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DEVELOPMENT OF A NEAR REAL-TIME EARLY WARNING AGRICULTURAL SYSTEM FOR DISASTER PREDICTION

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ABSTRACT

The effects of disasters are not uniform across all individuals and communities. One's preparedness and socioeconomic factors determine how much they will pay. Preparedness plays a crucial role in reducing the impact of disasters and aiding in their management and recovery. However, effectively preparing for unforeseen disasters becomes difficult when there is insufficient knowledge and expertise. Without accurate predictions and timely alerts about disasters, a community's level of readiness remains extremely low. Namibia has experienced various unavoidable climate-related dangers over time, making it vulnerable in the future. Inconsistencies in disseminating weather information and early disaster notifications are factors that obstruct the mitigation of climate-related disasters. Furthermore, disaster early warning system implementation has been slower in most African countries due to limited technical resources. Another notable challenge is upholding internationally standardized early warning systems in rural settings without overlooking the dynamics of the rural community, which leads to system ineffectiveness. Therefore, this study employed a mixed-methodology approach to gather qualitative and quantitative data from local farmers through the use of questionnaires to review the readiness to adopt early warning systems in northern Namibia, assess available technical resources, study the existing disaster mitigation practices in Namibia. Subsequently, historic and near real time weather data was collected from weather agencies, which ultimately designed and developed an early warning system to enhance resilience and preparedness for hazards and risks in farming communities by issuing comprehensive and timely alerts. The study confirmed the dire need for disaster prediction systems in Namibia, although it also highlighted pressing accessibility concerns that future researchers could study, especially under-resourced potential users.

Keywords: *Agriculture, Disaster, Early Warning, Mitigation, Namibia*

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1. Introduction

Namibia is known as one of the driest countries in southern Africa with a topology that is mostly flat with arid sandy soils. It 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. Additionally, Namibia is made up of different climatic zones, i.e., the tropical, semiarid, and desert regions. Most of these regions are not favourable for conducting agricultural activities due to fluctuating weather patterns and the occurrence of severe weather events linked to them. This makes it extremely vulnerable to several climatic disasters and other effects of climate variability. Despite these challenges, timely weather estimates in Namibia are barely available to help communities plan and foresee climatic misfortunes. Adding to the predicament, accessing historic rainfall records is often difficult as they are only accessible through meteorological and hydrological agencies that are not easily accessible. Furthermore, Namibia has a rich history of subsistence agro-silvo-pastoralism farming, mainly focusing on pearl millet (Pennisetum glaucum) and livestock husbandry. Therefore, the majority of Namibians, approximately 60% of the population, live in rural areas and rely mainly on agriculture for subsistence. In light of this heavy dependence on agriculture, Mtega (2017) suggests that it is of utmost importance to provide vulnerable communities with the knowledge and abilities required to embrace sustainable farming techniques. This includes imparting safety protocols to protect their means of living in the face of unforeseeable severe weather conditions, as well as offering them essential disaster management expertise.

Disaster management entails a comprehensive and interdisciplinary approach to identifying, assessing, and mitigating the risks associated with disasters. These events are notorious for causing severe disruptions in the functioning of societies or communities, leading to significant environmental, economic, material, and human losses. According to Muvhali (2013), these losses often surpass the capacity of the affected society or community to effectively respond. The impact of disasters is not uniform across communities; rather, it is influenced by pre-existing structures and social conditions. This leads to differential impacts, where certain members of the community may experience less severe consequences while others bear an extremely high burden (Amadhila *et al.*, 2013). Muvhali (2013) further attests that various factors contribute to an individual's vulnerability, including their proximity to hazards, their livelihood circumstances, access to social protection, and their ability to engage in self-protection measures. Furthermore, vulnerability is also determined by an individual's well-being, societal standing, possessions, financial circumstances, and the availability of supportive institutions (Baba-Adamu & Jajere, 2021). It is crucial to note that disasters have a significant bearing on both agricultural productivity and the overall well-being of individuals. As a result, it is essential that readiness improvement initiatives cover a broad spectrum of activities. This includes conducting thorough assessments of vulnerabilities within communities, developing flexible response plans, and providing training for individuals responsible for addressing these emergencies.

Meanwhile, the use of early warning systems is one of the attempts towards empowering and equipping those vulnerable to disasters with the necessary warning information to mitigate them. An early warning system contains the fundamental technologies required for the generation and timely dissemination of cautionary information. This serves to empower individuals, communities, and organizations confronted with potential risks, enabling them to institute necessary preparatory measures and execute appropriate responses to minimize damage or losses (Magomelo *et al.,* 2014). They comprise a collection of computerized systems, tools, and processes that possess the capability to alert individuals when a disaster is looming, thereby empowering them to take suitable actions with adequate lead time (Magomelo *et al.,* 2014).

Before the arrival of scientific weather modelling, the majority of traditional societies in Africa relied upon indigenous wisdom for weather prediction (Mbewe *et al.,* 2019). Interestingly, both indigenous knowledge and scientific knowledge share a common foundation in careful observation of the natural environment. According to Muzuwa (2017), indigenous knowledge is cultivated through extensive and spontaneous observation, accumulating wisdom over time, whereas scientific knowledge systems typically rely on a comparatively shorter duration of observation to generate scientifically proven results. Therefore, there exists an opportunity to explore the integration of indigenous knowledge into scientific weather forecasting systems as a means to enhance the resilience and effectiveness of weather and disaster prediction. This is possible by making weather and disaster modelling community-centred.

Early warning systems for weather and disaster modelling are essential for understanding and managing risks by offering risk assessment, monitoring, forecasting, warning, and response measures. These systems typically rely on numerical models to predict events beyond the immediate future (Somses *et al.,* 2020). Early warning systems are important for more than just agriculture. They can also protect communities and save lives. Therefore, the implementation of early warning systems presents a possible strategy for addressing both climate change and the related climatic events in Namibia. Different methods for sharing early disaster warning information include sirens, alarms, door-to-door notices, online platforms, radio and TV broadcasts, among others. This information should strive to uphold the standard of being easily accessible, reliable, relevant, actionable, and delivered in a timely and geospatially relevant manner to put in place preventive measures (UNDP, 2020). However, in most societies constantly exposed to different natural disasters such as floods, droughts and extreme heat, the existing disaster early warning systems and mitigation efforts are either inefficient, ineffective, or likely to fail at critical moments, thereby threatening lives and causing destruction (Magomelo *et al.,* 2014).

Early warning systems would encounter constraints unless they incorporated essential understandings pertaining to different environmental and societal variables. Hence, it is important that these systems possess clarity and foster confidence among the communities they are designed to assist (Magomelo *et al.,* 2014). Additionally, the effectiveness of warnings is significantly lessened if they fail to prioritize or reach the individuals who are most vulnerable to risks and prioritise the provision of appropriate education to enable effective responses to threats. Thus, the value of an early disaster warning lies in effective communication (Magomelo *et al.,* 2014).

Although developed continents have progressed well in advancing weather predictions, progress in most parts of Africa has been lagging behind because of limited important technological resources (Somses *et al.,* 2020). Furthermore, another challenge when it comes to the adoption of internationally recognised early warning systems in Africa's rural communities relates to the oversight of rural dynamics, resulting in system failure (Moises & Kunguma, 2023). Therefore, some communities in Africa still rely on indigenous knowledge for weather prediction, using their observations, experiences, and accumulated knowledge to predict natural tragedies (Mbewe *et al.,* 2019).

Areas for improvement in the utilization of early warning systems in Africa, and the adoption of standardized communication technologies and media for disseminating warnings, the public accessibility of historical weather data, fostering community engagement and participation in climate and disaster mitigation efforts, promoting the sharing of weather information, ensuring weather data quality, and establishing community-based weather stations. Additionally, enhancing public-private partnerships in disaster mitigation and the distribution of weather forecasts could further strengthen the effectiveness of early warning systems in the region (UNDP, 2020).

Therefore, this study explored the viability of ICT in contributing to the mitigation of climate-related risks by developing a community-centred near real-time interactive early warning agricultural system. This included the task of taking historical and current weather data from meteorological organizations, processing, and storing it within PostgreSQL spatial database. The data was then integrated into GeoServer for mapping and showcased through a web-based platform created using PHP. This platform aimed to exhibit data in the form of comparable vegetation images via the OpenLayers mapping library. This approach aimed to enhance understanding, navigation, pattern recognition, and the identification of risky zones. Notably, the system also featured an interactive community-centred forum that empowered users to send location-specific alerts to one another. This functionality enhanced community collaboration and streamlined the sharing of information among users, thus enabling them to take necessary precautions effectively.

2. Research Methods

This paper describes the process of developing an interactive early warning agricultural system to contribute to the mitigation of climatic disasters that hinder agricultural production in Namibia by providing location-specific, comprehensive early warnings about looming disasters. Before developing the system, it was crucial to assess the readiness to adopt an early warning system, and also gain a clear understanding of existing disaster mitigation practices, early warning tools, the means to communicate these warnings, and any challenges that could be improved. For this reason, a study was conducted.

2.1 Study Area

The chosen research area comprises the constituencies of Outapi and Anamulenge, situated in the Omusati region along the border between Namibia and Angola, within the northern central region of Namibia. The Omusati Region spans an approximate area of 26,551 square kilometres and is subdivided into 12 constituencies, including Anamulenge and Outapi (Taapopi *et al.,* 2018). This region stands out as one of the most densely populated areas in Namibia, with a total population of 243,166, of which over 90 percent reside in rural areas.

Geographically, the Omusati Region lies within the Cuvelai River Basin, a seasonal river system that transports surplus rainwater from southern Angola to the Etosha Pan in northern Namibia during the rainy season (Amadhila *et al.,* 2013). Covering an area of 353 square kilometres and 986 square kilometres respectively, the constituencies of Anamulenge and Outapi are inhabited by a combined population of 50,500, distributed across 9,500 households. The majority of these households possess agricultural plots as per the 2011 census. The rationale for selecting these constituencies stems from their location within a region that frequently faces escalating water scarcity and recurrent extensive flooding. Moreover, the agricultural output in the Omusati Region is anticipated to become unstable, leading to severe food insecurity (Amadhila *et al.,* 2013).

2.2 Research Design

A certain group of farmers was selected to participate in this study, namely those residing in the Outapi and Anamulenge constituencies within the Omusati region. The research employed a stratified sampling technique, as it enhances representation accuracy and minimizes potential sampling according to Nawa (2021). This involved categorizing farmers into two groups: communal, denoting those visibly engaged in farming activities within their traditional residences, and commercial, referring to individuals who own small to medium-sized farming projects. 88 farmers i.e., 73 communal and 15 commercial farmers participated. Data was gathered through the use of questionnaires, allowing for an inclusive collection of both qualitative and quantitative information. Qualitative data was collected by asking a series of open-ended questions to avoid limiting the responses.

Similarly, quantitative data was gathered by asking a sequence of close-ended questions using mostly scales. The objective of the survey was to get insights from farming communities vulnerable to disasters regarding their prior experiences with such events, their acts of information sharing, their altitude, and their readiness to adopt a system aimed at mitigating disaster impacts. Additionally, it conducted a thorough evaluation of the effectiveness of existing early warning systems and disaster prevention and detection measures in the region, while also pinpointing any existing shortcomings. Subsequently, region-specific historical and nearly real-time meteorological data was acquired from the Namibia Meteorological Service (NMS) as a prerequisite for developing the proposed early warning system.

2.3 Prototype Software Development Methodology

Subsequent to getting weather data, the prototype software development methodology, was employed to develop the early warning system. Munywoki (2020) defines this software development model as a model that allows a developer to create a prototype of the solution, providing an opportunity to showcase it to clients for feedback and modifications. Munywoki (2020) further explains that by employing this method, clients get a clear grasp of the application's overall concept and it helps avoid failure by identifying and addressing potential issues in the early stages. This ensured that system development only proceeded after a portion of potential users had given their approval for the prototype. In turn, this facilitated the achievement of a user-centred design. The survey findings aided the process of requirement analysis and laid the foundation for the initial software requirements. Requirement analysis includes defining the intended purpose of the proposed application and outlining the services it will offer. Afterwards, the system design was created, a process that involved conceptualizing the various elements of a system, including its architecture, system components, graphic interfaces, and database structure as explained by Nashandi (2020). Following this, a portion of the farmers were presented with prototypes for further refinement until all desired features were integrated. The results obtained from the survey informed the initial prototype. Afterwards, the process of system development was initiated which transformed the prototype into a functional interactive near real-time early warning agricultural system. The weather data gathered from the Namibia Meteorological Service (NMS) was integrated into the early warning system tailored for agricultural purposes. This allowed the system to thoroughly analyse the data to make disaster predictions. The prototype software development methodology is presented in Figure 1.

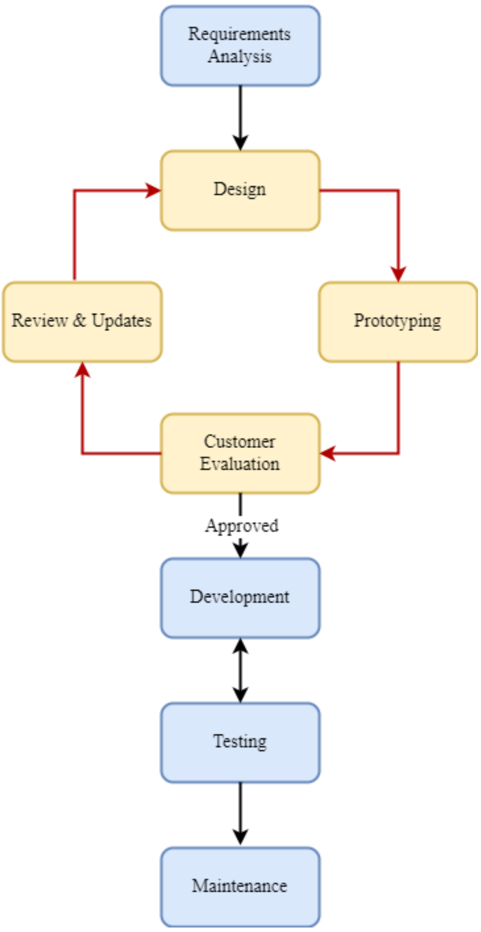

Figure 1. Prototype Software Development Methodology

The system was primarily built using open-source tools. The system consists of a combination of technologies and components that enable it to be a functional application. At its core, the system embodies a geographic information system (GIS), a computerized tool for visualizing, mapping, and analysing spatial data (Taufik *et al.*, 2023). Figure 2 shows the underlying components of the early warning system:

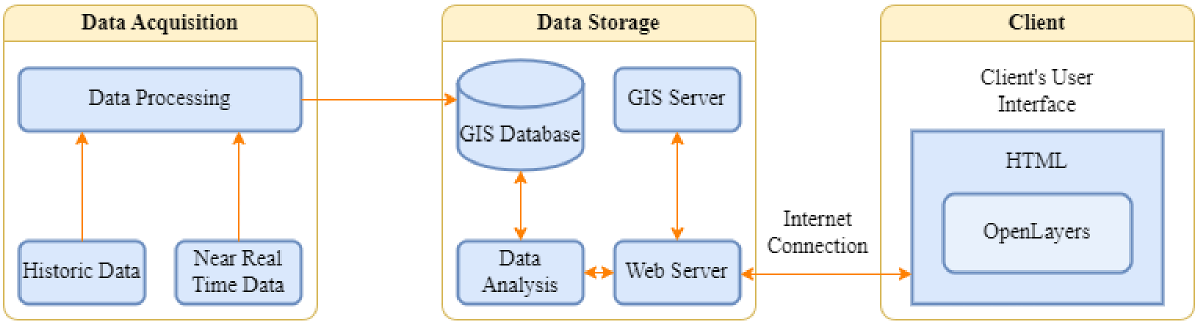

Figure 2. System Architecture

The components illustrated are explained in detail in Table 1:

Table 1. Components of the system.

Component	Description
Client	A device that a user uses to connect to the system through the internet. This could be any device that supports web browsers such as Google Chrome, Mozilla Firefox, Microsoft Edge, etc. Hypertext Markup Language (HTML), PHP, jQuery, and OpenLayers were used to visualise warnings and present the maps.
OpenLayers	OpenLayers is a pure JavaScript library for displaying maps in modern web browsers with no server-side dependencies, that uses JavaScript API to build rich web-based geographic applications. 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.
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.
Web Server	A web server is a computer that handles access to centralised resources through the web (Dhanalakshmi *et al.*, 2020). It handles queries from clients using Hypertext Transfer Protocol (HTTP), stores and retrieves web pages for clients' devices. Apache Web server was used for this project.
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 (Dhanalakshmi *et al.*, 2020). PostGIS and PostgreSQL were used for creating and storing the data, and providing the necessary storage support for geospatial data.
GIS Server	An open-source platform for publishing spatial data and interactive mapping applications on the web (Dhanalakshmi *et al.*, 2020). 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. GeoServer was used as a GIS Server.
Data Acquisition	The acquisition process involved obtaining near real time and historical daily rainfall data from various weather stations across Namibia through a third party, Namibia Meteorological Services (NMS), which maintains the largest and oldest rainfall database in the country. The weather stations are located in different regions of Namibia. Additionally, input data from users was also taken into account during the data acquisition process.
Data Processing	This involved encoding the acquired GIS data into a format that could be read and supported by the GIS applications to ensure that the data met the desired format. The

	data was converted to the Comma Separated Values (CSV) format before being imported into the GIS database.

Next, the system was evaluated and tested by a panel of 12 farmers, examining its possible effectiveness, usefulness, learnability, and user satisfaction. Additionally, the evaluation process sought to determine the relevance of different aspects of the early warning agricultural system, its acceptance and sustainability within the farming communities in northern Namibia. This evaluation process involved a comprehensive introduction to the study's purpose, and system requirements. Following this, a demonstration of the system's capabilities was carried out, after which the farmers were provided with questionnaires to rate their level of agreement with a series of statements in order to evaluate the usability of the system. Lastly, as the requirements of the system may evolve due to different reasons in the future, maintenance as a final phase in the prototype software development methodology is reserved for future advancements to the systems.

3. Results and Discussion

3.1 Research Findings

The data collected using a questionnaire was subjected to analysis, and the findings were generated, some of which were graphically presented in charts to enhance readability. Firstly, all survey participants unanimously indicated the absence of an early warning agricultural system in use within their respective communities. When it comes to the frequency of obtaining weather information, farmers exhibit a diverse range of practices. Specifically, 52% of respondents never seek weather information, while 15% access it on a daily basis, 28% receive it weekly, and the remaining 5% acquire it on a monthly basis. These statistics are graphically represented in Figure 3 presented:

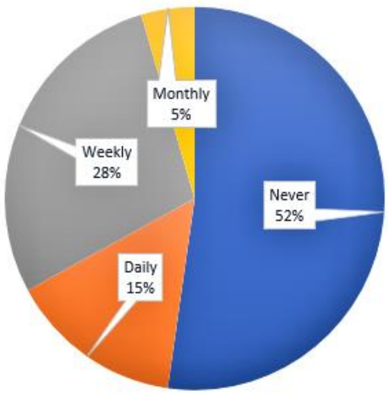

Figure 3. Weather Updates Frequency

Among those farmers who actively seek weather information, the primary sources include radio, television, mobile applications, community channels, and the internet. Furthermore, when there is a need, the majority of farmers disseminate weather information or forecasts to others through verbal communication with fellow farmers, with some also employing channels such as radio, television, and social media for this purpose. The farmers' disaster mitigation practices included various strategies, including rotational grazing, relocation to higher grounds, accepting the inevitability of disasters, engaging in prayer, setting aside surplus resources for times of calamity, and choosing more resilient farming locations.

The study also evaluated the technical preparedness for the adoption of an early warning agricultural system, comprising an assessment of farmers' proficiency in computer literacy and the existing resources available to support the utilization of the early warning agricultural system. As a result, the survey revealed that 28% of farmers demonstrated an advanced level of computer literacy, while 33% were classified as beginners in this regard. Notably, 39% of the respondents lacked computer literacy skills. These findings are graphically represented in Figure 4:

Figure 4. Farmers' Computer Literacy Skills

Furthermore, it was observed that only 69% of the respondents had access to the necessary means for internet connectivity, whereas the remaining 31% did not possess such access. This distribution is illustrated in Figure 5:

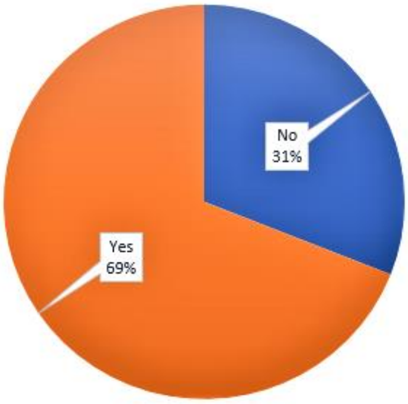

Figure 5. Farmers versus Internet Gadgets

Farmers also confirmed the utilization of indigenous knowledge within their communities, wherein they relied on environmental cues, such as the behaviour of local flora such as mopane trees, and the activities of animals such as dogs and birds, as indicators of impending disasters. On entities that should be responsible for helping farmers prepare, mitigate, and recover from disasters, farmers believed it should be the government, farmers could also help themselves, while a small percentage believed private organisations could also lend a helping hand.

3.2 Early Warning Agricultural System

The development process produced a system that analyses the historic and near-real time data, picks up patterns, and signs of upcoming disasters, and it presents graphic warning notifications on a map as illustrated in Figure 6. Indicators of predicted disasters are shown in Figure 7.

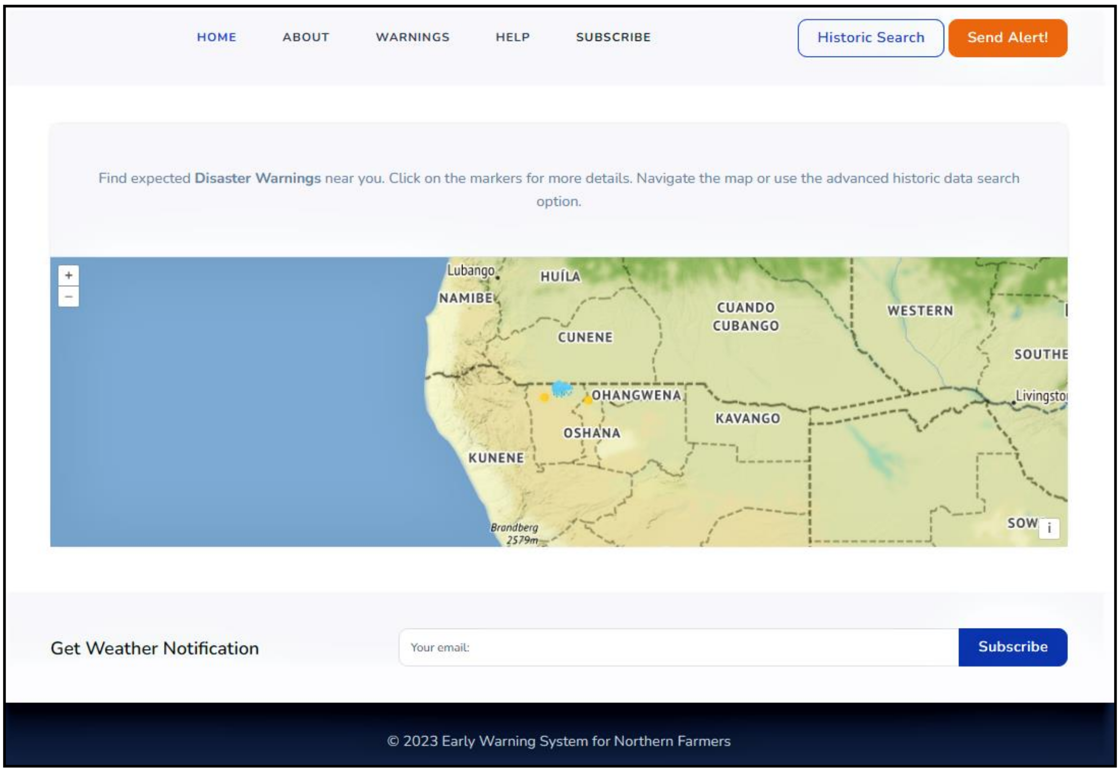

Figure 6. Final Prototype

Figure 7. Indicators of Disasters Predicted by the System

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 8.

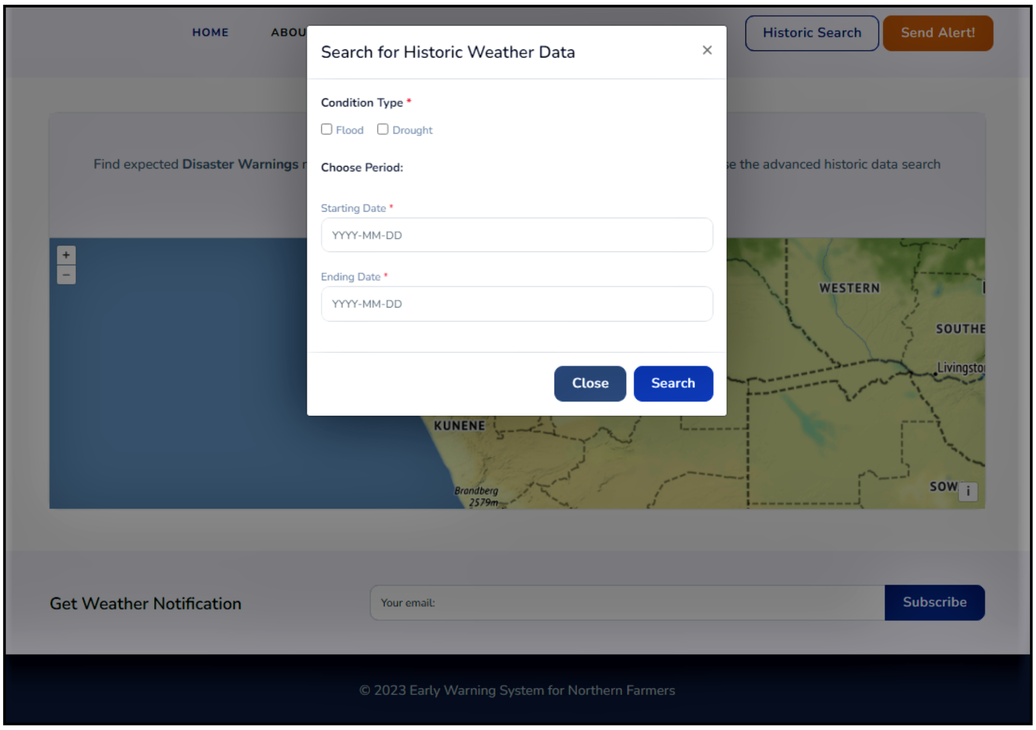

Figure 8. Advanced Historic Search

In the same vein, farmers are able to send detailed geotagged warnings to other farmers about disasters or signs of disaster in their areas, which are also presented on a second map. 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, as demonstrated in Figure 9. Geotagged warnings will appear on the map as demonstrated in Figure 10.

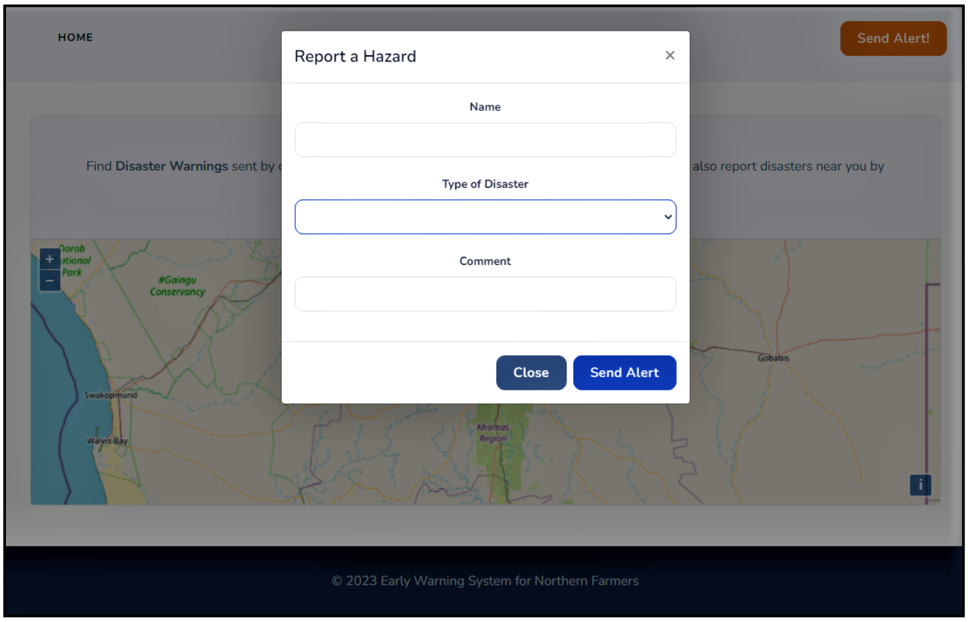

Figure 9. Sending an Alert

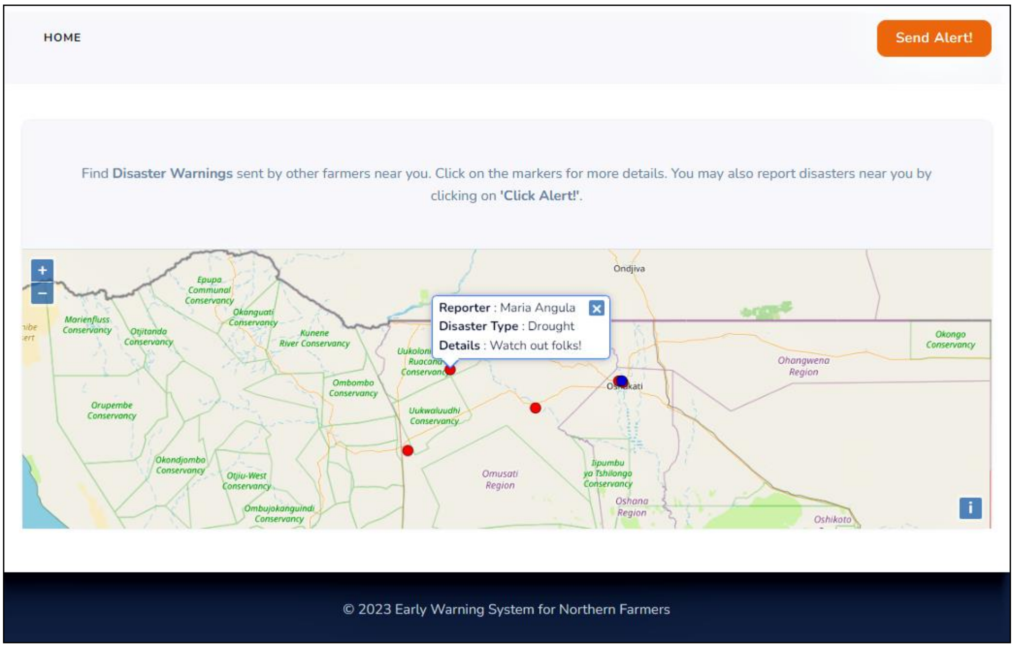

Figure 10. Geotagged Warning

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. This feature ensures that other farmers in the area are promptly alerted about the reported disasters.

3.3 System Evaluation Findings

Several other qualities were evaluated by requesting respondents to indicate the degree to which they agreed with a number of statements. The results are presented in Figure 11, 12, 13, 14, and 15.

- Usefulness:

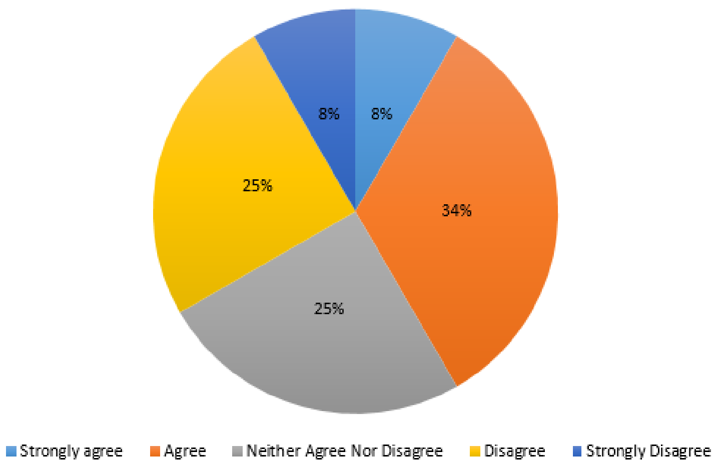

Figure 11. Usefulness

- System Ease of Use:

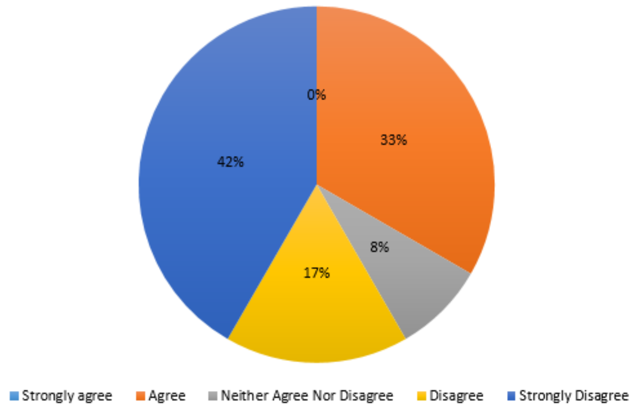

Figure 12. Ease of Use

- System Learnability:

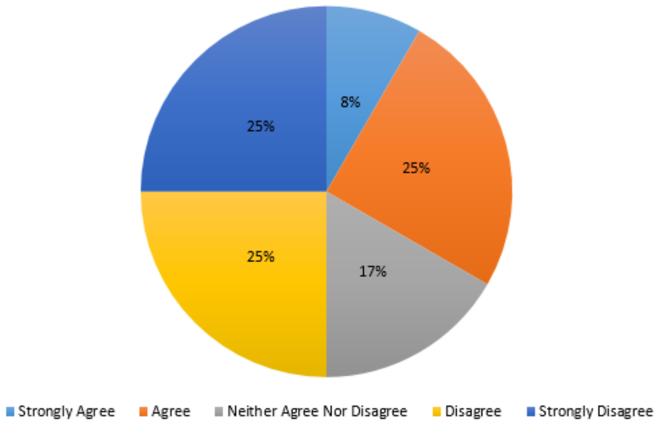

Figure 13. Learnability

- System understandability:

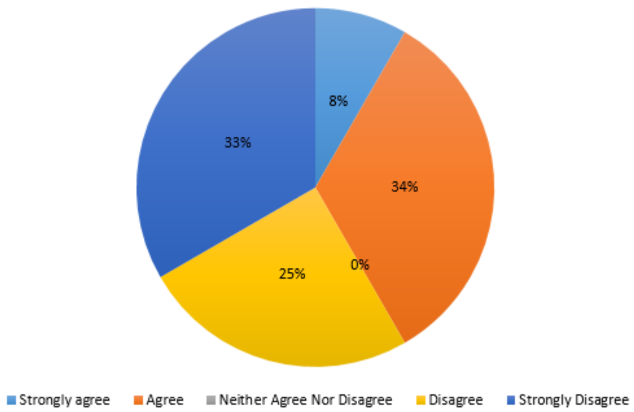

Figure 14. Understandability

- 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 that the system could be deployed at the community leaders' offices for leaders to interpret 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. 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 reduce internet costs. Lastly, it was suggested that the system should be zoomed in for a clearer view.
- System Anticipated Effectiveness:

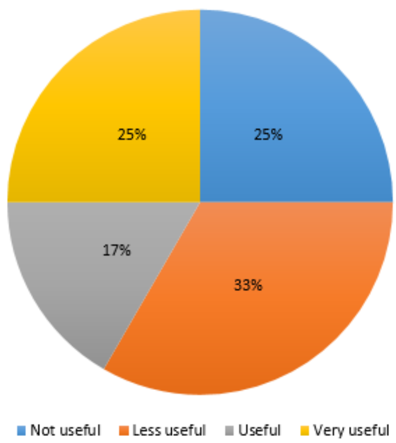

Figure 15. Anticipated Effectiveness

3.4 Discussion

The study has proven that the northern Namibian community is exposed to different disasters. Hence, an effective early warning system should incorporate different disasters that affect farmers, such as floods, droughts, pest outbreaks and wildfires. Furthermore, the study further revealed that the community receives weather predictions and shares them through various means. This includes face-to-face verbal communication, radio, television, and occasionally interpreting environmental warnings. Hence, there could be a need to explore the use of modern technologies, such as the internet, to share information more efficiently among these predominantly rural communities. Furthermore, it was demonstrated that early warning systems are underutilized in Namibia, particularly in the context of disaster prediction and disaster management. Additionally, the readiness for full utilisation of early warning systems remains debatable. This is because there is still a significant portion of potential users who lack computer literacy, while another considerable fraction do not have internet-enabled devices. Therefore, implementing early warning systems would involve acknowledging and tackling the projected challenges uncovered by the study. These difficulties have the potential to hinder the effectiveness and success of early warning systems in Namibia. These challenges include issues of accessibility of the application, uncertainties regarding the reliability and credibility of the generated early warnings, and the costs associated with internet usage.

The usability evaluation conducted as part of the prototype software development methodology proved that the system is useful although it might be difficult to use for some of the users. Furthermore, the system was found to be fairly learnable and understandable. For this reason, training the potential users before adopting the system should be mandatory.

Despite the anticipated challenges and hiccups, the system could still prove to be useful. This is due to Namibia possessing ICT infrastructure and reasonable network coverage capable of facilitating the implementation and utilization of digitalized and web-based systems for early warnings and information exchange. Similarly, the country also possesses a significant quantity of mobile phones, including smartphones compatible with internet connectivity. Therefore, the study has proven that Namibia has the necessary resources to support the use of internet-based early warning systems, although they are not fully utilised currently. Despite the available resources, the affected communities might still need the help of the government and private institutions to recover from devastating disasters. In conclusion, the success of an early warning system would be determined by the manner in which the users receive early warnings and whether they respond promptly to the warnings in a way that minimizes the damage that the disasters would cause. It is therefore essential for the system to be deployed in a way that meets the users' expectations.

4. Conclusion

The early warning system 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 various reasons. The reasons may include access to resources and the possession of certain skills. Also, managing disasters in Namibia is largely an affected society's responsibility, despite most societies being poorly equipped to manage disasters. However, over time, this circumstance could enhance with the ongoing development of ICT infrastructure in Namibia, confidence in the application grows, and collaborations between people, government, and private institutions are established. It is therefore recommended that government agencies, private institutions, and humanitarian organizations join hands with farmers in managing and mitigating disasters.

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

- Firstly, it is strongly advised that local agencies overseeing climatological datasets, along with other relevant organizations, should keep data up to date. This can be achieved by deploying additional weather stations, particularly in rural areas, to capture near real-time weather information. This initiative would empower farmers with the information needed to implement effective disaster mitigation strategies.
- Finally, considering the significant reliance on indigenous knowledge for disaster prediction in Namibia, forthcoming research studies could concentrate on validating the accuracy of this traditional knowledge and incorporating it into contemporary early warning systems.

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Author Contribution

Author1 conducted the study and wrote the article under the supervision of Author2 and Author3.

Conflict of Interest

The authors declare no competing interests.

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