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Research article

Integration and use of climate data by the national health system in Mozambique

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ABSTRACT

Introduction: Mozambique is increasingly affected by extreme weather events and associated infectious disease outbreaks, highlighting a significant gap in knowledge on use of data to better inform health system preparedness and response.
Methods: In this qualitative study, we collected data from 29 key informants using customized semi-structured questionnaires. Data were then triangulated and analyzed using content and thematic methods.
Results: The National Institute of Meteorology is primarily responsible for producing and supplying weather data to the national health system (NHS). NHS has access only to weather data, and there is no specific platform or system for integrating weather or climate data and health data. Other notable barriers to sharing and using climate data include poor geographical coverage of the meteorological network and lack of systematic records on the impact of extreme events. Facilitating factors include multiple policies that mention the link between climate change and health, and the existence of health data management platforms and an early warning system piloted by the National Institute of Health.
Conclusion: Ongoing work to develop a health sector climate change adaptation plan and revitalize the Public Health Emergency Operations Center could be key to accelerating efforts to improve climate data use to inform infectious disease outbreak preparedness and response. Results from piloting of the early warning system could be used to advocate for climate data integration into the NHS to help in identifying the impact of climate change on health and designing effective plans to address climate-related infectious disease outbreaks.

1. Introduction

Due to human activity, the earth's surface temperature has risen by more than 0.8°C in the last century and by around 0.6°C in the last three decades [1], triggering global climatic and environmental changes that pose a growing threat to the health and survival of people around the world [2]. These changes have led to extreme weather events such as floods, droughts, and stronger and more frequent storms. In Africa, the health impacts of global warming encompass heightened vulnerability to vector-borne, airborne, and waterborne diseases, alongside food insecurity [1], as well as water insecurity, poor sanitation, and increased heat-related mortality rates [2]. Mozambique, in southeastern Africa, the third most vulnerable country to climate change on the continent, confronts these challenges due to its geographical location and extensive coastline [3], elements combined with socioeconomic and infrastructural vulnerabilities.

Abbreviations: AIDS, Acquired Immune Deficiency Syndrome; BES, Weekly Epidemiological Bulletin; CHAI, Clinton Health Access Initiative; COESP, Public Health Emergency Operations Center; COVID-19, coronavirus disease 2019; DHIS2, District Health Information Software 2; e-VIDR, electronic Integrated Disease Surveillance and Response; GNL, Government National Level; GSL, Government Subnational Level; HeRAMS, Health Resources and Services Availability Monitoring System; INAM, National Institute of Meteorology; INS, National Institute of Health; KI, key informant; MOH, Ministry of Health; NGO, nongovernmental organization; NHS, national health system; PL, Provincial Level; rDSA, r Data Science Assignments; SDSMAS, District Services for Health, Women's Affairs and Social Action; SIS-MA, Health Information System for Monitoring and Evaluation; TAMP, Turnkey Asset Management Program; UNFPA, United Nations Population Fund; UNICEF, United Nations Children's Fund; UN OCHA, United Nations Office for the Coordination of Humanitarian Affairs; WHO, World Health Organization

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Mozambique's population, estimated at 33.2 million [4], is mostly rural. Although endowed with diverse natural resources—arable land, abundant water sources, energy and mineral resources, and recently discovered natural gas deposits [5]—it is one of the poorest and least developed countries, ranked 183rd of 191 countries in the Human Development Index [6]. The high poverty rate is sustained by disease, high population growth, low agricultural productivity, unequal distribution of wealth, conflict, and extreme weather events.

The country's tropical and subtropical climate, characterized by high temperatures and variable rainfall patterns, creates an ideal environment for transmission of vector-borne diseases [7,8]. Additionally, Mozambique's frequent extreme weather events, including cyclones, floods, and droughts, disrupt sanitation systems and access to clean water, facilitating the transmission of waterborne diseases like cholera, dysentery, and diarrhea [9,10]. The link between climate variability and infectious diseases is evident in the increased incidence of malaria during the rainy season, when mosquito breeding sites proliferate, and in the outbreaks of cholera following heavy rainfall and flooding, which contaminate water supplies [7–11].

These climatic conditions directly influence the transmission dynamics of climate-related infectious diseases by affecting the life cycles of vectors and pathogens, altering their geographic distribution, and increasing human exposure to disease [12,13]. Malaria prevalence rose to 44.2% in households severely damaged by Cyclone Idai, compared to 22.1% in undamaged homes [14]. Since September 2022, the cholera outbreak has resulted in 5,237 suspected cases and 37 deaths, predominantly in flood-prone areas. Heavy rainfall exacerbated the spread, affecting districts with limited cholera response capacity [15]. Moreover, rising temperatures and shifting rainfall patterns associated with climate change are expected to exacerbate the burden of infectious diseases in the region, posing significant challenges to public health systems [8].

Yet, there does not seem to be effective preparedness for climate-related infectious disease outbreaks as supplies for routine programming are often redirected to address emergency needs, and there has been an upsurge in vaccination campaigns to minimize outbreaks as a result of extreme weather events, also impacting the continuity of high-quality routine health services. There are substantial gaps in understanding if climate data are available to the national health system (NHS); and, if so, how the data are used to predict infectious disease patterns and needed resources to address potential outbreaks within any given period. While the Ministry of Health (MOH) has established surveillance systems like Integrated Disease Surveillance and Response, these often lack real-time weather data integration, leading to delayed responses and limited forecasting capabilities. The health management information system is intended to support decision-making with comprehensive data, including data related to infectious disease incidence and management, but frequently suffers from inaccuracies and untimely updates [16,17]. Furthermore, it lacks a framework to integrate or triangulate with available climate[1] and weather[2] data for effective prediction, trend analysis, and response to infectious disease outbreaks.

These gaps underscore the need for a more robust approach to integrating climate and health data to inform decision-making, essential for improving public health adaptation to climate change [17]. For these reasons, this study aimed to (1) outline the current practices around sharing climate data to support preparedness and response decisions to climate-related infectious disease outbreaks in Mozambique; (2) identify barriers and facilitators to use of climate data for outbreak preparedness and response; and (3) highlight actions or interventions currently undertaken by the NHS and non-governmental organizations (NGOs) to improve sharing and use of climate data for outbreak preparedness and response.

2. Materials and methods

2.1. Study design and population

This exploratory qualitative study was designed to examine the practices of sharing and using climate data within Mozambique's NHS, with particular focus on identifying facilitators and barriers that influence the effectiveness of data usage in preparing for and responding to climate-related infectious disease outbreaks. The participant pool consisted of key informants (KIs) such as health system managers at national and provincial (Zambézia) levels and representatives from multilateral agencies and NGOs actively engaged in emergency management and response initiatives for Cyclone Freddy. This study aimed to discern central- and provincial-level decision-making processes, and as such did not include district or health center staff. Inclusion criteria to participate in the study: (1) work in an entity that deals with data/information related to climate, emergency, and health; (2) be involved in health emergency preparedness and response activities; and (3) agree to participate and give informed consent.

2.2. Data collection and analysis

Prospective participants were identified through a selection process that involved elaboration of a preliminary list based on the National Institute of Health's (INS) experience in previous work in the area of health and climate change. The list included professionals from government agencies and partner organizations/NGOs involved in the management of climate-sensitive diseases, who were then contacted via email. A total of 29 KIs, including government officials and NGO managers directly involved in the Cyclone Freddy response, were selected through purposive sampling, adhering to inclusion criteria that ensured their direct involvement in climate and health data management and health emergency preparedness and response.

The study coordinator conducted in-person and virtual interviews (approximately one hour each) in November 2023. Virtual interviews were held on Microsoft Teams, Zoom, and Google Meet. Semi-structured interview guides customized to match the unique expertise and operational focus of each KI group ensured collection of data relevant to the study's objectives: interviews with government institution representatives included questions designed to elucidate how they acquired and used climate data in decision-making processes; interviews with nongovernmental and multilateral organizations focused on understanding of their management of climate data and their role in assisting the government with leveraging this information to prepare for and respond to outbreaks of climate-related infectious diseases.

Following a deductive approach, the study coordinator and principal investigator conducted thematic data analysis to identify and refine major themes for organization and interpretation. This involved pre-exploration of information, selection of analysis units, and categorization/subcategorization of information. Data were organized in Microsoft Excel and analyzed for frequency of themes mentioned by KIs (Annex 1).

2.3. Ethical considerations

The study received ethical approval from the INS Institutional Ethics Committee (reference 146/CIE-INS/2023). Administrative authorization was granted by the MOH. Written informed consent was obtained from all participants prior to their interviews, ensuring adherence to ethical standards and participant confidentiality.

[1] Climate data: Records of observed climate conditions taken at specific sites and times with particular instruments following standard procedures. For more details, see: World Meteorological Organization. Climate data homogenization, https://community.wmo.int/en/climate-data-homogenization; 2020 [accessed 15 August 2024].

[2] Weather data reflect short-term atmospheric conditions. For more information, see: National Geographic Society. Weather or climate: What's the difference?, https://education.nationalgeographic.org/resource/weather-or-climate-whats-difference/; n. d. [accessed 15 August 2024].

Table 1
Study participant characteristics.

Key informant type	Organization	Sector(s)	Number
National-level staff in a management/decision-making capacity	MOH	National Directorate of Public Health National Malaria Control Program Department of Epidemiology Environmental Health Department National Directorate for Planning and Cooperation	11 (38%)
	INS	Health and Environment Program	
	National Institute of Meteorology	National Directorate for Weather Analysis and Forecasting	
	National Institute for Disaster Management	National Emergency Operations Center	
	Ministry of Public Works, Housing and Water Resources	National Directorate of Water Resources Management	
Zambézia provincial government staff in a management or decision-making capacity	Provincial Directorate of Health	Environmental Health Surveillance	5 (17%)
	INS, Zambézia	Health and Environment Program	
	Quelimane Municipality	Health Council	
	National Institute for Disaster Risk Reduction and Management, Zambézia	National Institute for Disaster Risk Reduction and Management, Zambézia	
Multilateral and nongovernmental organization staff in a management or decision-making capacity	World Health Organization (WHO)	Public health and environment Climate change Emergencies WHO Zambézia	13 (45%)
	United Nations Children's Fund (UNICEF)	Health Emergencies UNICEF Zambézia	
	United Nations Population Fund (UNFPA)	Environmental health Climate change Health UNFPA Zambézia	
	United Nations Office for the Coordination of Humanitarian Affairs (UN OCHA)	UN OCHA	

3. Results

3.1. Participant characteristics

Approximately half of the 29 KIs were aged 30 to 45 years, and half were older than 45 years; 63.5% had completed a bachelor's degree; 25.6% had completed a master's degree; and 10.9% had completed a doctoral degree. Participants included national-level MOH staff in a decision-making/management capacity (38%), their counterparts at the Provincial Directorate of Health in Zambézia (17%), and multilateral organizations and NGOs (45%) (Table 1).

3.1.1. Participant perceptions of the impact of climate change on the health sector

Most KIs understood that climate change has a negative impact on individual and collective health, resulting in the proliferation of vectors, spread of diarrheal diseases, and destruction of social and health infrastructure, culminating in the breakdown of health services.

> *Climate change destroys health infrastructures and causes disruption in the provision of health services.* (KI, Government Subnational Level [GSL])

Diseases most frequently identified as particularly aggravated by climate change: malaria, measles, and cholera and other diarrheal diseases. Less frequently mentioned: COVID-19, tuberculosis, influenza, pneumonia, bronchitis, and tonsillitis.

> *Diseases aggravated by climate change include some of the deadliest, such as measles, malaria, and diarrheal diseases.* (KI, GSL1)

Additionally, KIs noted that all provinces are affected, depending on geographical location and the type and magnitude of the extreme event caused by climate change.

3.2. Current practices around sharing and using climate data to inform decision-making on preparedness for and response to infectious diseases

To assess how climate data are shared and used within Mozambique's NHS to enhance preparedness and response to infectious diseases, the study team first mapped the existing health data management platforms used by the NHS, including those for routine health data, epidemiological surveillance, and emergency health data management. The assessment focused on evaluating the platforms' capability to incorporate climate data into decision-making processes. Finally, Cyclone Freddy was examined as a case study to identify the barriers and facilitators of integrating climate and health data in practice.

3.2.1. Overview of health data management systems

Study participants reported there are approximately 11 platforms for collecting and sharing routine, epidemiological, and emergency health data in Mozambique (Table 2). Three are managed by the government (Weekly Epidemiological Bulletin [BES], Health Information System for Monitoring and Evaluation [SIS-MA], and electronic Integrated Disease Surveillance and Response [e-VIDR]). The others are operated by NGOs: 5W (what, who, when, where, why), 4W (what, where, when, who), 3W (what, where, when), the Health Resources and Services Availability Monitoring System (HeRAMS), r Data Science Assignments (rDSA), an open-source electronic medical records system, the Turnkey Asset Management Program (TAMP), and rapid needs assessment.

SIS-MA is the main data management and analysis platform in District Health Information Software 2 (DHIS2) and operates at the central, provincial, and district levels of the NHS. BES is the weekly epidemiological report on notifiable diseases and is reported at the national level. The e-VIDR platform, designed for electronic integrated disease surveillance and emergency response, is the most comprehensive model within the NHS for addressing data related to

Table 2
Platforms for managing routine, epidemiological, and emergency health information in Mozambique.

Organization type	Name	Level	Data management platform(s)
Government	Provincial health services	Provincial	BES, SIS-MA
	Provincial Health Directorate		BES, SIS-MA, e-VIDR
	District Services for Health, Women's Affairs and Social Action	District	BES, SIS-MA, e-VIDR
Humanitarian partner/NGO/ community-based organization	University College for Aspiring Medical Missionaries	District	SIS-MA, TAMP
	World Health Organization		SIS-MA, BES, 5W, 3W, HeRAMS, rDSA, e-VIDR, rapid needs assessment
	Mozambican Association for Family Development		SIS-MA
	Ariel Foundation against Pediatric AIDS		SIS-MA, open-source electronic medical records system
	United Nations Population Fund		SIS-MA, 5W
	Office for the Coordination of Humanitarian Affairs		5W

climate-sensitive diseases such as cholera, diarrhea, and malaria. 5W, 4W, and 3W were designed to provide essential information on which organizations (who) are carrying out which activities (what), in which locations (where), over what period (when), and for which beneficiaries (who) within an emergency context.

KIs reported that while the level of coverage of the main NHS data platforms (SIS-MA and e-VIDR) was 100% in the roll-out phase, current e-VIDR coverage is between 30% and 40%.

> *We have many platforms and there are many systems that we have in the Ministry of Health, but they are not operating. Interoperability is one of the challenges.* (KI, GNL6)

3.2.2. Understanding the e-VIDR platform: Data collection, user engagement, and decision-making potential

e-VIDR was designed to collect data on indicators related to notifiable diseases, including cholera and other diarrheal diseases and malaria. As of September 2022, BES data were recommended for inclusion in e-VIDR to allow the MOH to access the data directly upon entry. Primary users of e-VIDR include epidemiological surveillance focal points (e.g., preventive medicine technicians, district maternal and child health nurses, primary health care–level heads, health unit clinicians). At higher levels, provincial surveillance focal points, district and provincial chief medical officers, and the provincial health services are also key users of the platform, working in coordination to manage and respond to public health data.

Implementation of e-VIDR was primarily driven by the need to improve disease surveillance and response capabilities, especially in the wake of outbreaks following cyclones. However, it does not integrate climate data and, according to KIs, there is no other NHS platform for managing climate data and associated infectious disease outbreaks, making e-VIDR the primary monitoring tool at the government level.

> *In order to improve disease surveillance and prompt response, we started using e-VIDR.* (KI, Provincial Level [PL] 4)

> *Due to the occurrence of outbreaks after cyclones, there was a need to strengthen surveillance by introducing e-VIDR.* (KI, PL1)

Despite its intended role in real-time reporting and decision-making, challenges hinder the platform's effectiveness. The information it provides is not comprehensive enough to inform reliable decision-making.

> *I'm going to base myself on e-VIDR, and at no point is it used for decision-making for various reasons.* (KI, GNL6)

> *e-VIDR doesn't use the data for decision-making because it has limitations.* (KI, GNL7)

Several institutions are involved in implementation of e-VIDR (Table 3). The Clinton Health Access Initiative (CHAI) has been supporting the government in developing and strengthening digital systems to improve disease surveillance, management, and response. CHAI has been responsible for funding, training, and monitoring the implementation of the system and providing devices and supervision.

Table 3
Institutions responsible for implementation of e-VIDR.

Institution	Responsibility
MOH, INS	Training, monitoring for system implementation and supervision
Provincial Directorate of Health	Training, monitoring
District Services for Health, Women's Affairs and Social Action	Training, device distribution, monitoring
CHAI	Financing, training, monitoring system implementation, provision of devices, supervision
Health facility	Trainees and platform users

Primary disease-related data are collected at the health facility level using e-VIDR data collection forms. Once the data are analyzed, they are entered into the e-VIDR platform via Android mobile phone by the surveillance focal points at the health facilities and then sent directly to the MOH, with viewing at the level of the District Services for Health, Women's Affairs and Social Action (SDSMAS) and District Statistics Nucleus. Only the MOH, INS, and CHAI have access to the data once the data reaches the MOH. If the MOH has concerns or notices inconsistencies, the information is returned to the district to check for accuracy. According to the surveillance focal points at the district level, SDSMAS is involved in this process.

The surveillance focal points also stated that SDSMAS sometimes receives notification of cases from health facilities in physical summary reports in addition to the data reported in e-VIDR. The health data management platforms/systems—although they do not collect climate data—generate monitoring and evaluation data for decision-making around programming interventions to address seasonal diseases, assessing incidence according to season and determining geographic locations of these diseases. This information is sent to the MOH daily to inform where and when an intervention should be implemented to address each disease.

3.2.3. Practices around sharing, integrating, and using climate data to inform decision-making

According to all study participants, there has never been a platform at the MOH/national level where climate data are integrated and used to inform health programming.

> *The Ministry of Health does not integrate climate data into any electronic health information system; however, climate data is used by the National Directorate of Public Health for decision-making; when there is a forecast of peaks of heat or cold, for example, [the MOH] sends information via [short message service] and social networks of good practices in favor of the health of citizens. In the event of natural*

Table 4
Barriers and facilitators to sharing and using climate data to inform national health system preparedness and response to climate-related infectious disease outbreaks (Cyclone Freddy as a case study).

Barrier	Facilitator
No specific platform for integration of climate data into the NHS.	Existence of multiple policies that mention aspects related to the intersection between climate change and health.
Dependence on INAM to provide weather and climate data, which depends on a hydrometeorological network with poor geographical coverage.	Existence of health data management platforms in the NHS (e.g., SIS-MA and e-VIDR) that can be used to integrate climate and health data and allow for data analysis and decision-making based on historical evidence and real-time evidence.
Dysfunctionality of the e-VIDR platform due to problems in synchronizing and updating the software, lack of electricity in many health facilities to charge the devices, and poor training/socialization of technicians on using the platform.	Community radio and television stations, district disaster committees, district meteorological stations, mobile units, social networks, the media, and community health workers play a key role in disseminating information on the occurrence of extreme weather events.
Poor training of NHS staff to respond with emergency interventions in the face of extreme weather events.	
Late or slow reporting of information related to notifiable diseases.	
Lack of constant supervision and monitoring to guarantee good response operations in the event of emergencies.	
Lack of reporting of information already being collected at community and health facility levels related to incidence of notifiable diseases.	
Lack of funding to implement existing emergency preparedness and response plans to control epidemic outbreaks.	
Ineffective dissemination of health messages during the response, despite multiple communication channels.	
Lack of preparedness to maintain essential health services and and manage the expected rise in infectious diseases during and after the cyclone, due to inadequate training and funding.	
Constant turnover of government sectoral focal points and partners, reducing historical knowledge of how to respond to emergencies.	
Structural issues around the overall nature of the response—including perceived lack of importance given to protecting health care providers.	
Insufficient stock management of antiretroviral drugs and other emergency medicines to ensure an appropriate response.	

disasters, the public health sector is mobilized in coordination with [the National Emergency Operations Center], which includes [the National Institute of Meteorology], [the National Institute for Disaster Management], and others, to respond to these extreme climatic events. (KI, GNL8)

According to KIs, only weather data such as maximum and minimum temperature, humidity, and rainfall are shared by the National Institute of Meteorology (INAM) with other government institutions and the public.

INAM shares climate data (weather reports) with the different sectors of the state, including the National Directorate of Public Health in the Ministry of Health and the National Institute of Health. This data is shared via communication platforms such as WhatsApp and also via email on a daily basis. INAM also shares weather and climate forecast data on a daily basis and alerts in the event of extreme events through the media [television and radio]. Weather data is also available on INAM's Facebook pages and website. (KI, GNL8)

The information shared by INAM and the National Directorate of Water Resources Management in the National Emergency Operations Center, of which the National Directorate of Public Health is a part, includes daily meteorological data, which is the weather forecast for the provincial capitals, river flow data, tropical cyclone or drought warning data, data related to heavy rains, strong winds, heat waves, cold waves. (KI, GNL8)

KIs reported that disease-related data are collected at health facilities and sent to SDSMAS to be entered into e-VIDR or SIS-MA. These data are then shared with the Provincial Directorate of Health, provincial health services, the MOH, and NGO partners.

We collect cases of suspected measles, diarrhea, and malaria and provide it to the following levels of the health system through BES and SIS-MA. (KI, GNL5)

Additionally, a fundamental gap pertains to the difficulties of collecting climate data in real time to enable better planning and response in the event of an emergency. KIs pointed out that weather stations do not exist in all districts, and those that do operate with considerable difficulty.

We have no way forward. Another issue is the lack of weather stations in some districts of the province, which makes it difficult to monitor weather phenomena in vulnerable districts. (KI, PL2)

3.3. Cyclone Freddy: Leveraging climate data to enhance national health system preparedness and response to climate-related infectious diseases

Cyclone Freddy struck Mozambique in March 2023, with the most severe impact felt in Zambézia Province, followed by Sofala, Nampula, and Manica Provinces. The cyclone affected 886,487 people, displacing 98,975 and resulting in 165 deaths and 511 injuries. This event served as a critical case study for exploring the integration of climate data into the NHS to enhance preparedness and response to climate-related infectious disease outbreaks. [18].

Through interviews with KIs involved in the emergency response—particularly those in Zambézia—the study identified significant barriers and facilitators of use of climate data to inform NHS preparedness and response efforts (Table 4). Key barriers include the absence of a dedicated platform for integrating climate data within the NHS, reliance on insufficiently covered meteorological data from INAM, and issues with existing health data management platforms such as e-VIDR, which suffered from functional challenges like software synchronization problems and power shortages, as well as inadequate user training. Additionally, delayed disease reporting, insufficient emergency preparedness funding, and inadequate training of NHS staff were identified as major hurdles. Facilitators include existing policies that intersect climate change and health; established health data management systems capable of integrating and

analyzing climate and health data in real time; and effective communication networks comprising community radio, media, and health workers to support information dissemination and emergency response.

3.4. Current efforts to improve sharing and use of climate data to prepare for and respond to outbreaks of infectious diseases

Study participants highlighted that while some initiatives are in place, no standardized policy for sharing climate data exists within the NHS. A disaster management committee has prepared contingency plans; however, practical implementation of these plans often falls short due to lack of funding specifically earmarked for emergency management and infectious disease outbreaks.

> *The problems that arise are already known because there is no concern before disasters. We have committees that are prepared, but in theory. In practice, there is nothing.* (KI, GNL9)

KIs reported that weak implementation of relevant plans and policies was primarily due to a lack of robust functionality across the central, provincial, and district levels of the health system, specifically in key locations such as Zambézia Province and Maputo, where gaps in coordination, resource allocation, and execution significantly hindered effective application of these plans.

> *It's their implementation, the policies are there, maybe the implementation should be more robust, more reinforced, I think that's the part where I see we might have a gap.* (KI, PL5)

Additionally, there was consensus that existing policies are insufficient due to lack of compliance, operationalization, and centralized control of funds within the National Institute for Disaster Management.

> *They are not enough because nothing is implemented.* (KI, GNL3)

Despite these challenges, several actions and interventions are currently underway to improve sharing and use of climate data to better prepare for and respond to infectious disease outbreaks. According to the National Strategy for Adaptation and Mitigation of Climate Change (2013–2025), the MOH, along with other government agencies (e.g., Ministries of Agriculture and Rural Development, Land and Environment, and Public Works, Housing and Water Resources) are working to enhance the capacity to collect, store, manage, and process climate data. This strategy includes creating an integrated network of meteorological, agrometeorological, and hydrometric stations; developing a standardized climate data system; and establishing a national measurement, reporting, and verification system. The health sector, with support from the World Health Organization, is taking steps to strengthen NHS capacity to respond to climate change impacts. The MOH, in collaboration with INS, Eduardo Mondlane University, and with the support of WHO, is currently developing the National Health Adaptation Plan to Climate Change. While this plan is being finalized, the MOH has revitalized the Public Health Emergency Operations Center (COESP), originally established in 2019, to enhance its preparedness and response to climate change-related health issues. COESP serves as a centralized coordination structure, strengthening the country's ability to effectively manage public health emergencies. The Public Health Law was created to reinforce COESP's authority to develop contingency plans and action protocols for various types of public health emergencies. Moreover, the Ministry of Land and Environment identified adaptation and climate risk reduction measures in the updated Nationally Determined Contribution to the United Nations Framework Convention on Climate Change (2020–2025). These include strengthening the early warning system through the provision of dedicated meteorological information for specific target users, including the MOH, and expanding the system to reach district levels with timely meteorological and hydrological information. One significant ongoing effort is development of the National Health Observatory, focused on monitoring climate-sensitive diseases such as malaria, dengue, cholera, and diarrhea. The INS spearheaded a pilot project aimed at integrating climate and epidemiological data to create an early warning system that was tested in Inhambane, Maputo, Nampula, and Sofala Provinces. The goal of this initiative was to enhance the capacity of provincial and district health bodies to enable them to better prepare for and respond to health risks associated with climate-related disasters.

4. Discussion

This study aimed to explore how climate data are accessed and used by the NHS to inform preparedness and response to infectious disease outbreaks in Mozambique. While all participants acknowledged the impact of climate change on the health sector, there is no specific platform that integrates climate data with health data. INAM is primarily responsible for producing and supplying weather data to various sectors, including health [19,20]. These data are used in preventive health messaging, but it does not appear they are used to predict and prepare for extreme weather events; the primary data platforms, SIS-MA and e-VIDR, focus solely on the incidence of infectious diseases. This information suggests that climate data may not be adequately considered in planning and decision-making for infectious disease control within the NHS, thus affecting national preparedness and response to climate-related infectious diseases.

A significant challenge to the production and use of climate data in Mozambique is poor geographical coverage of the country's hydrometeorological network [3]. The observed coverage of e-VIDR data platforms in the NHS is between 30% and 40%, meaning that even if climate data were integrated into the health information system, using these platforms nationally, especially in remote rural areas, would be challenging. Additionally, weather reporting stations are not uniformly distributed; most are clustered along the coast, exacerbating existing challenges related to climate data availability. Further, there are no systematic records of the impact of extreme events, particularly at the district level. Although impact and response reports exist for some events, these are not documented systematically with details of affected geographies and populations.

The e-VIDR platform was implemented with the primary goal of facilitating real-time reporting of disease outbreaks to inform timely decision-making around public health responses. Despite its potential, the platform faces significant challenges that impede its effectiveness. The core issue lies in the quantity and quality of data collected by e-VIDR, which are not comprehensive enough to support robust decision-making. Decision-makers require accurate and complete data to formulate effective public health strategies. By integrating climate data into health surveillance systems like e-VIDR, health authorities could transform their approach from reactive to proactive. Currently, e-VIDR facilitates response after an outbreak has been detected; however, with integrated climate data, the system could predict outbreaks before they occur. By analyzing the correlation between climate change and increased disease incidence, authorities could anticipate how vectors like mosquitoes might behave under similar conditions in the future. This predictive capability would enable preemptive measures—like targeted vaccination or vector control—thereby preventing outbreaks and enhancing overall public health resilience.

Study results suggest that the availability, access, and use of climate data in the NHS could be improved by integrating the data into the system's data platforms so they can be part of the decision-making process for responding to seasonal diseases and extreme weather

events, either predictively (using historical data to predict when the next outbreak might happen) or in real time should climate conditions alter to a point where a warning could be issued. For this integration to be effective, the MOH should strengthen health system capacity by training providers on the health risks associated with climate change, enabling them to incorporate climate considerations into decision-making processes and address risks such as the spread of vector- and waterborne diseases and heat-related illnesses. Additionally, providers would be better equipped to manage the impacts of air quality degradation, food security challenges, extreme weather events, zoonotic diseases, and mental health issues linked to climate change [21,22]. A similar conclusion was drawn from a cross-sectional study in Ethiopia, Ghana, Kenya, Namibia, Nigeria, and South Africa, which highlighted the necessity to update policies and strengthen providers' skills to better respond to climate change [23].

Although the MOH and partners have developed contingency plans for emergencies caused by extreme weather events, these plans remain largely theoretical and have not yet been fully approved or implemented. Moving forward, the focus should be on finalizing and operationalizing the plans to ensure they are actionable during actual emergencies [24,25].

Integrating early warning systems for extreme weather events into public health strategies can greatly enhance the ability to prevent disease outbreaks. For example, health services can implement timely interventions by raising community awareness during high-risk periods [26]. The MOH and INS should explore alternative data sources, such as the US National Oceanic and Atmospheric Administration's Earth System Research Laboratory for temperature, the Multi-Source Weighted-Ensemble Precipitation for precipitation, and the European Centre for Medium-Range Weather Forecasts' Climate Data Store for humidity [27].

In addition, the INS pilot project to integrate climate and epidemiological data to create an early warning system represents a crucial step toward making Mozambique's health system more resilient to the impacts of climate change. Moreover, an innovative approach in Japan that integrates natural hazard monitoring and social media data could serve as a model to improve disaster awareness in Mozambique [26]. Emergency plans should also consider the varying levels of vulnerability within the population, particularly in poor rural and peri-urban areas, ensuring that those most at risk are adequately protected [28–30].

Mozambique's response to Cyclone Freddy highlighted several barriers, among them lack of resources to implement existing emergency preparedness and response plans to control epidemic outbreaks. In addition, while an adaptation plan is currently being finalized, there is not yet a comprehensive MOH-wide strategy for responding to extreme weather events or adapting to climate change. This gap leaves the public health sector vulnerable. In cases of natural disasters, the MOH typically relies on the government's contingency plan [31].

In our study, the presence of policies that address both climate change and health is identified as a key facilitating factor for sharing and using climate data. This integration helps inform the NHS in its preparedness and response to climate-related infectious disease outbreaks. This was also noted in a study conducted by the INS, the US Agency for International Development, and Chemonics International [27,31]. Currently, the NHS and its partners are making efforts to improve how climate data are shared and used. According to the Ministry of Land and Environment, government agencies are taking measures to adapt to climate change, reduce risks, and increase resilience in communities, including the use of climate data [31].

In future research, we recommend the MOH, in collaboration with the INS and other implementation partners, conduct comprehensive studies to address critical gaps in preparedness and response measures. Specifically, we propose:

- Investigating the effectiveness of digital tools in predicting extreme weather events, with a focus on evaluating the accuracy and reliability of these tools in forecasting events such as cyclones, which can have significant implications for climate-related infectious diseases.
- Assessing the functionality, acceptability, and suitability of using an early warning system during climate events. This evaluation should investigate its effectiveness in alerting communities and health systems to prevent infectious disease outbreaks, particularly seasonal malaria outbreaks coinciding with cyclone periods.
- Expanding analysis of seasonal malaria incidence over the past five years and correlating it with cyclone occurrences to enhance predictive modeling. Researchers could identify high-risk areas and prioritize resource allocation by linking malaria incidence data with cyclone periods. This may involve use of geospatial mapping techniques and implementation of resource allocation pilots to optimize response strategies.
- Evaluating the implementation fidelity of emergency plans and the functionality of emergency operations centers. This assessment should identify gaps in capacity and operational efficiency to provide insight into areas for improvement in disaster response protocols. By addressing these research areas, we could strengthen Mozambique's capacity to effectively mitigate the impact of climate-related disasters on infectious diseases and enhance resilience within the health system.

5. Conclusion

The NHS in Mozambique lacks the capacity to effectively manage climate data to mitigate climate-related infectious disease outbreaks. None of the existing health information systems integrate climate, weather, or health data. INAM is responsible for providing weather data and its integration into the health sector remains limited. Ongoing efforts to develop a health sector climate change adaptation plan and revitalize the COESP are crucial steps toward better preparedness. Integrating climate data into health systems will enable more accurate predictions of infectious disease outbreaks and the design of effective response strategies. The future course of action should focus on fully operationalizing these plans to address the impacts of climate change on health.

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Declaration of competing interest

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Judite Pinto: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Nelson Cossa:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mara Ferrari:** Writing – review & editing, Writing – original draft, Project administration. **Patricia S. Coffey:** Writing – review & editing, Conceptualization. **Melanie Picolo:** Writing – review & editing, Funding acquisition, Data curation. **Tatiana Marrufo:** Writing – review & editing, Investigation, Funding acquisition. **Ana Paula Cardoso:** Writing – review & editing, Funding acquisition.

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Supplementary materials

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