design:

weatherData	
PK	entry_id int NOT NULL
	station_id char(255) NOT NULL
	station_name char(255) NOT NULL
	eventLatitude char(255) NOT NULL
	eventLongitude char(255) NOT NUL
	rainMeasurements char(255) NOT NU
	eventDate date NOT NULL

eventWarnings	
PK	eventWarning_id int NOT NULL
	eventType char(255) NOT NULL
	eventGeom geometry NOT NULL
	eventWarning_date date NOT NULL

forumWarnings	
PK	farmerWarning_id int NOT NULL
	farmer_ name char(255) NOT NULL
	warningType char(255) NOT NULL
	comment char(255) NOT NULL
	warning_date date NOT NULL
	forumGeom geometry NOT NULL

Figure 3.12: Database Design *Source: Willbard Kamati*

3.13.3 System Development

Geographical Information System (GIS) among other technologies was incorporated into the development of the system. This is because GIS is great for the creation of digital maps, analysis, and visualization of spatial data (Muvhali, 2013). Additionally, GIS combines database management tools with mapping software to collect, share, edit, organise, share, and visualise georeferenced data (Munywoki, 2020). With web GIS, an extension of GIS, the early warning system will be able to use web technology to communicate early warnings between farmers over the web. Similarly, GIS can best handle large volumes of spatial and temporal data, allowing the integration of data from various sources, including historic and near real-time weather data, into a single database. Furthermore, weather data and vegetation imagery can be overlaid on maps, helping users to easily interpret and analyse complex data. Therefore, data integration, visualization, analysis, navigation, and communication are factors that make GIS an ideal technology for this early warning system.

3.13.3.1 Methodology

The system was developed using mostly open-source tools. The tools that helped build the early warning agricultural system are shown in Table 3.2:

Tools	Description
Apache	Apache is an open-source web server for modern operating systems.
PHP	A popular general-purpose scripting language that is used for web development.
jQuery	A front-end JavaScript library.
PostgreSQL	PostgreSQL is an open-source object-relational database system that uses and extends the SQL language. It incorporates features that safely store and scale complicated data workloads.
PostGIS	PostGIS is an open-source spatial extension for PostgreSQL.
GeoServer	GeoServer is an open-source web mapping server for sharing geospatial data.
OpenLayers	OpenLayers is an open-source JavaScript frontend web mapping library for dynamic maps in web-based

	geographic applications with no server-side dependencies.

Table 3.2: Tools and Technologies Used Source: Willbard Kamati

3.13.3.2 System Overview

The system consists of a homepage that acts as a dashboard where farmers can view information about floods and droughts near their location. Additionally, the system provides a feature that allows farmers to alert other farmers about activities or events in their surroundings. Figure 3.13 illustrates the layout of the homepage:

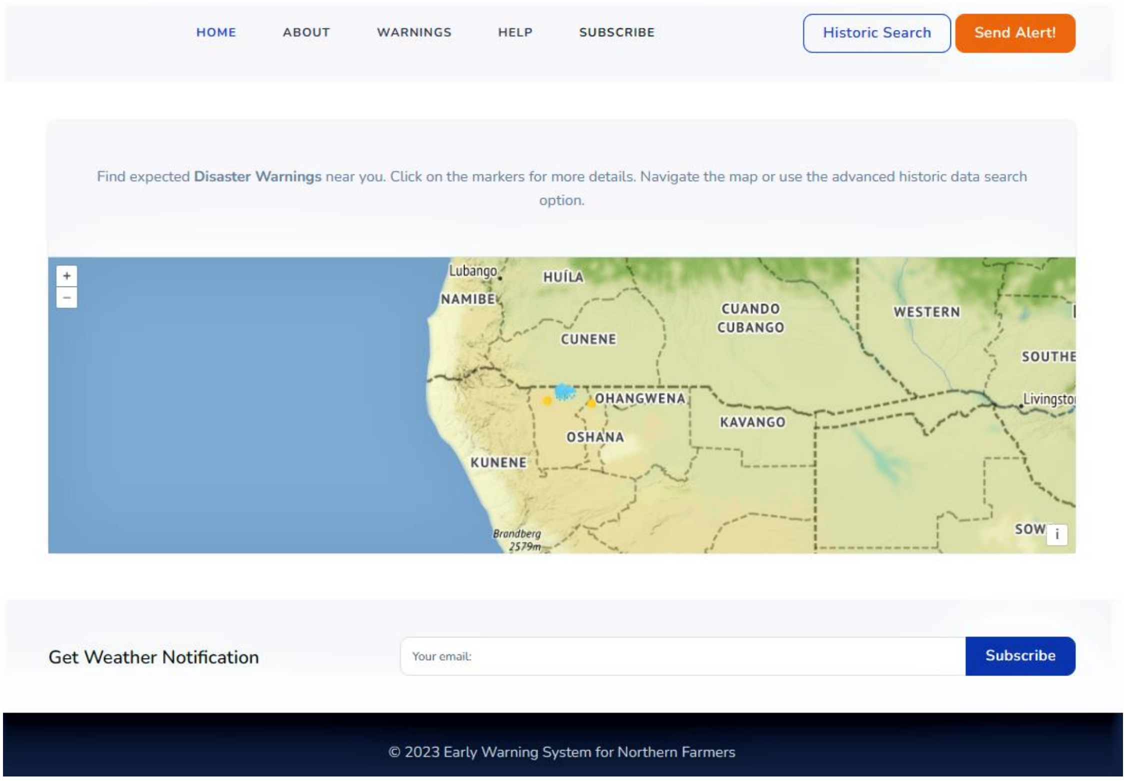


Figure 3.13: EWAS Homepage Source: EWAS Screenshot

Furthermore, they have the option to conduct an advanced historical search to review past disasters. They do this by selecting the types of disasters they would like to view on the map. Additionally, they can choose specific time frames to narrow down the results. This is shown in Figure 3.14:

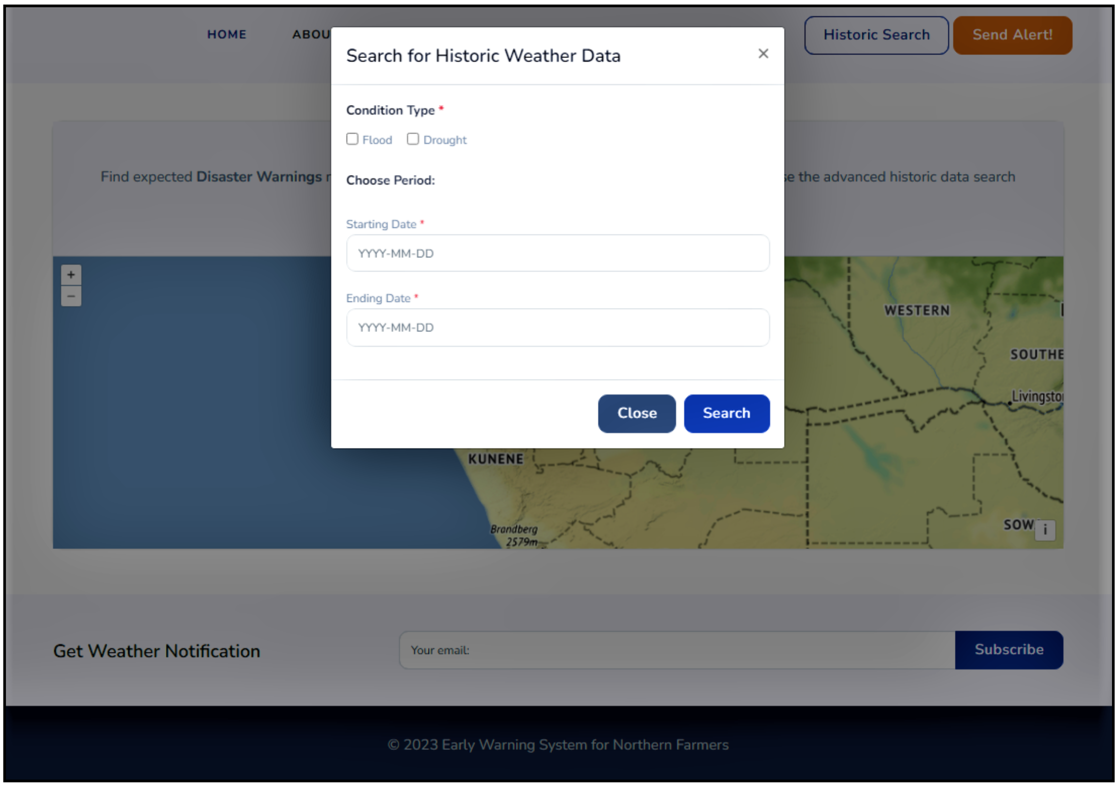


Figure 3.14: Advanced Historic Search Source: EWAS Screenshot

Once a farmer chooses to view other farmers' warnings, the system takes them to a page that displays geotagged warnings from other farmers. The warnings are colour-coded based on the kind of disaster they represent, providing a better visual representation of the different types of disasters. This is displayed in Figure 3.15:

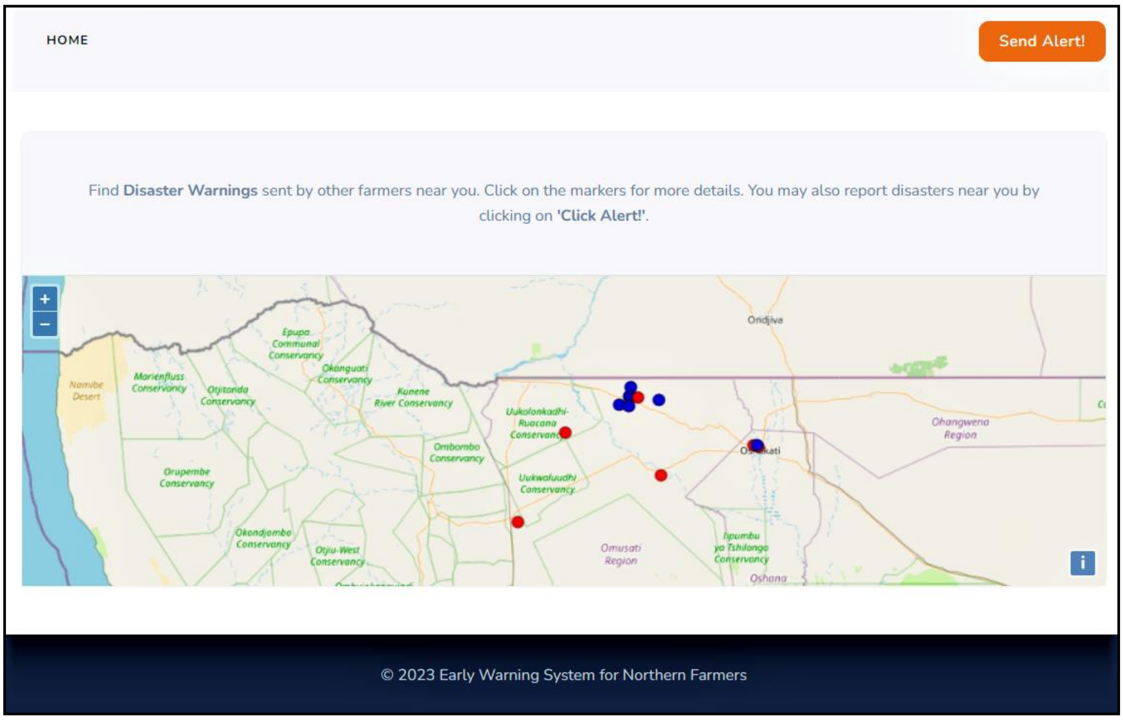


Figure 3.15: Geotagged Warnings *Source: EWAS Screenshot*

Once a user clicks on the warning markings on the map, the system simulates and displays the details of the alert. This includes information such as the name of the sender, the kind of disaster being reported, and the sender's message or additional details about the reported disaster. Figure 3.16 and Figure 3.17 show what happens when a farmer selects or clicks on a marking:

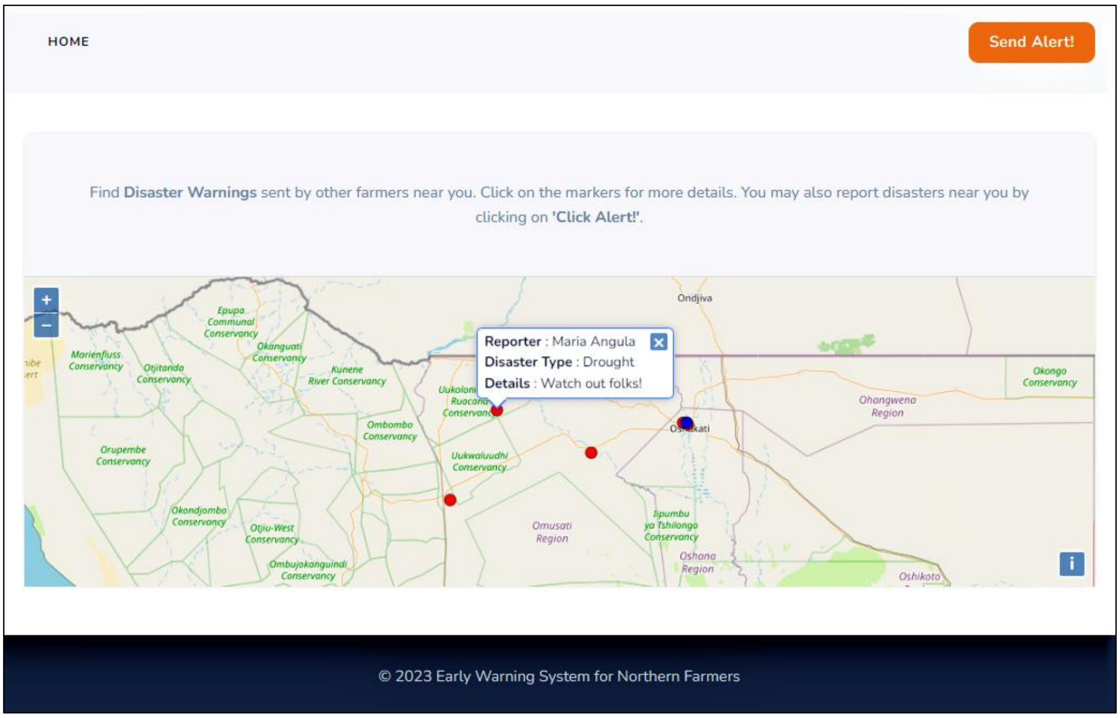


Figure 3.16: Detailed Drought Warning *Source: EWAS Screenshot*

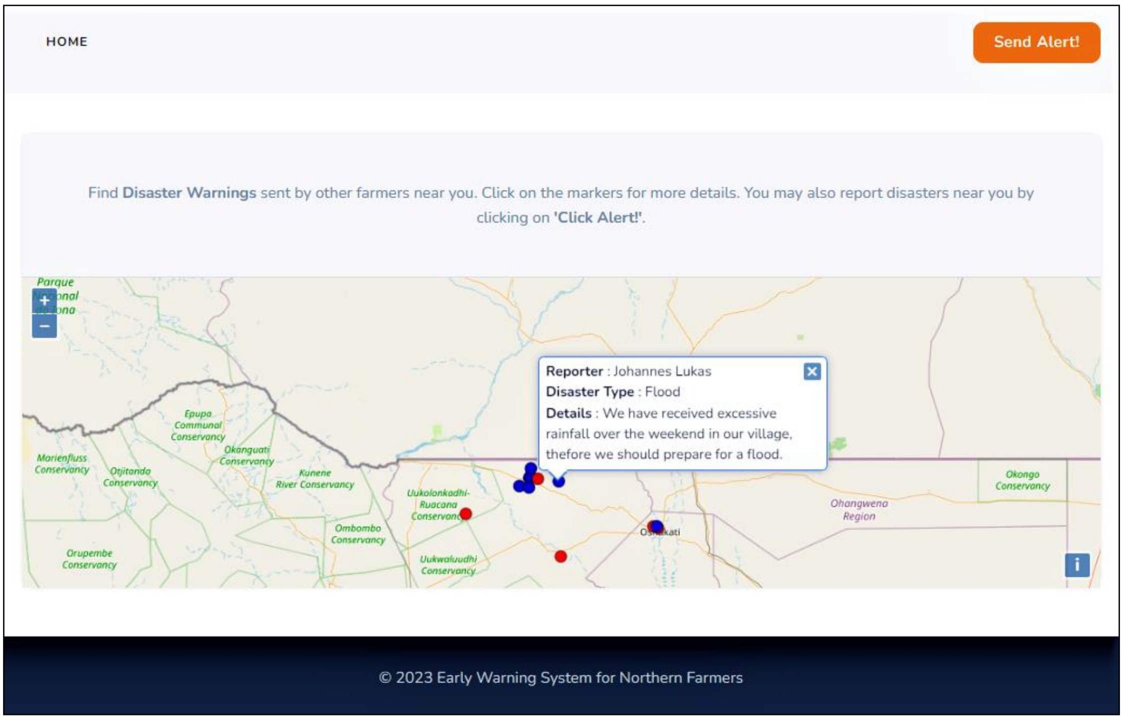


Figure 3.17: Detailed Flood Warning *Source: EWAS Screenshot*

In the same vein, if a user wishes to send a geotagged alert, they can click on the 'Send Alert!' button. This opens a form where they can fill in the necessary details and then click on the 'Send Alert' button to submit the alert. Figure 3.18 demonstrates this:

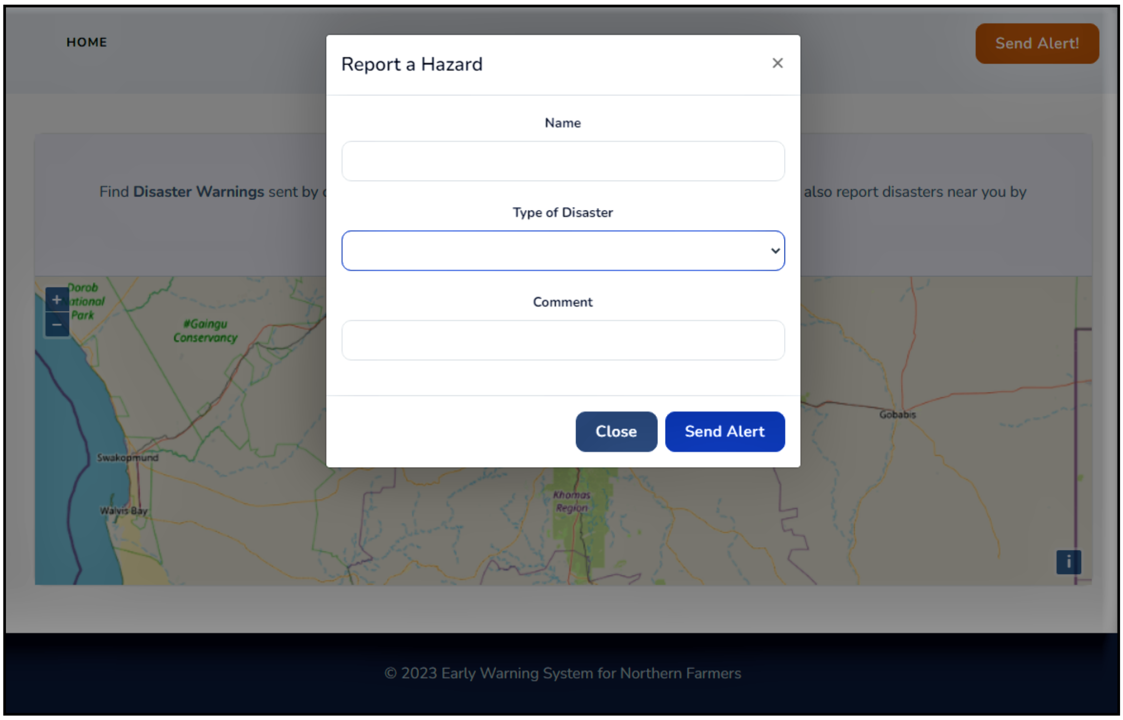


Figure 3.18: Sending an Alert *Source: EWAS Screenshot*

In conclusion, the system effectively displays anticipated disasters based on the data stored in the PostgreSQL database, which is sourced from various data sources. This information is presented on a single map, providing users with a comprehensive view of potential disasters. Additionally, the system allows users to report disasters in their specific locations, and these reported incidents are displayed on a separate map. These incidents may include floods, droughts, storms, veld fires, pest outbreaks, strong winds, etc. This feature ensures that other farmers in the area are promptly alerted about the reported disasters.

3.13.4 System Evaluation

After the development of the system, system testing was accomplished through a comprehensive system evaluation process, which was carried out to achieve Objective c). This objective aimed to evaluate the system's performance and usability. The evaluation targeted to assess aspects such as the system's usefulness, efficiency, effectiveness, learnability, user satisfaction, and acceptance testing, all conducted using authentic weather data. The system embraced weather data acquired from the Namibia Meteorological Service. This dataset included records of drought and rainfall spanning from 2011 to 2022, the year of data acquisition. These records were sourced from three Namibia Meteorological Service weather stations located in the Omusati Region: Onaanda (Station ID: 1148594A), Tsandi (Station ID: 1198644A), and Outapi (Station ID: 1199001A). This data was then integrated into the system for thorough analysis, and generating simulated disaster risk alerts on the system.

The system was evaluated by 12 farmers. The system evaluation process entailed a thorough introduction of the purpose of the study, the research objectives, and the functionality of the system. Subsequently, a demonstration of the system's functions was conducted. The farmers were given questionnaires to rate the system's usability. The system evaluation further aimed to determine the relevance of the early warning agricultural system and its applicability in northern Namibia.

3.14 Summary

This chapter detailed the research methodology employed in the study, covering the research design, participants, sampling, data collection, research procedures, data analysis, ethical considerations, and the steps taken to convert system requirements into a fully operational system.

Chapter 4: Results

This chapter outlines a detailed outcome of the semi-structured interviews that were conducted and the questionnaires that were handed out to farmers.

4.1 Introduction

After the process of data collection from the selected sample, content data analysis was done. Content analysis involved studying the collected data to understand contexts, meanings, relationships, partiality, and patterns. The most occurring keywords were used as codes, which were used to create a linkage to the theme of the research and to accomplish the research Objective a), which was to review existing early warning agricultural systems and disaster mitigation approaches in northern Namibia. Objective a) served as a foundational step in establishing the system requirements necessary for accomplishing Objective b), which focused on the development of a near real-time interactive early warning agricultural system. Furthermore, Objective c) aimed to assess the performance of the system developed in pursuit of Objective b). Likewise, Objective a) was a crucial prerequisite to Objective (c), as it was the attainment of Objective a) that enabled the researcher to pinpoint area-specific historical and near real-time data relevant to disaster mitigation efforts and available early warning systems. The main codes pinpointed were natural disasters, floods, droughts, preparation, early warning, information sharing, harvest, and farming.

4.2 Demographic Information

The study targeted 100 farmers, i.e., 20 commercial farmers and 80 communal farmers. However, it only achieved an 88% response rate. This is illustrated in Figure 4.1:

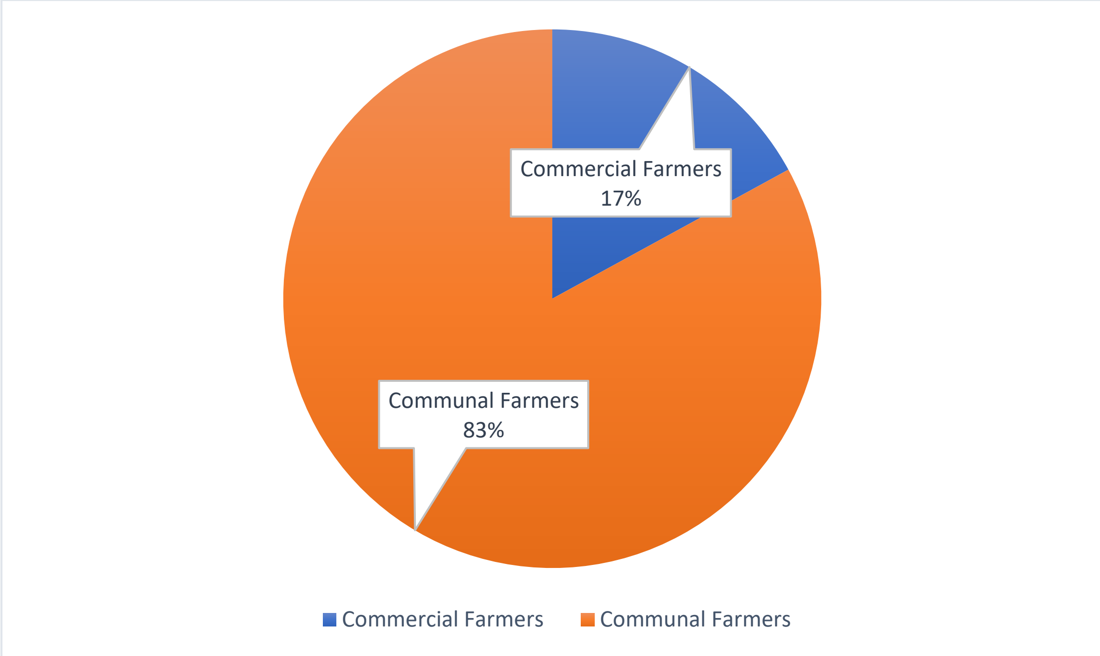


Figure 4.1: Participants' Categories *Source: Primary Data*

The majority of the respondents, 69%, were farming with livestock and crops simultaneously. On the other hand, 12% of the farmers were livestock farmers while 19% were crop farmers. This is illustrated in Figure 4.2:

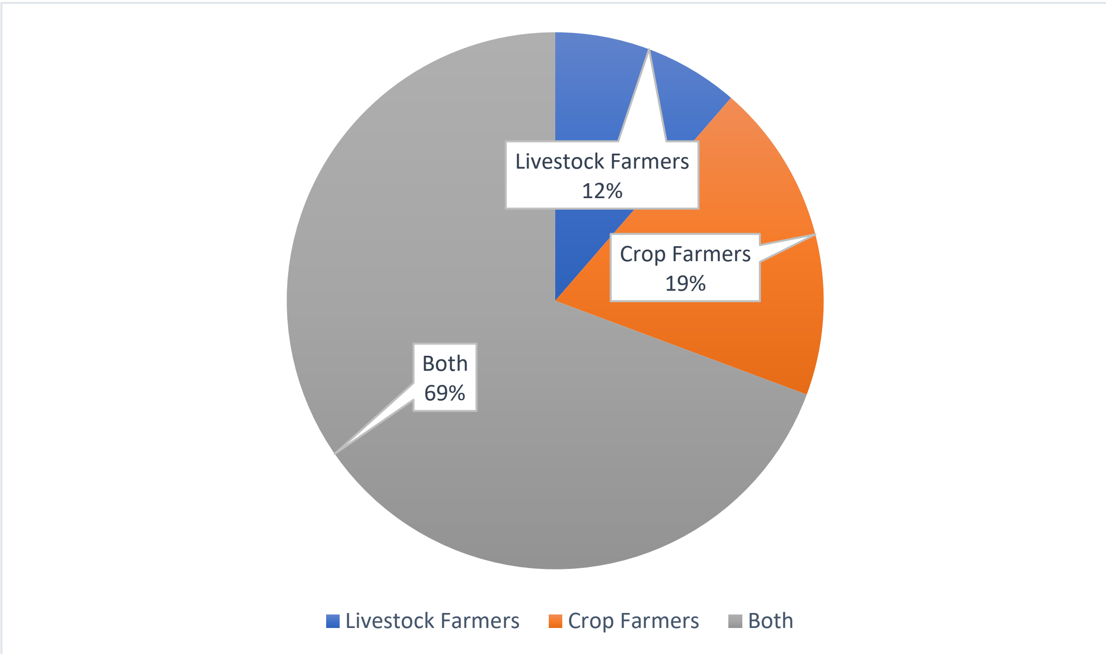


Figure 4.2: Farmers' Categories *Source: Primary Data*

The farming experience of the participants varied. Ten percent (10%) of the farmers have been farmers for at most 2 years, while only 14% of farmers have been in operation for 2-5 years, and another 9% have 6-10 years of experience in farming. Lastly, 67% of the farmers have been farmers for over 10 years. This is illustrated in Figure 4.3:

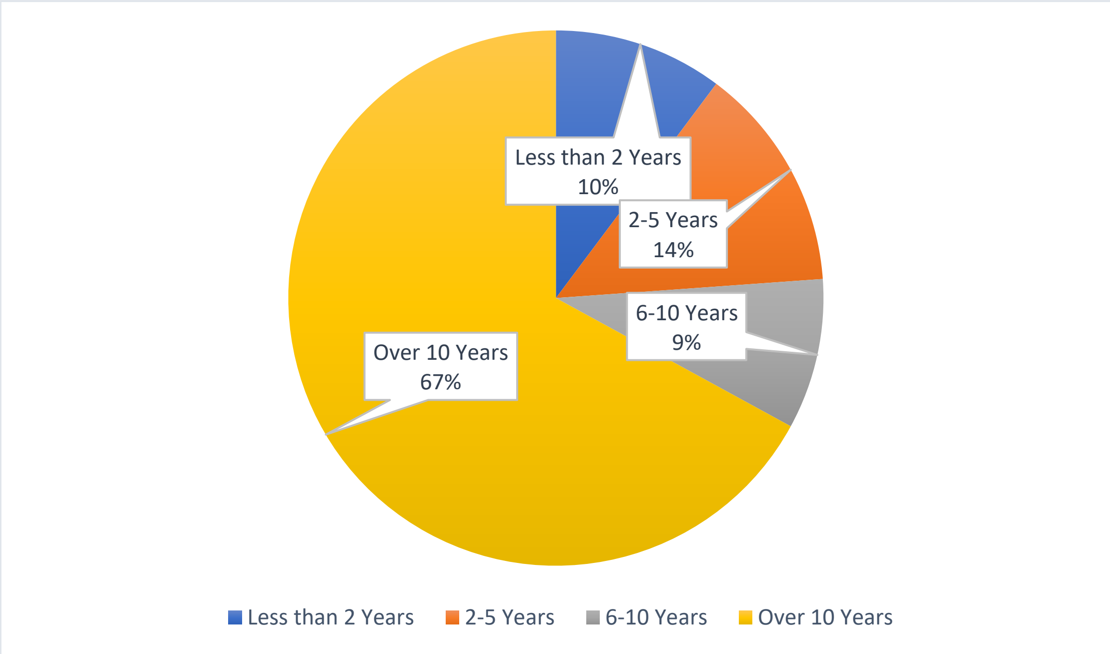


Figure 4.3: Farmers' Experience *Source: Primary Data*

Collecting demographic information was crucial for providing a clear picture of who the respondents were and ensuring they represented the intended population. Similarly, it was necessary to categorize farmers based on what they farm to determine the extent to which each category was affected. Additionally, gathering information on the farmers' farming experience was essential to assess their exposure to disasters over the past years and how this informed their responses.

4.3 Disasters' Impacts

When asked to indicate which natural disaster the farmers were mostly concerned about, 44.1% were mostly concerned about the possibility of a flood, while 65.9% were afraid of drought. The findings have been presented in Figure 4.4:

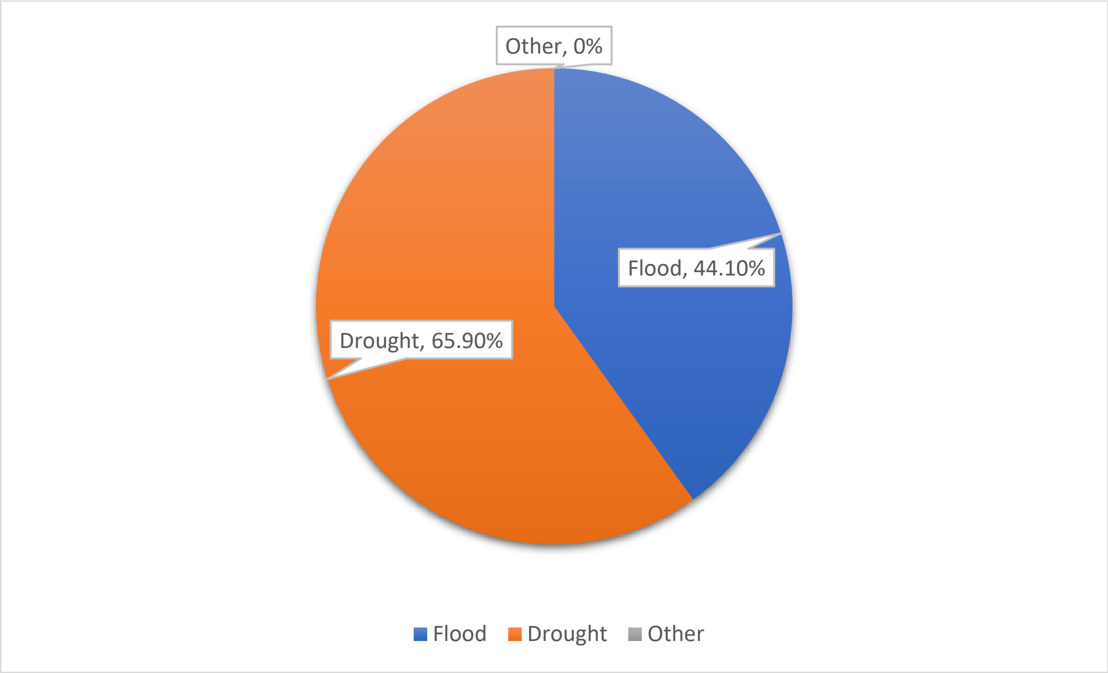


Figure 4.4: Disasters of Concern *Source: Primary Data*

Additionally, 92% of the farmers who participated have experienced a natural disaster in their farming journey, while 8% indicated they have not. The findings have been presented in Figure 4.5:

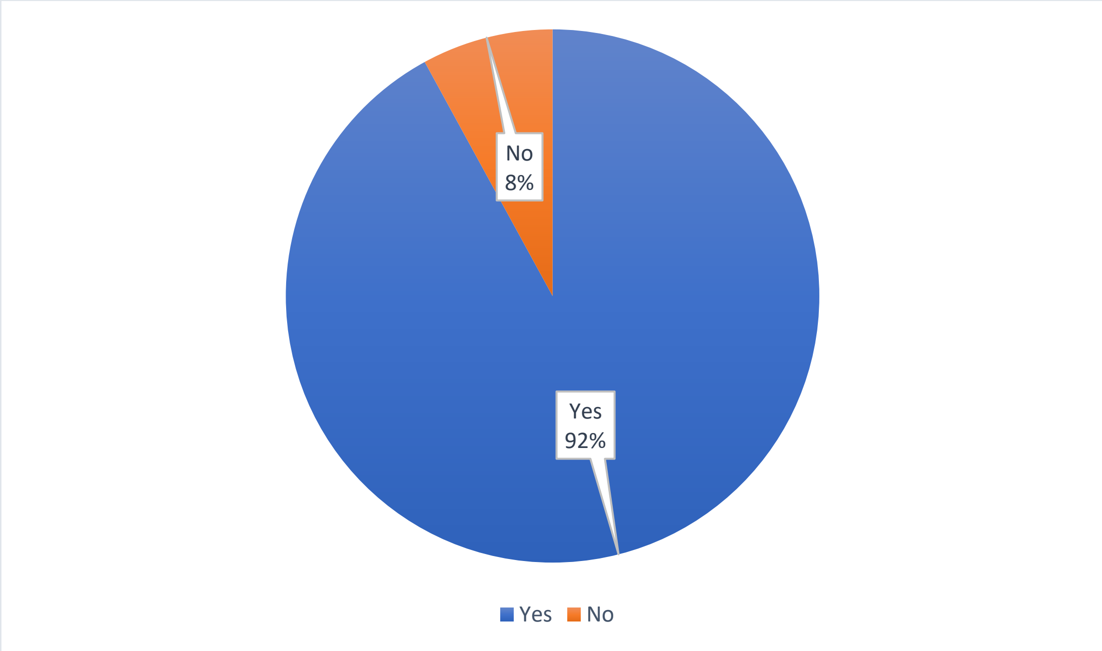


Figure 4.5: Farmers' Natural Disaster Exposure *Source: Primary Data*

Among the disasters that the farmers were exposed to, drought and flood are at the top of the list. Other disasters that made the list included plant poisoning and pest outbreaks. Asked to indicate the degree to which the disasters have affected their agricultural production, 33% indicated the disasters had a severe impact, while 63% recorded a mild impact. Lastly, 4% recorded a minor impact. The findings have been presented in Figure 4.6:

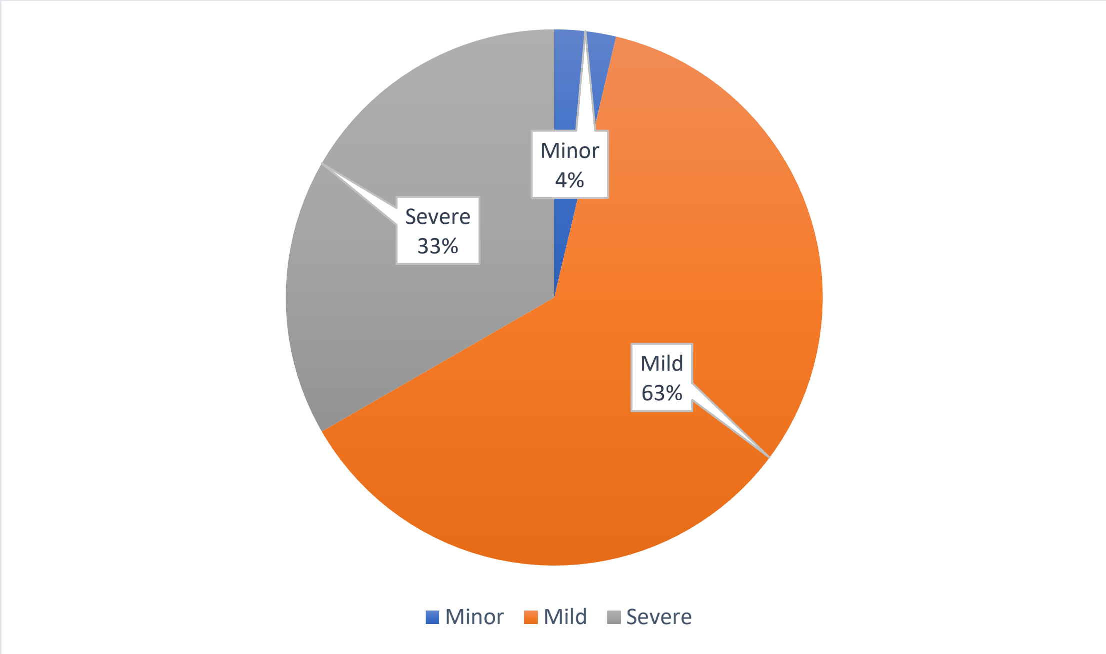


Figure 4.6: Degree of Disasters' Impact *Source: Primary Data*

On entities that should be responsible for helping farmers prepare, mitigate, and recover from disasters, 100% of the farmers believe it is the government. Similarly, 13.6% also believed that besides the government, farmers could also help themselves, while 0.03% believed private organisations could also lend a helping hand. The findings have been presented in Figure 4.7:

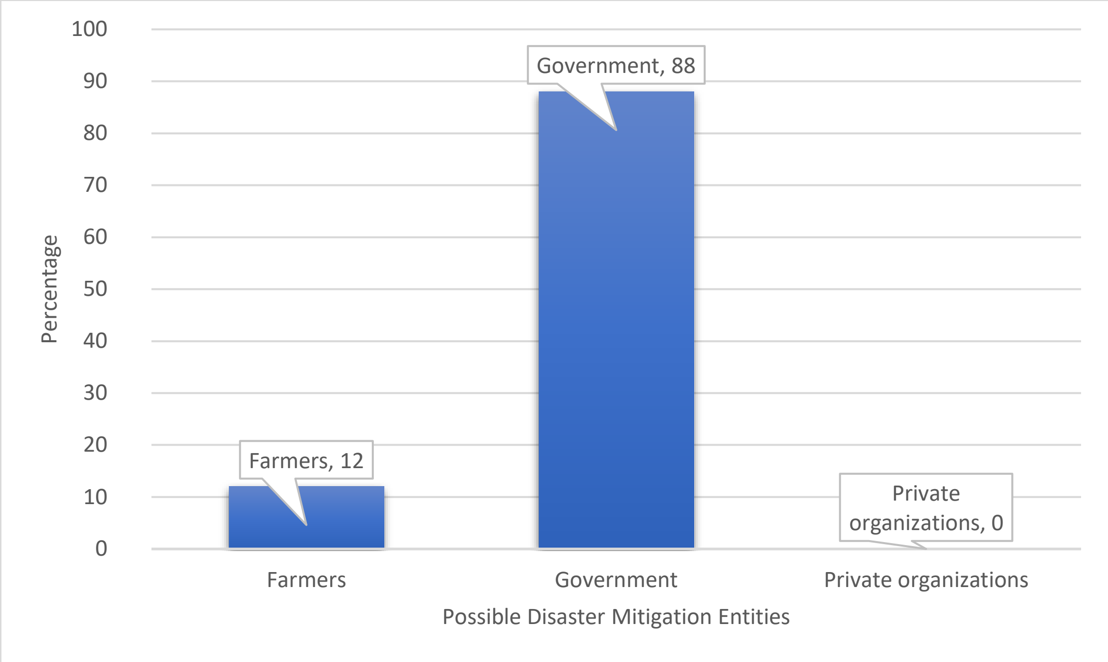


Figure 4.7: Proposed Disaster Mitigation Entities *Source: Primary Data*

The respondents prepare for disasters differently. This includes using rotational grazing, relocating to higher grounds, disaster acceptance, praying, reserving surplus for disaster days, and picking better locations for farming.

It was important to understand the respondents' concerns about disasters to know what to focus on and whether they had experienced what they considered a disaster, which helps to contextualize their overall responses. To understand the respondents' experiences, it was necessary to record the disasters they experienced, their severity, and how they managed them. On the other hand, to understand their expectations, the survey needed to identify who the farmers expect to manage the disasters.

4.4 Usage of Early Warning and Information Sharing Systems

All respondents indicated that they do not have an early warning agricultural system they use in their community. Furthermore, farmers get weather information at different frequencies. 52% never check for weather information. 15% get it daily, and 28% get it weekly. Lastly, 5% get it monthly. The findings have been illustrated in Figure 4.8:

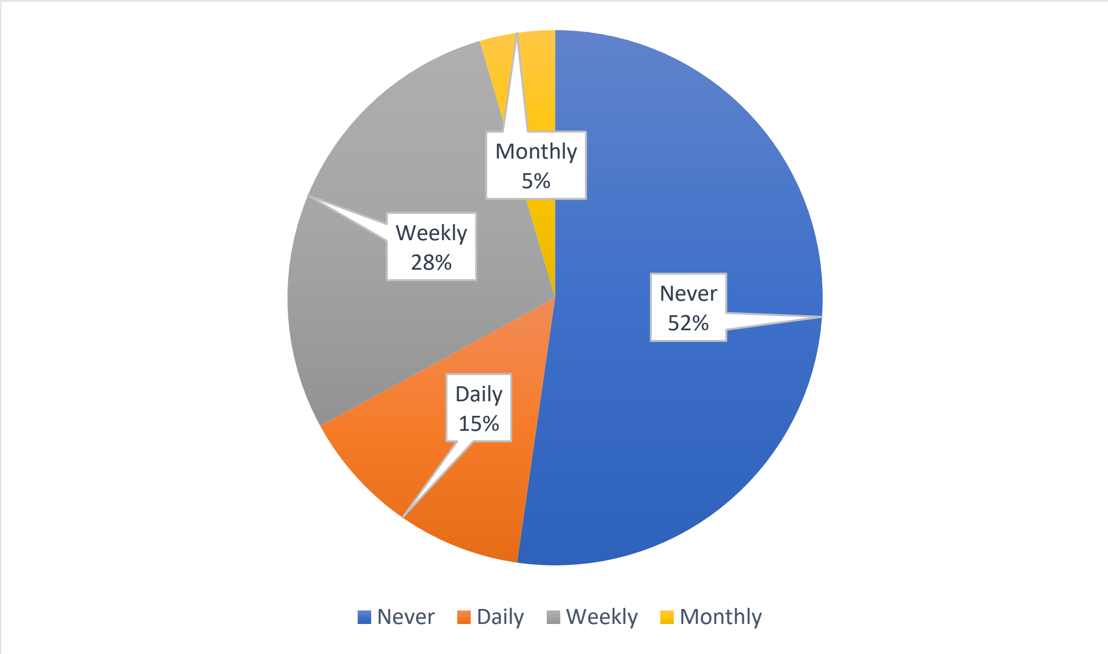


Figure 4.8: Weather Updates Frequency *Source: Primary Data*

Amongst those that get weather information, the majority of the farmers get weather information or forecasts from radio, television, mobile applications, the community, and the internet. The findings have been presented in Figure 4.9:

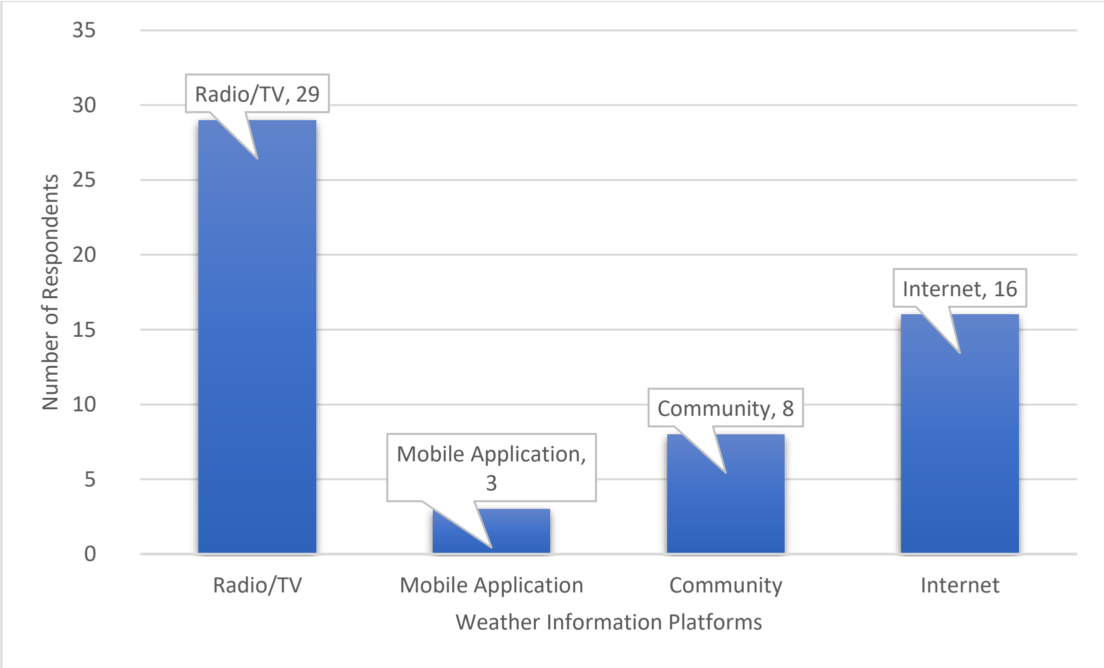


Figure 4.9: Weather Information Platforms *Source: Primary Data*

The majority of the farmers share weather information or forecasts with other farmers verbally, while others share through radio, television, and social media. The findings have been presented in Figure 4.10:

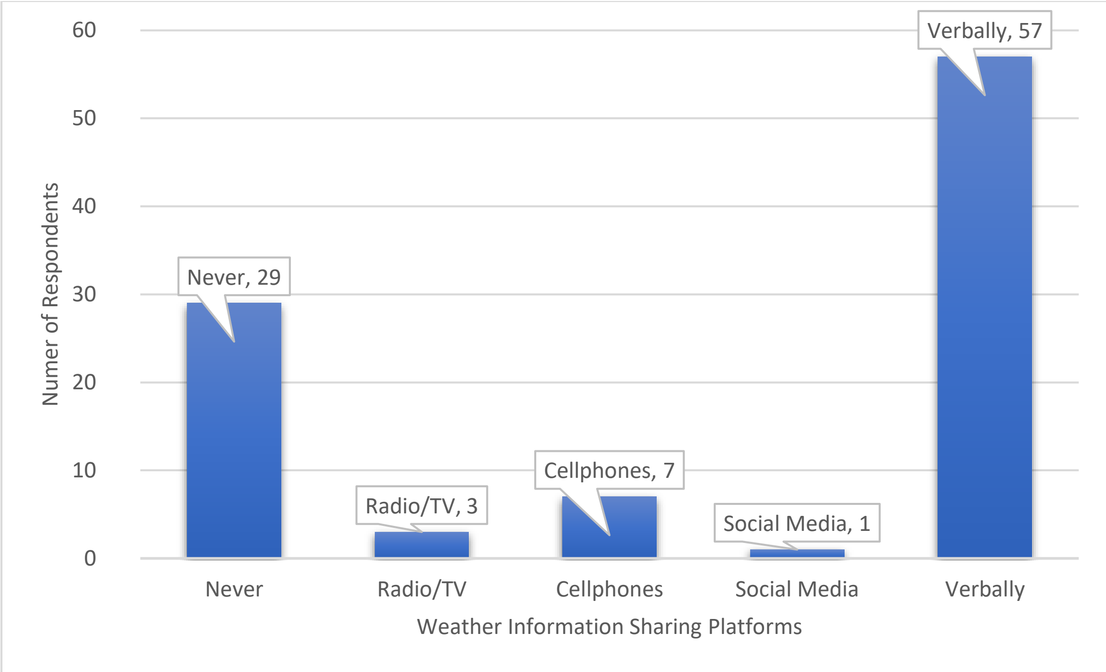


Figure 4.10: Weather Information Sharing Platforms *Source: Primary Data*

It was important to study the usage of early warning and information sharing systems to understand the current mitigation practices, current early warning systems, and their effectiveness, and subsequently to make recommendations for possible improvement efforts.

4.5 Availability of Resources and Skills

The technical readiness of the use of an early warning agricultural system was also assessed. This included the farmers' computer literacy skills and the overall resources currently in place to support the use of the early warning agricultural system. Therefore, the survey showed that 28% of farmers are experts when it comes to computer literacy, while 33% are beginners. 39% of the respondents were not computer literate. The findings have been presented in Figure 4.11:

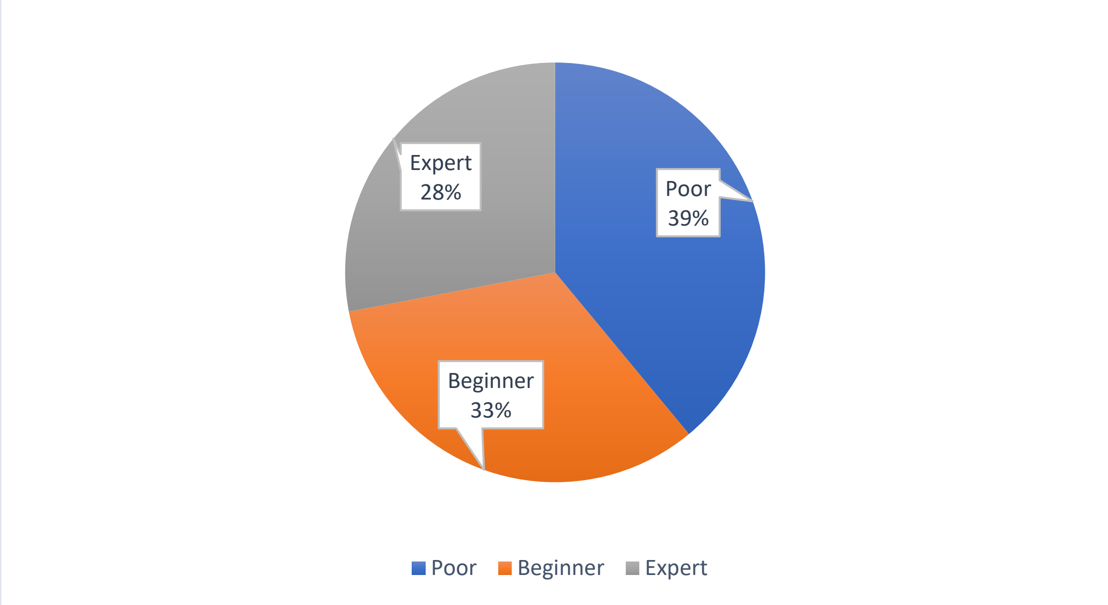


Figure 4.11: Farmers' Computer Literacy Skills *Source: Primary Data*

Moreover, only 69% of the respondents have the means to connect to the internet, while 31% do not. This has been presented in Figure 4.12:

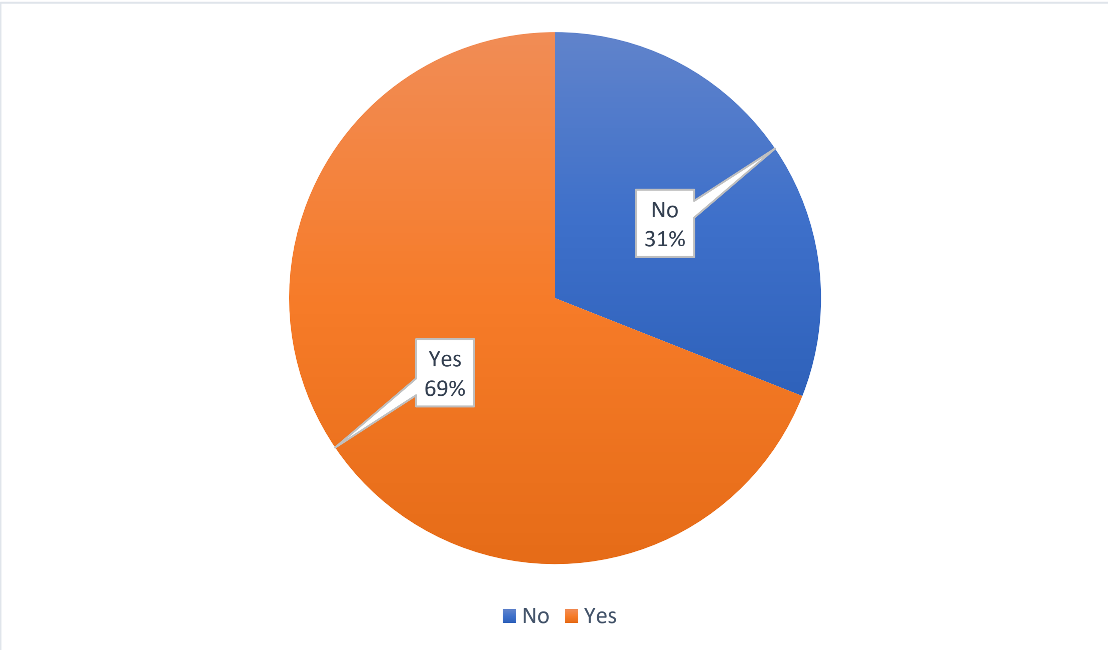


Figure 4.12: Farmers versus Internet Gadgets *Source: Primary Data*

Before developing the system, it was important to determine if sufficient resources and skills were available for the system to be received by its intended users.

4.6 Usage of Indigenous Knowledge

Farmers have confirmed the use of indigenous knowledge in their communities, whereby they look at their environments, plants, and animals as disaster warning signs. Heavy rain warning signs that the farmers outlined include rashes on dogs and hot temperatures during the day. Among the drought warning signs are the late fruition of mopane trees between December to February, and the presence of certain birds' nests on palm trees in the area. Therefore, some farmers strongly believe destroying the signs is a method of avoiding and possibly reducing the severity of the disasters. This information was crucial to the study because indigenous knowledge could be used by farmers to confirm or contradict the warnings from the system, possibly affecting its reception.

4.7 System Evaluation Results

Several other qualities were evaluated by requesting respondents to indicate the degree to which they agreed with a number of statements. Similarly, open-ended questions were also asked to get farmers' input. The statements, questions, and responses are listed:

i. The system will make it easy to prepare for disasters. The findings are presented in Figure 4.13:

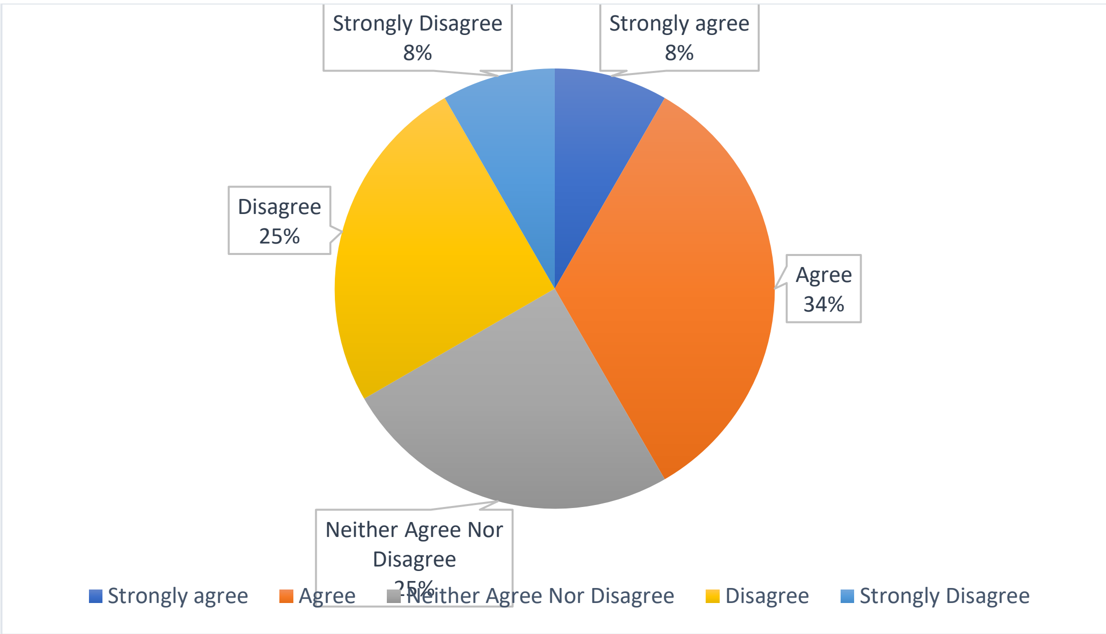


Figure 4.13: System Usefulness *Source: Primary Data*

ii. It looks easy to use the system. The findings are presented in Figure 4.14:

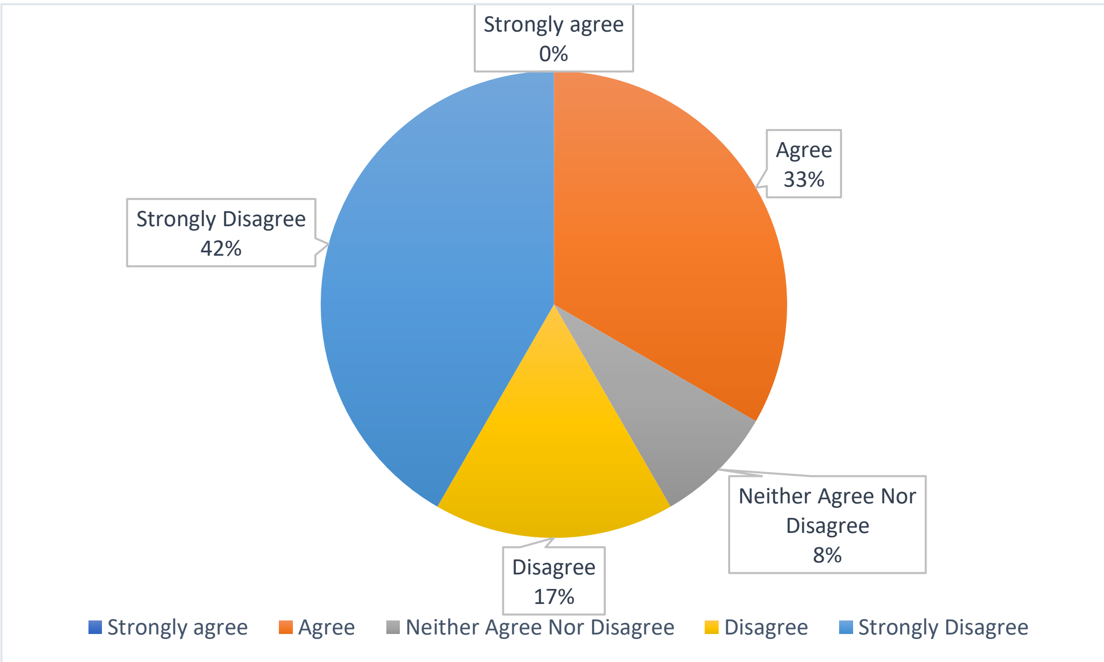


Figure 4.14: System Ease of Use *Source: Primary Data*

iii. It looks easy to learn how to use the system. The findings are presented in Figure 4.15:

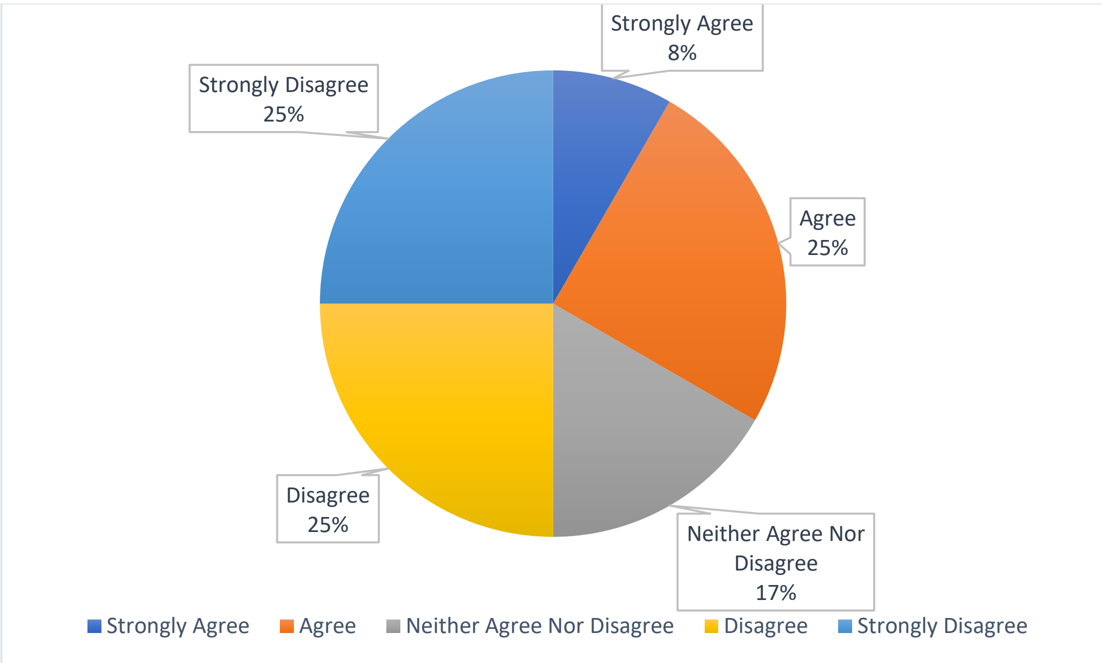


Figure 4.15: System Learnability *Source: Primary Data*

iv. The information and language on the system is clear and can be understood. The findings are presented in Figure 4.16:

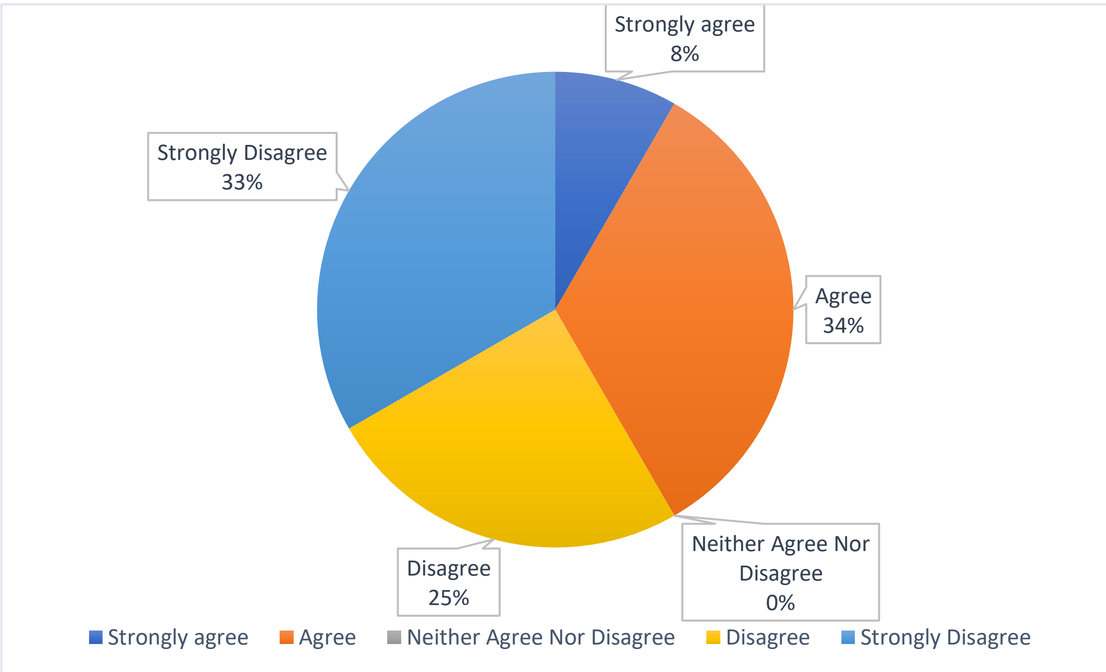


Figure 4.16: System Understandability *Source: Primary Data*

v. Do you foresee challenges the proposed system might bring?

The respondent anticipated that several challenges could arise from the use of the early warning system. This includes false alerts and the system not being accessible to all farmers who may need it. Hence, a suggestion was made suggesting that the system could be deployed at the constituency councillors' offices for councillors to take the warnings and broadcast them on local radio stations, which most users have access to rather than smart devices. While others anticipated that it would take time for the users to have confidence in the system.

vi. What can be included in the design to improve its usefulness?

Respondents suggested that the system would be easier if it were translated into Namibia's native languages, most importantly Oshiwambo. Others suggested the system be made offline to increase its accessibility. Lastly, it was suggested that the system should be zoomed in for a clearer view.

vii. To what extent do you think the proposed system will be helpful in warning farmers about natural disasters?

Furthermore, 75% of respondents foresee that the system would be useful and impactful to different degrees. The findings have been presented in Figure 4.17:

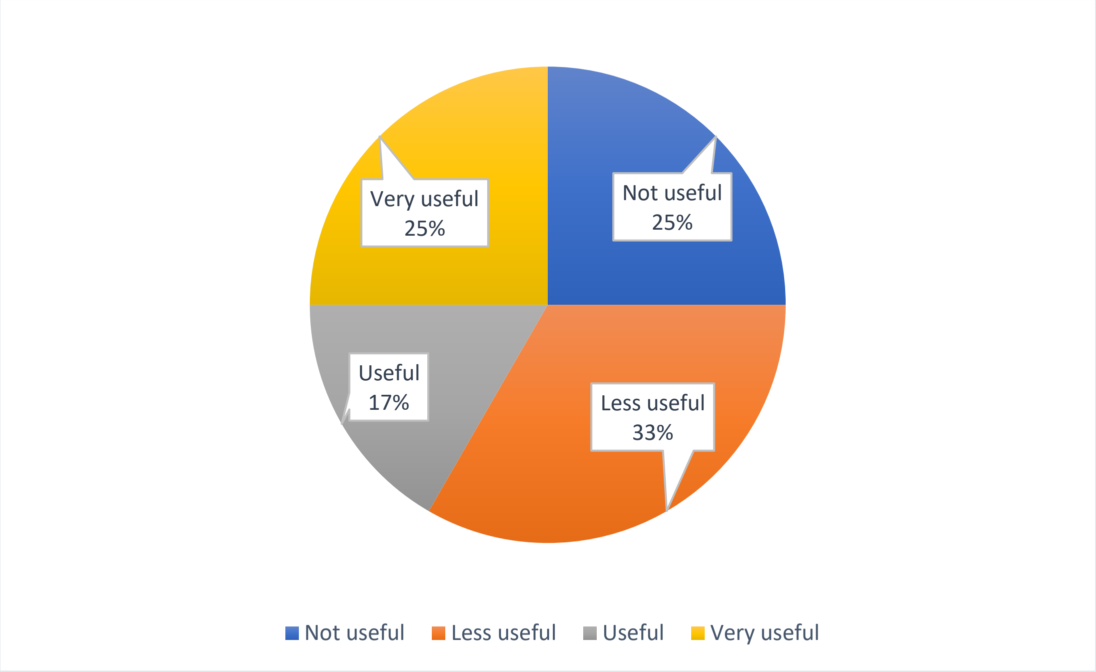


Figure 4.17: System Anticipated Effectiveness *Source: Primary Data*

A system evaluation by potential users was crucial as it provided feedback on the software's performance, usability, and effectiveness. It also helped ensure the software meets the users' needs and expectations.

4.8 Summary

This chapter gave a detailed outcome of the semi-structured interviews that were conducted, the questionnaires that were handed out to farmers, and the system evaluation results.

Chapter 5: Discussions

This section discusses the results of the study in relation to the obstacles encountered, significant factors to take into account, and the factors contributing to the system's success.

5.1 Challenges and Considerations

The purpose of the study was to study disasters that the northern farmers experienced, the existing disaster mitigation practices, information-sharing methods used by farmers, the extent to which different kinds of early warning systems are utilised in Namibia, and potential challenges that could be associated with the early warning agricultural system in northern Namibia. Therefore, the study has proven that the main disasters that northern Namibian farmers are exposed to are primarily floods and droughts. Identifying the primary disasters of concern in northern Namibia was crucial, as the reviewed literature emphasized the need to understand disaster vulnerability. This understanding helps in determining what potential victims should be protected against. Hence, an effective early warning agricultural system should be centred around the above-mentioned disasters while also incorporating other disasters, for instance, pest outbreaks.

The literature reviewed has highlighted the significance of agriculture in Namibia, particularly in northern Namibia, despite various disasters faced and varying vulnerability levels among farmers, which are often influenced by their circumstances, as confirmed by the farmers themselves. In efforts to foster communication and information sharing on these challenges and early warnings, the study examined current platforms available for communications and information sharing. The study further revealed that the means of information sharing among farmers vary. This includes mostly the traditional mediums of communication, i.e., face-to-face communication, radio, and television, which do not always guarantee effectiveness. Seldom times, farmers communicate telephonically and using social media platforms. In most cases, farmers communicate disasters, and weather information verbally, which makes the information vulnerable to distortion. Hence, there could be a need to strengthen the use of modern technologies such as the internet to share information among farmers.

Furthermore, the study revealed that early warning systems are underutilised in Namibia, especially when it comes to disaster management and mitigation. This aligned with the studies reviewed that confirmed the limited use and impact of existing early warning systems, such as the CEOS system and the TIGER-NET system. However, the Namibia Meteorological Service was mentioned in the farmers' responses, as they confirmed receiving weather forecasts through traditional mediums, such as radio and television, most of which are from the Namibia Meteorological Service. There was no proof of farmers getting early warnings and forecasts directly from the Namibia Meteorological Service without a third party. Additionally, farmers also get involved in the interpretation of environmental signs. This information could not be sufficient to trigger action among farmers, and it is not always area-specific. Therefore, this proves the need for a new, accessible system that is an improved extension of the existing ones.

Then again, the use of the EWAS would require accepting some of the anticipated possible challenges that the study revealed, which could hinder the effectiveness and success of early warning agricultural systems in Namibia. This includes the issues of accessibility of the application, and building the trust and confidence in the early warnings that the application would generate. The application also comes with internet costs that would fall on the shoulders of the farmers.

Afterwards, a farming-specific warning system was developed, and rainfall data was utilized to evaluate its performance and usability. This revealed some of the farmers' concerns regarding the system's ease of use, understandability, and learnability. Therefore, providing comprehensive training and detailed user manuals is highly recommended when deploying the system regardless of a farmer's level of confidence in their computer proficiency.

5.2 Readiness and Success Factors

One of the study's aims was to evaluate the readiness of northern farmers to use this system and the factors that instil confidence in its success. Therefore, the study further aimed at assessing farmers' readiness for the use of early warning agricultural systems, and the resources readily available to support the deployment of early warning systems. This assessment was important to address the gaps identified in the previous studies reviewed and ensure effort is made to improve disaster prediction. Therefore, the study further showed that the readiness for full utilisation of early warning agricultural systems is still debatable. This is because there is still a huge fraction of farmers that is not computer-literate, while another fraction does not have internet-enabled devices.

On the other hand, Namibia has ICT infrastructure and an incredible network coverage that could support the deployment and use of digitalised and internet-based information-sharing systems. Similarly, Namibia is also known to have substantial numbers of mobile phones, some of which are smartphones that are compatible with the internet. Therefore, the study has shown that Namibia has resources available to support the use of internet-based early warning systems, although they are not fully used.

However, a huge fraction of farmers predicted that the system would be useful despite the few challenges identified. The success of the application would be determined by the way the farmers receive early warnings and whether they respond to the warnings in a way that lessens the damage that the disasters would cause. It is therefore important for the application to be implemented in a way that would live up to the farmers' expectations.

In conclusion, the EWAS application would be of great use to a fraction of its intended users, while another faction might not be able to fully explore its potential due to different reasons. This could, however, improve with time as ICT infrastructure continues to be built in Namibia, and confidence is built in the application.

5.3 Summary

This chapter presented a comprehensive summary of the results from the semi-structured interviews that were conducted and the questionnaires that were distributed to farmers.

Chapter 6: Conclusions and Recommendations

The closing chapter of this paper concludes and summarises the study. It also highlights the outcome of the study, the achievements, and the shortcomings. It further presents recommendations made for future research.

6.1 Introduction

The research aimed at addressing the mitigation of climatic disasters, specifically floods and droughts, as they hinder agricultural production in the northern regions of Namibia through studying existing early warning agricultural systems and disaster mitigation practices. Secondly, the research aimed to develop a near real-time interactive early warning agricultural system. Lastly, the research aimed to evaluate the performance and usability of the system.

6.2 Conclusions

The research revealed that although there is an abundance of technological resources to support early warning agricultural systems, they have not yet been fully explored and utilised in Namibia. The researcher further noted that there is poor documentation of weather information in Namibia, which has led to a shortage of historic weather datasets that could be used to identify historic patterns and trends. Interestingly, farmers are well aware of disasters that they are exposed to. However, they are left with little to no options except acceptance of disasters and the damages associated with them. On the other hand, the study has proven that technological interventions like early warning agricultural systems should come with clear guidelines and extensive training to acquaint farmers with varying computer skills.

Although some farmers in northern Namibia are aware of the problems at hand, they failed to grasp the concept of solving them with technological interventions. This could be blamed on their poor utilization of technology to enhance their agricultural practices in northern Namibia. The study proved that the best way to achieve effective disaster mitigation, preparedness, and recovery, should be collaborative efforts from both farmers, government institutions, and private agencies at all levels to collectively manage disasters and to help all vulnerable parties.

In conclusion, the research successfully accomplished its objectives. Firstly, objective (a) which aimed to determine existing early warning agricultural systems and disaster mitigation practices, was achieved. Secondly, objective (b) was met by developing a near real-time interactive early warning agricultural system. Thirdly, objective (c) was accomplished by evaluating the performance and usability of the system, with the results presented. Thus, achieving these sub-objectives led to the fulfilment of the main objective, developing a near real-time interactive early warning agricultural system to contribute to the mitigation of climatic disasters that hinder agricultural production in northern Namibia.

6.3 Recommendations

Based on the findings of this study, several observations and recommendations were made accordingly:

- Firstly, access to weather data was very important in achieving objective b) as data is the primary input for the application to work effectively. However, it was challenging due to the limited weather data available to feed the application. Therefore, it is recommended that the Namibia Meteorological Service (NMS) and other local agencies that manage climatological datasets address the issue of limited historic and near real-time data on weather, which is caused by the limited number of weather stations that capture data. Similarly, available data is difficult to access as requests take a long time to be attended to. Therefore, it is highly recommended that the Namibia Meteorological Service (NMS) and other agencies should do a better job of keeping the data up-to-date by setting up more weather stations, especially in rural areas. Furthermore, the datasets should be readily available to the general public without compromising their integrity and security.

- Similarly, to strengthen the prediction capabilities of the EWAS, weather data from credible international weather institutions was very important to the system, although attempts to acquire it were met with challenges. It is therefore recommended that international institutions that manage global climatological datasets have strict measures in place when it comes to granting researchers access to the data. This results in most researchers' requests being rejected for different reasons, despite their good intentions. Hence, it is recommended that international institutions prioritise all researchers when granting access to their datasets.
- Achieving objective c) goes beyond just ensuring that the system is usable. It primarily aims to make the application effective, which is determined by how the targeted users receive the early warnings and how they manage disasters with the help of the system. On the other hand, managing disasters in Namibia is largely the responsibility of the affected society, despite most societies being poorly equipped to handle disasters. It is therefore recommended that government agencies, private institutions, and humanitarian organizations join

hands with farmers in managing and mitigating disasters predicted by a system such as this.

- Future research in the area of managing and mitigating disasters should focus on integrating early warning agricultural system functionalities into a mobile application to complement the web-based application.
- Similarly, there is a need to incorporate the early warning agricultural system functionalities into an offline SMS-based system to accommodate users without internet access. Therefore, future studies could cover that.
- Furthermore, future research could also focus on other disasters that affect agricultural activities and other parts of the country.
- Lastly, given the strong use of indigenous knowledge in predicting disasters in Namibia, future researchers could focus on testing the accuracy of this knowledge and integrating it into modern early warning systems.

6.4 Summary

The final chapter of this paper concluded and summarized the study. It also highlighted the study's outcomes, achievements, and shortcomings, and offered recommendations for future research.

References

A.Walli, C.Tøttrup, V.Naeimi, P.Bauer-Gottwein, M.Bila, P.Mufeti, J.W.Tumbulto, C.Rajah, LS.Moloele, & B.Koetz. (2013). TIGER-NET – Enabling an earth observation capacity for integrated water resource management in Africa. Retrieved from http://m.tiger-net.org/fileadmin/documents/LPS_TIGERNET_paper_v10.pdf

Adeleke, A. K. (2018). Web-based GIS Modelling of Building-integrated Solar Photovoltaic System for the City of Cape Town. Retrieved from https://open.uct.ac.za/bitstream/handle/11427/29181/thesis_ebe_Adeleke_2018.pdf?sequence=1&isAllowed=y

Akashambatwa, C. L., Zuwarimwe, J., & Teweldemedhin, M. (2017). Communal livestock husbandry practices and their impact on market participation: A case study from Zambezi region in Namibia. Retrieved from https://core.ac.uk/download/pdf/234657338.pdf

Amadhila, E., Shaamhula, L., Rooy, G. v., & Siyambango, N. (2013). Disaster risk reduction in the Omusati and Oshana regions of Namibia. Retrieved from http://dx.doi.org/10.4102/jamba.v5i1.65

Angombe, S. T. (2012). Evaluation of drought indices using the 40-percentile threshold for the north-central regions of Namibia. Retrieved from https://repository.unam.edu.na/bitstream/handle/11070/669/evaluationocr.pdf?sequence=1&isAllowed=y

Awala, S. K., Hove, K., Wanga, M. A., Valombola, J. S., & Mwandemele, O. D. (2019). Rainfall trend and variability in semi-arid northern Namibia: Implications for smallholder agricultural production. Retrieved from https://www.researchgate.net/publication/338855058_Rainfall_trend_and_var iability_in_semi-arid_northern_Namibia_Implications_for_smallholder_agricultural_production

Bauer-Gottwein, P., Jensen, . H., Guzinski, R., Bredtoft, G. K., Hansen, S., & Michailovsky, C. I. (2015). Operational river discharge forecasting in poorly gauged basins: the Kavango River basin case study. Retrieved from https://doi.org/10.5194/hess-19-1469-2015

Bloemertz, L., Naanda, M., Wingate, V., Angombe, S., & Kuhn, N. (2018). Land, livelihoods and housing Programme 2015-18. Retrieved from https://ilmi.nust.na/sites/default/files/WP10-BLOEMERTZ-ET-AL-Ecosystem-services-and-small-holder-farming-practices-WEB-20190123-Update.pdf

Council for Scientific and Industrial Research. (2014). Climate Information and Early Warning Systems for Supporting the Disaster Risk Reduction and Management Sector in South Africa under Future Climates. Retrieved from https://www.sanbi.org/wp-content/uploads/2018/04/ltas22-24-jan-workshop-day-1csirclimate-information-and-ews.pdf

Dambe, N. (2020). Riverine Flooding using GIS and Remote Sensing. Retrieved from https://open.uct.ac.za/bitstream/handle/11427/31738/thesis_ebe_2020_dambe_natalia.pdf?sequence=4&isAllowed=y

Davies, J., Spear, D., Chappel, A., Joshi, N., Togarepi, C., & Kunamwene, I. (2019). Considering Religion and Tradition in Climate Smart Agriculture: Insights from Namibia. In T. S. Rosenstock, A. Nowak, & E. Girvetz, *The Climate-Smart Agriculture Papers* (pp. 113-126). Cham: SpringerOpen.

Department of Environmental Affairs. (2016). Climate Information and Early Warning Systems for Supporting the Disaster Risk Reduction and Management Sector in South Africa under Future Climates. Retrieved from https://www.dffe.gov.za/sites/default/files/reports/ltasbook2of7_climateinformationandearlywarningsystemsforsupportingtheDRR.pdf

Frye, S., Percivall, G., Moe, K., Mandl, D., Handy, M., & Evans, J. D. (2013). Towards a sensor web architecture for Disaster management: Insights from the Namibia flood pilot. Retrieved from http://dx.doi.org/10.1109/IGARSS.2013.6721281

Gill, J. C., & Malamud, B. D. (2014). Reviewing and visualizing the interactions of natural hazards. Retrieved from https://doi.org/10.1002/2013RG000445

IFRC, Save the Children, Oxfam, FAO, & WFP. (2014). Early warning early action: Mechanisms for rapid decision making. Retrieved from https://www.droughtmanagement.info/literature/IFRC_Early_Warning_Early_Action_2014.pdf

Kaundjua, M. B., Angula, M. N., & Angombe, S. T. (2012). Community perceptions of climate change and vanability impacts in Oshana and Ohangwena Regions. Retrieved from https://www.researchgate.net/publication/310614736_Community_perceptions_of_climate_change_and_variability_impacts_in_Oshana_and_Ohangwena_Regions

Lameck, A. M. (2016). Designing a mobile application to increase open data awareness and consumption in Namibia: A best practice example of public transportation in Windhoek. Retrieved from https://ir.nust.na/xmlui/bitstream/handle/10628/626/Lameck_Mbangula_Amugongo_Thesis_Final_Print.pdf

Licke, T. (2023). Adapting to extreme weather events: Addressing flood risks through planning and Policy in Namibia. Retrieved from https://www.diva-portal.org/smash/get/diva2:1771725/FULLTEXT02.pdf

Magomelo, M., Chikwiriro, H., & Gurure, C. (2014). An Implementation of Early Warning of Floods along Zambezi Basin Throughthe Use of Context-Awareness. Retrieved from https://isindexing.com/papers/1409669609.pdf

Mandl, D., Frye, S., Cappelaere, P., Sohlberg, R., Handy, M., & Grossman, R. (2012). The Namibia Early Flood Warning System, A CEOS Pilot Project. Retrieved from https://papers.rgrossman.com/proc-125.pdf

Mbeeli, K. K. (2019). An Analysis of the casual relationship between agricultural exports and economic growth in Namibia. Retrieved from https://repository.unam.edu.na/bitstream/handle/11070/2827/mbeeli_2019.pdf?sequence=1

Mbewe, M., Phiri, A., & Siyambango, N. (2019). Indigenous Knowledge Systems for Local Weather Predictions: A Case of Mukonchi Chiefdom in Zambia. Retrieved from https://doi.org/10.5539/enrr.v9n2p16

Moises, D. J., & Kunguma, O. (2023). Improving flood early warning systems in Kabbe, Namibia: A situational analysis approach. Retrieved from https://doi.org/10.1016/j.ijdrr.2023.103765

Montle, B. P. (2016). Production frontier of small scale pearl millet farmers under conservation agriculture in northern Namibia. Retrieved from https://ir.nust.na/bitstream/10628/814/1/Thesis%20Final-Bonolo%20Pontsho%202016.pdf

Mtega, W. P. (2017). Strengthening agricultural knowledge systems for improved rural livelihoods in Morogoro region of Tanzania. Retrieved from http://hdl.handle.net/10500/22964

Mubita, L. K. (2019). Investigating the relationship between agricultural productivity and economic growth in Namibia. Retrieved from https://repository.unam.edu.na/bitstream/handle/11070/2524/mubita2019.pdf

Mukumbira, S. (2012). Development of a Crime Mapping, Analysis and Prediction Tool for Windhoek. Retrieved from https://ir.nust.na/bitstream/10628/385/1/Mukumbira.%20MIT.%20Dev%20of%20a%20crime%20mapping,%20analysis%20and%20prediction%20tool%20for%20Windhoek.pdf

Munywoki, M. N. (2020). Integrating a web-based GIS in the optimization of the customer connection process for utility company: A case of Kenya Power & Lighting Company, Ltd. Retrieved from https://open.uct.ac.za/bitstream/handle/11427/36035/thesis_ebe_2021_munywoki%20margaret%20ngeli.pdf?sequence=1

Musungu, K. (2012). A participatory GIS approach to flood risk assessment of informal settlements the case of Cape Town. Retrieved from https://open.uct.ac.za/bitstream/handle/11427/12155/thesis_ebe_2012_musungu_k.pdf?sequence=1&isAllowed=y

Mutelo, S. C. (2019). Designing a Health Information System Adoption Roadmap for Quality Healthcare in Namibia. Retrieved from https://ir.nust.na/bitstream/10628/750/1/MASTER%20OF%20INFORMATICS%20by%20SINTE%20MUTELO,%20200962078.pdf

Muvhali, P. S. (2013). Using sensor web technologies to help predict and monitor floods in urban areas. Retrieved from https://open.uct.ac.za/bitstream/handle/11427/5590/thesis_ebe_2013_peter_muvhali_thesis.pdf?sequence=1&isAllowed=y

Muzuwa, T. (2017). Towards developing a prediction model for managing river flood disasters in the SADC-region. Retrieved from https://repository.nwu.ac.za/handle/10394/25590

Nashandi, N. T. (2020). A Persuasive Souvenir System (PSS) to increase Namibian museums turnout using RFID Technology. Retrieved from https://ir.nust.na/bitstream/10628/772/1/Master%20of%20Computer%20Science%20Thesis-Nashandi.pdf

Nawa, E.-L. T. (2021). Developing a cybersecurity framework for the banking sector of Namibia. Retrieved from https://ir.nust.na/bitstream/10628/817/1/DEVELOPING%20A%20CYBERSECURITY%20FRAMEWORK%20FOR%20THE%20BANKING%20SECTOR%20OF%20NAMIBIA.pdf

Niipare, A.–M., Jordaan, A., & Siyambango, N. (2020). Flood Impacts in Oshana Region, Namibia: A Case Study of Cuvelai River Basin. Retrieved from https://doi.org/10.5539/jgg.v12n1p8

Oluyemi, A. A. (2015). Remote Sensing and Geographical Information System (GIS) Modelling of Landuse/ Landscape Over and Climate Change in the Derived Savannah Region of Nigeria. Retrieved from https://ir.unilag.edu.ng/handle/123456789/4106

Shaamhula, L., & Rooy, G. v. (2019). Here comes the water: Risk assessments, observation and knowledge of Ompundja village. Retrieved from https://doi.org/10.4102/jamba.v10i1.507

Sheya, M. N. (2019). Factors influencing the adoption and redesign of the eWallet service in Namibia. Retrieved from https://ir.nust.na/bitstream/10628/775/1/Maria%20Sheya%20Masters%20Thesis.pdf

Shifidi, V. T. (2014). Socio-economic assessment of the consequences of flooding in Namibia. Retrieved from https://scholar.sun.ac.za/handle/10019.1/96066

Shikangalah, R. N. (2020). The 2019 drought in Namibia: An overview. Retrieved from https://www.academia.edu/43492435/The_2019_drought_in_Namibia_An_overview

Somses, S., Bopape, M.-J. M., Ndarana, T., Fridlind, A., Matsui', T., Phaduli, E., Limbo, A., Maikhudumu, S., Maisha, R., & Rakate, E. (2020). Convection Parametrization and Multi-Nesting Dependence of a Heavy Rainfall Event over Namibia with Weather Research and Forecasting (WRF) Model. Retrieved from https://doi.org/10.3390/cli8100112

Spear, D., & Chappel, A. (2018). Livelihoods on the Edge without a Safety Net: The Case of Smallholder Crop Farming in North-Central Namibia. Retrieved from https://doi.org/10.3390/land7030079

Steyn, C. (2021). An analysis of Extreme Temperature Events (ETEs) of Namibia. Retrieved from https://wiredspace.wits.ac.za/server/api/core/bitstreams/c9cfc777-64bc-4179-8fef-9ae50b33338c/content

Strohbach, B. (2014). The SASSCAL / MAWF Weather Stations Network in Namibia. Retrieved from https://ir.nust.na/server/api/core/bitstreams/520cf6c6-3b31-4270-8f80-fe3df4811fd8/content

Taapopi, M., Kamwi, J. M., & Siyambango, N. (2018). Perception of Farmers on Conservation Agriculture for Climate Change Adaptation in Namibia. Retrieved from https://doi.org/10.5539/enrr.v8n3p33

Tshilunga, S. E. (2014). A study of the 2011 floods on human security in Namibia: a case study of the Oshoopala informal settlement in Oshakati. Retrieved from https://repository.unam.edu.na/bitstream/handle/11070/830/tshilunga2014.pdf

UNDP. (2020). Climate Information and Early Warning Systems. Retrieved from https://www.undp.org/sites/g/files/zskgke326/files/publications/UNDP-Issues-Brief-Climate-Information-and-Early-Warning-Systems-EN.pdf

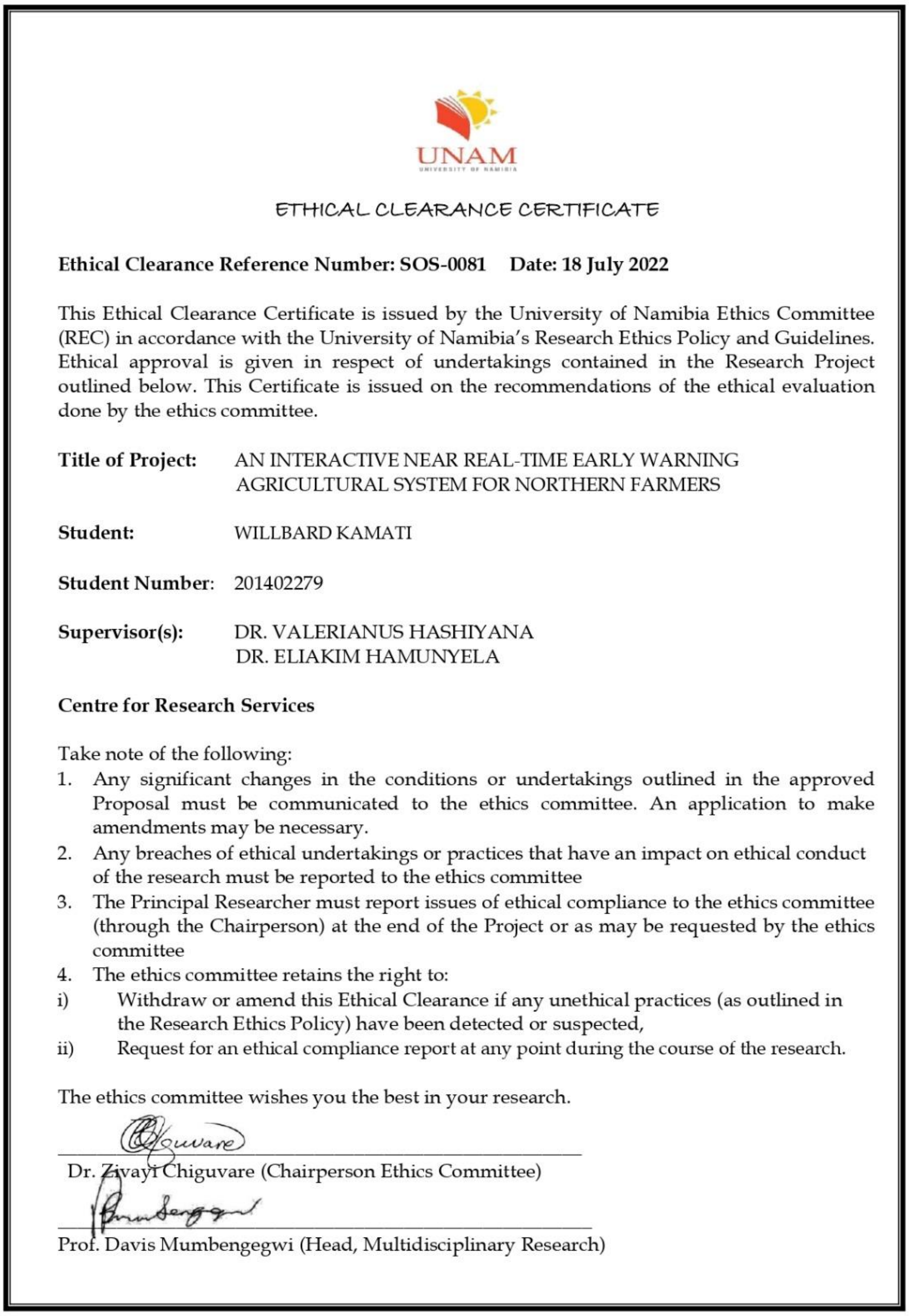
Wilhelm, M. (2012). Impact of Climate Change in Namibia- A Case Study of Omusati Region. Retrieved from https://ir.nust.na/handle/10628/381

Wyss, D., Negussie, K., Staacke, A., Karnagel, A., Engelhardt, M., & Kappas, M. (2022). A comparative analysis of MODIS-derived drought indices for Northern and Central Namibia. Retrieved from http://dx.doi.org/10.5897/AJEST2022.3096

APPENDICES

This chapter presents the interview questions and questionnaire questions.

Appendix A: Ethical Clearance Certificate



UNAM
UNIVERSITY OF NAMIBIA

ETHICAL CLEARANCE CERTIFICATE

Ethical Clearance Reference Number: SOS-0081 Date: 18 July 2022

This Ethical Clearance Certificate is issued by the University of Namibia Ethics Committee (REC) in accordance with the University of Namibia's Research Ethics Policy and Guidelines. Ethical approval is given in respect of undertakings contained in the Research Project outlined below. This Certificate is issued on the recommendations of the ethical evaluation done by the ethics committee.

Title of Project: AN INTERACTIVE NEAR REAL-TIME EARLY WARNING AGRICULTURAL SYSTEM FOR NORTHERN FARMERS

Student: WILLBARD KAMATI

Student Number: 201402279

Supervisor(s): DR. VALERIANUS HASHIYANA
DR. ELIAKIM HAMUNYELA

Centre for Research Services

Take note of the following:

1. Any significant changes in the conditions or undertakings outlined in the approved Proposal must be communicated to the ethics committee. An application to make amendments may be necessary.
2. Any breaches of ethical undertakings or practices that have an impact on ethical conduct of the research must be reported to the ethics committee
3. The Principal Researcher must report issues of ethical compliance to the ethics committee (through the Chairperson) at the end of the Project or as may be requested by the ethics committee
4. The ethics committee retains the right to:

i) Withdraw or amend this Ethical Clearance if any unethical practices (as outlined in the Research Ethics Policy) have been detected or suspected,

ii) Request for an ethical compliance report at any point during the course of the research.

The ethics committee wishes you the best in your research.

Dr. Zivayi Chiguvare (Chairperson Ethics Committee)

Prof. Davis Mumbengegwi (Head, Multidisciplinary Research)

Figure 8.1: Ethical Clearance Certificate *Source: Certificate's Screenshot*

Appendix B: Interview Questions

The interview questions were structured as follows:

1. What kind of farmer are you?
2. What do you farm with?
3. How long have you been a farmer?
4. Which kind of disaster are you more concerned/afraid of?
5. Have you experienced any natural disasters as a farmer?

   5.1. If yes, what kind of disaster?

   5.2. How did that affect your agricultural harvest?

6. Who should be responsible for helping farmers prepare and recover after natural disasters?
7. Does your community have a weather prediction/forecasting system?

   7.1. If yes, what kind of system? If No, go to Question 8.

   7.2. How helpful or useful is the system in place?

8. How do you access weather information/forecasts?
9. How often do you get weather information?
10. How do the farmers in your community share information amongst themselves?
11. How do you prepare for disasters?
12. What are the signs traditionally believed to serve as early warnings of disasters in your community?
13. How do you rate your computer literacy?
14. Do you have a device that can connect you to the internet?

15. Do you foresee challenges the proposed system might bring?
16. To what extent do you think the proposed system will be helpful in helping farmers prepare for natural disasters?

Appendix C: Questionnaire Questions

My name is **Willbard Kamati**, a final year **Master of Science: Information Technology** student at the University of Namibia. I would like to kindly work with you in completing this questionnaire, which forms part of a research project titled: '**An interactive near real-time early warning agricultural system for northern farmers in Namibia.**' The project aims to develop an interactive early warning agricultural system to warn farmers in northern Namibia about upcoming disasters (floods/droughts) and help them prepare for disasters.

The questionnaire is to be completed after reviewing the prototype presented to you. Your response will then be used to improve the design of the system. Completing

1. What kind of farmer are you?

   ☐ Communal (farm for food)   ☐ Commercial farmer (farm for business)

2. What do you farm with?

   ☐ Livestock   ☐ Crop   ☐ Both

3. How long have you been a farmer?

   ☐ Less than 2 Years   ☐ 2-5 Years   ☐ 6-10 Years   ☐ Over 10 Years

4. Which kind of disaster are you more concerned/afraid of?

   ☐ Flood

   ☐ Drought

   ☐ Other, specify:

   ……………………………………………………………………………………

5. Have you experienced any natural disasters as a farmer?

☐ Yes ☐ No

5.1. If yes, what kind of disaster? If No, go to Question 6.

…………………………………………………………………………………………

5.2. How did that affect your agricultural harvest?

☐ Minor ☐ Average ☐ Severe

6. Who should be responsible for helping farmers prepare and recover after natural disasters?

☐ Community/farmers ☐ Government ☐ Private organization ☐ Other:…...

7. Does your community have a weather prediction/forecasting system?

☐ Yes ☐ No

7.1. If yes, what kind of system? If No, go to Question 8.

…………………………………………………………………………………………

7.2. How helpful or useful is the system in place?

☐ Not useful ☐ Less useful ☐ Useful ☐ Very useful

8. How do you access weather information/forecasts?

☐ Radio/TV

☐ Mobile Application

☐ Community

☐ Other, specify:

………………………………………………………………………….......

9. How often do you get weather information?

☐ Never ☐ Daily ☐ Weekly ☐ Monthly ☐ Other:…….

10. How do the farmers in your community share information amongst themselves?

☐ Radio/TV

☐ Cellphones

☐ Social Media

☐ Other, specify:

…………………………………………………………………………...

11. How do you prepare for disasters?

……………………………………………………………………………………

……………………………………………………………………………………

………………

12. What are the signs traditionally believed to serve as early warnings of disasters in your community?

……………………………………………………………………………………

……………………………………………………………………………………

………………

13. How do you rate your computer literacy?

☐ Not good ☐ Beginner ☐ Very good

14. Do you have a device that can connect you to the internet?

☐ Yes ☐ No

15. Do you foresee challenges the proposed system might bring?

………………………………………………………………………………………

………………………………………………………………………………………

………………

16. To what extent do you think the proposed system will be helpful in helping farmers prepare for natural disasters?

………………………………………………………………………………………

………………………………………………………………………………………

……………………

Appendix D: More Screenshots of the System

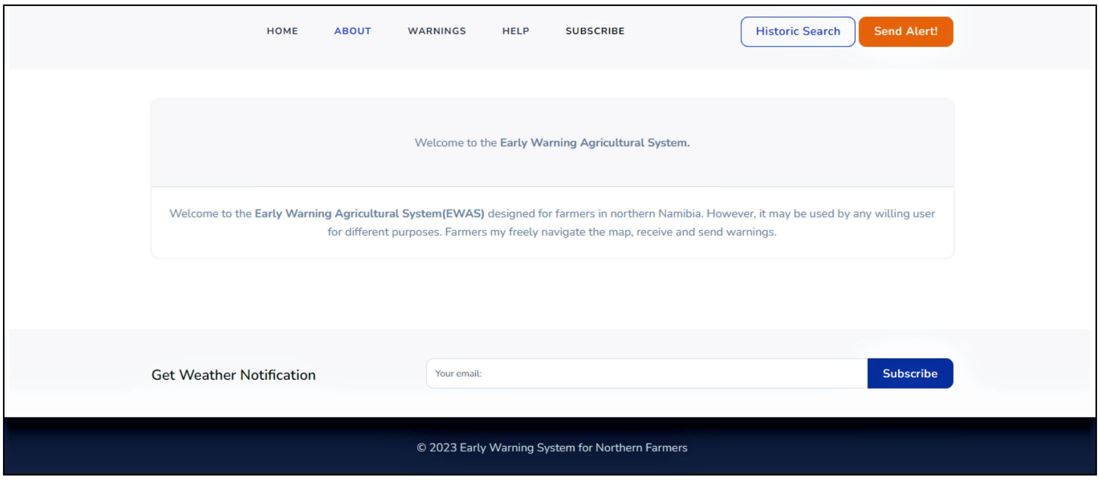


Figure 8.2: About the System *Source: EWAS Screenshot*

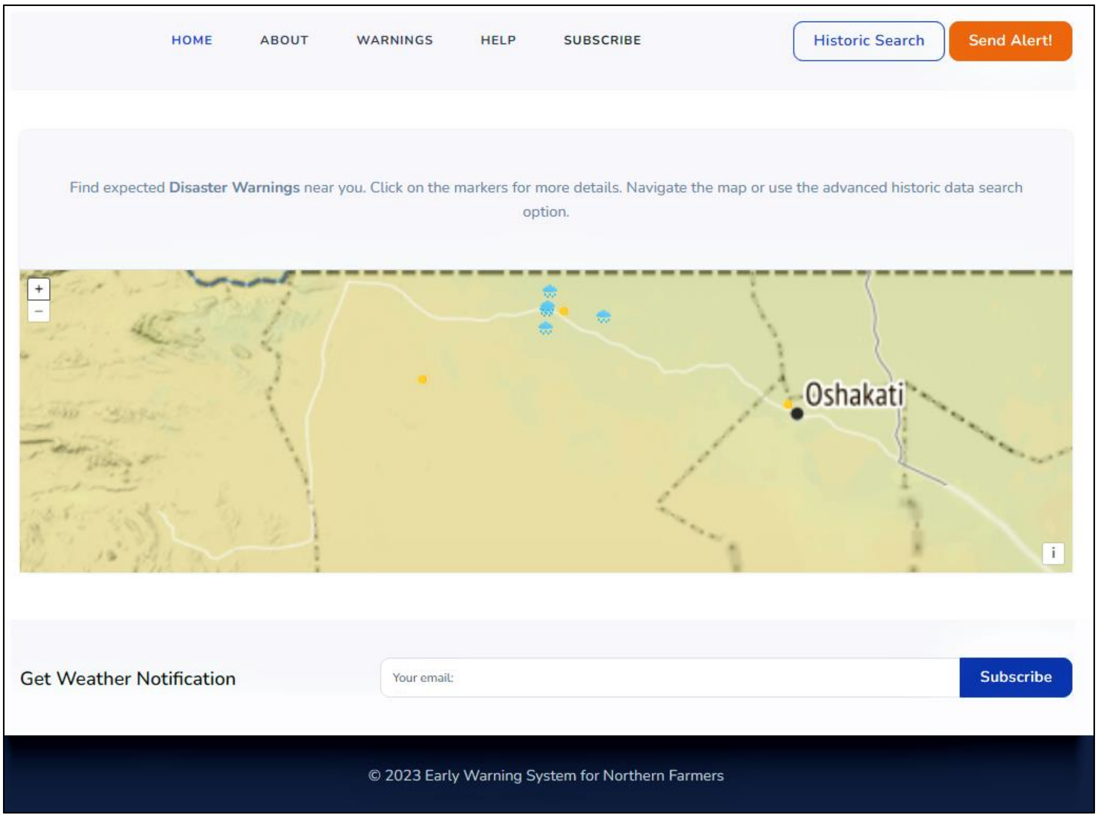


Figure 8.3: Disasters Predicted by the System *Source: EWAS Screenshot*

Figure 8.4: Indicators of Disasters Predicted by the System Source: EWAS Screenshot

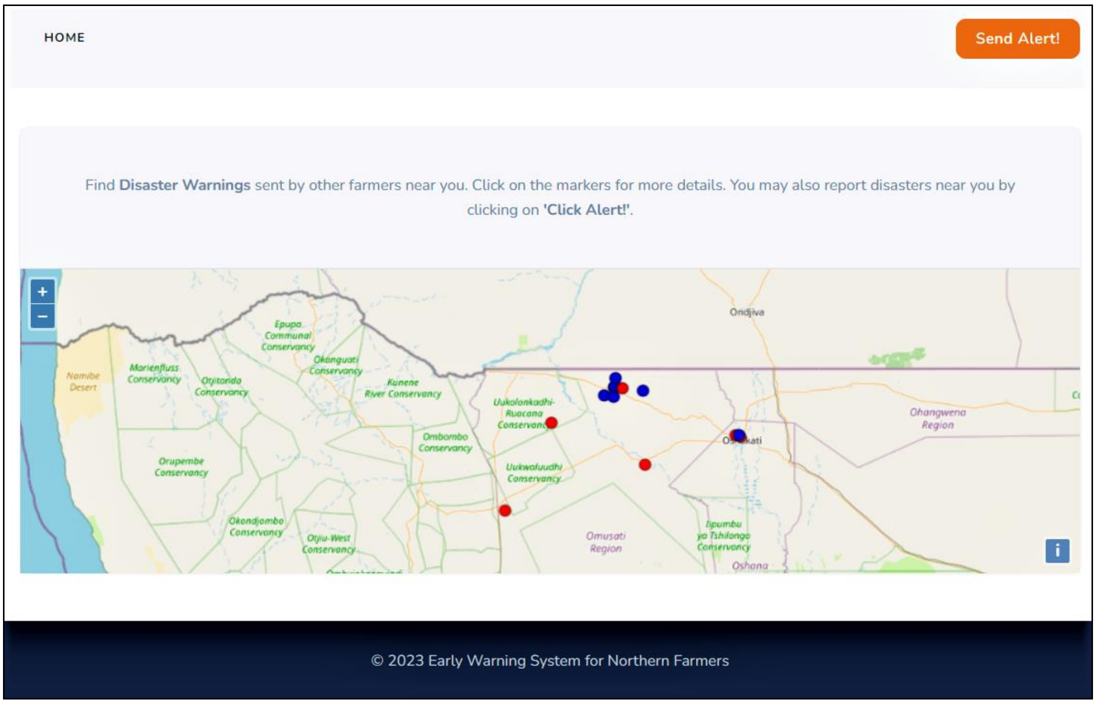


Figure 8.5: Disasters Reported by Farmers Source: EWAS Screenshot

Figure 8.6: Indicators of Disasters Reported by Farmers Source: EWAS Screenshot

Appendix E: System Codes

This section presents major system codes. Starting with the PHP file shown in Figure 8.7, data.php, which intends to retrieve near real time disaster alerts. Additionally, it facilitates the retrieval of past disaster alerts after an advanced historical search.

```
<?php
include 'db.php';
if (isset($_GET['startingdate'])) {
  $startingdate = $_GET['startingdate'];
  $endingdate = $_GET['endingdate'];
  $get_sql = "SELECT eventType, name, ST_AsGeoJSON(eventGeom), comment,
eventWarning_date FROM public.\"eventWarnings\" WHERE eventWarning_date >=
'$startingdate' AND eventWarning_date <= '$endingdate'";
  if (isset($_GET["getflood"]) && empty($_GET["getdrought"])) {
    $getflood = $_GET["getflood"];
    $get_sql .= " AND eventType = '$getflood'";
  }
  if (isset($_GET["getdrought"])&& empty($_GET["getflood"])) {
    $getdrought = $_GET["getdrought"];
    $get_sql .= " AND eventType = '$getdrought'";
  }
  $resultArray = pg_fetch_all(pg_query($dbcon, $get_sql));
  echo json_encode($resultArray);
} else {
  $get_sql = "SELECT eventType, eventWarning_id, ST_AsGeoJSON(eventGeom),
eventWarning_date FROM public.\"eventWarnings\" WHERE eventWarning_date >=
'0001-01-01' AND eventWarning_date <= '9999-12-31'";
  $resultArray = pg_fetch_all(pg_query($dbcon, $get_sql));
  echo json_encode($resultArray);
}
?>
```

Figure 8.7: Data Retrieval Code *Source: EWAS Source Code*

The JavaScript code shown in Figure 8.8, `main.js`, displays retrieved system-generated alerts on the map.

```
// Custom variables
var geojsonobj = {};
var HeatMapLayer;
var dataSource;
// Define view layer and default central point
var view = new ol.View({
    center: [1665248.5545242599, -2014336.2649255611],
    zoom: 6,
});
```

```
// Basemap layer
var basemapLayer = new ol.layer.Tile({
    source: new ol.source.Stamen({
        layer: 'terrain',
    }),
});
// Layers Array
var mylayerArray = [basemapLayer];
// Initiating Map
var mymap = new ol.Map({
    target: 'mymap',
    view: view,
    layers: mylayerArray,
});
// Creating geojson from database response
function creatingGeojson(arrayofdata) {
    geojsonobj['eventType'] = 'FeatureCollection';
    var features = [];
    for (i = 0; i < arrayofdata.length; i++) {
        var featobj = {};
        featobj['eventType'] = 'Feature';
        featobj['properties'] = {
            eventType: arrayofdata[i].eventType,
            eventWarning_id: arrayofdata[i].eventWarning_id,
        };
        featobj['geometry'] = JSON.parse(arrayofdata[i].st_asgeojson);
        features.push(featobj);
    }
    geojsonobj['features'] = features;
    // Define source to show this data
    dataSource = new ol.source.Vector({
        features: new ol.format.GeoJSON().readFeatures(geojsonobj),
    });
    //Display flood & drought indicators
    var AttributeLayer = new ol.layer.Vector({
        source: dataSource,
        style: function(feature) {
            var imageSrc1 = 'rain (1).png';
            var imageSrc2 = 'sun (1).png';
            var imageSrc3 = '';
            if (feature.get('eventType') === 'Flood') {
                return new ol.style.Style({
                    image: new ol.style.Icon({
                        src: imageSrc1,
                        scale: 0.5
                    })
                });
            } else if (feature.get('eventType') === 'Drought') {
```

```
                return new ol.style.Style({
                    image: new ol.style.Icon({
                        src: imageSrc2,
                        scale: 0.5
                    })
                });
            } else {
                return new ol.style.Style({
                    image: new ol.style.Icon({
                        src: imageSrc3,
                        scale: 0.5
                    })
                });
            }
        }
    });
    mymap.addLayer(AttributeLayer);
    AttributeLayer.setVisible(true);
    var source = new ol.source.Vector({
        features: new ol.format.GeoJSON().readFeatures(geojsonobj),
    });
}
function clearMap() {
    dataSource.clear();
}
// set up geolocation to track farmer's position
var geolocation = new ol.Geolocation({
    tracking: true,
    projection: map.getView().getProjection(),
    enableHighAccuracy: true,
});
// attach geolocation to the view's projection and update the view as the
farmers relocates
geolocation.on('change:position', function() {
    myview.setCenter(geolocation.getPosition());
    addmarker(geolocation.getPosition())
});

function addmarker(array) {
    marker.setPosition(array);
}
var deviceOrientation = new ol.DeviceOrientation({
    tracking: true
});
//rotate the view so that as user changes directions
deviceOrientation.on('change:heading', onChangeHeading);
function onChangeHeading(event) {
    var heading = event.target.getHeading();
```

```
    view.setRotation(-heading);
}
```

Figure 8.8: System Warnings Displaying Code *Source: EWAS Source Code*

The PHP script provided in Figure 8.9, `save.php`, sends and saves alerts from farmers, notifying fellow farmers about nearby disasters:

```
<?php
include 'db.php';
$type = $_POST['typeofgeom'];
$name = $_POST['nameofgeom'];
$currentLatitude = $_POST['currentLatitude'];
$currentLongitude = $_POST['currentLongitude'];
$comment = $_POST['commentongeom'];
$add_query = "INSERT INTO public.\"forumWarnings\" (warningType,
farmer_name, forum_geom, comment) VALUES ('$type', '$name',
ST_GeomFromGeoJSON('{\"warningType\":\"Point\",\"coordinates\":[$currentLo
ngitude,$currentLatitude]}'), '$comment')";
$query = pg_query($dbcon, $add_query);
if ($query) {
    echo json_encode(array("statusCode" => 200));
} else {
    echo json_encode(array("statusCode" => 201));
}
?>
```

Figure 8.9: Disaster Reporting Code *Source: EWAS Source Code*

Lastly, the JavaScript code in Figure 8.10, forum.js, retrieves and displays alerts from farmers on the map through GeoServer:

```
// All Global Variable
var draw
var flagIsDrawingOn = false
var PointType = ['Flood', 'Drought', 'Pests', 'Fire', 'Other'];
var selectedGeomType
// Custom popup
var popup = new ol.Overlay.Popup({
    popupClass: "default anim",
    closeBox: true,
    onclose: function() {
        console.log("You close the box");
    },
    positioning: 'auto',
    autoPan: true,
    autoPanAnimation: {
        duration: 100
    }
});
```

```
// View
var myview = new ol.View({
    center: [1665248.5545242599, -2014336.2649255611],
    zoom: 14
})
// OSM Layer
var baseLayer = new ol.layer.Tile({
    source: new ol.source.OSM({
        attributions: 'Surveyor Application'
    })
})
//Retrieves alerts through Geoserver
var featureLayersourse = new ol.source.TileWMS({
    url: 'http://localhost:8080/geoserver/survey_app/wms',
    params: {
        'LAYERS': 'survey_app:forumWarnings',
        'tiled': true
    },
    serverType: 'geoserver'
})
var featureLayer = new ol.layer.Tile({
    source: featureLayersourse
})
var drawSource = new ol.source.Vector()
var drawLayer = new ol.layer.Vector({
    source: drawSource
})
// Layer Array
var layerArray = [baseLayer, featureLayer, drawLayer]
// Map
var map = new ol.Map({
    target: 'mymap',
    view: myview,
    layers: layerArray,
    overlays: [popup]
})
// Function to save information into Database
function savetodb() {
    var params = featureLayer.getSource().getParams();
    params.t = new Date().getMilliseconds();
    featureLayer.getSource().updateParams(params);
    $("#enterInformationModal").modal('hide')
    clearDrawSource()
}
function clearDrawSource() {
    drawSource.clear()
}
// set up geolocation to track a user's position
```

```
var geolocation = new ol.Geolocation({
    tracking: true,
    projection: map.getView().getProjection(),
    enableHighAccuracy: true,
});
// bind it to the view's projection and update the view as the user moves
geolocation.on('change:position', function() {
    myview.setCenter(geolocation.getPosition());
    addmarker(geolocation.getPosition())
});
//add a marker to display the current location
var marker = new ol.Overlay({
    element: document.getElementById('currentLocation'),
    positioning: 'center-center',
});
map.addOverlay(marker);
// and bind it to the geolocation's position updates
function addmarker(array) {
    marker.setPosition(array);
}
// create a new device orientation object set to track the device
var deviceOrientation = new ol.DeviceOrientation({
    tracking: true
});
// when the device changes heading, rotate the view so that
deviceOrientation.on('change:heading', onChangeHeading);
function onChangeHeading(event) {
    var heading = event.target.getHeading();
    view.setRotation(-heading);
}
// Get information about warning color coded indicators
map.on('click', function(evt) {
    popup.hide();
    var resolution = map.getView().getResolution();
    var coord = evt.coordinate
    var projection = map.getView().getProjection()
    var url = featureLayersourse.getGetFeatureInfoUrl(coord, resolution,
projection, {
        'INFO_FORMAT': 'application/json'
    })
    console.log(url)
    if (url) {
        $.getJSON(url, function(data) {
            console.log(data)
            content = '<b>Reporter</b> : ' +
data.features[0].properties.farmer_name + ' <br> <b>Disaster Type </b> : '
+ data.features[0].properties.warningType + ' <br> <b>Details </b> : ' +
data.features[0].properties.comment
```

```
            if (data.features[0].geometry.warningType == 'Polygon') {
                popup.show(data.features[0].geometry.coordinates[0][0],
content);
            } else if (data.features[0].geometry.warningType == 'Point') {
                popup.show(data.features[0].geometry.coordinates,
content);
            } else {
                popup.show(data.features[0].geometry.coordinates[0],
content);
            }

        })
    }
})
```

Figure 8.10: Users Warnings Displaying Code *Source: EWAS Source Code*