ASSESSING TROPICAL CYCLONES IN MOZAMBIQUE CHANNEL THAT AFFECTED MALAWI (2014-2023)

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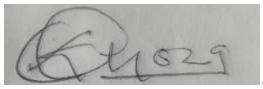
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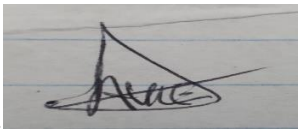
Dissertation submitted to Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology in partial fulfilment of the requirement for Bachelor of Science in Meteorology and Climate and Climate Science.

MAY, 2025

DECLARATION

We Elias Khoza and Davie Mwakabanga declare that this research project represents our own work and that it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged.

Signature ………..

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Date ……..21 May 2025……..

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ACRONYMS/ABBREVIATIONS

DCCMS : Department of Climate Change and Meteorological Services

DoDMA : Department of Disaster Management Affairs

NASA : National Aeronautical Space Administration

SSTs : Sea Surface Temperatures

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ABSTRACT

This study assesses tropical Cyclones originating in the Mozambique Channel that impacted Malawi from 2014 to 2023, focusing on their frequency, intensity, and impacts. The southern region of Malawi, characterized by high population density and vulnerability to climate change extremes, serves as a study area. Utilising a quantitative methodology, the research analyses secondary data from NASA, the Department of Climate Change and Meteorological Services (DCCMS), and the Department of Disaster Management Affairs (DoDMA). Key climatic parameters, including Sea Surface Temperatures (SST), humidity, observed temperatures, and rainfall trends, are evaluated using Mann-Kendall statistical tests, Python and Excel to identify patterns and correlations with cyclone activity.

Results indicate that a rising trend in cyclone frequency and intensity, linked to increasing SSTs (0.022°C/year) and humidity (+0.036g/kg/year) in Mozambique Channel. Tropical Cyclones such as Idai (2019), Ana (2022), and Freddy (2023) caused catastrophic impacts, including over 500 fatalities, displacement of 362,928 people, and widespread destruction of infrastructure, agriculture, and livelihoods. The 2023 Cyclone Freddy alone displaced 86,604 households, damaged 253 schools, and disrupted critical services, exacerbating existing variabilities. Statistical analyses of rainfall data revealed significant variability, with peaks coinciding with major Cyclone events, though no long-term trend was statistically significant

The study underscores the role of climate change in amplifying Cyclone risks, with warmer SSTs and atmospheric moisture creating favourable conditions for Cyclogenesis. Findings emphasize the urgent need for enhanced early warning systems, resilient infrastructure, and regional collaboration to mitigate future disasters.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Tropical cyclones are among the most destructive extreme weather systems, causing extensive damage to life, property and ecosystems due to strong winds, heavy rainfall, and storm surge (N. Kodunthirapully Narayaswami, 2022). These systems are characterised by intense low-pressure centres, strong winds, and heavy rainfall, with their impacts amplified by climate change which usually have debilitating impact on the affected communities. (D. Chokodzi, 2021).The south-western Indian Ocean, including Mozambique is one of the world's most active regions for tropical cyclone with conditions, such as high sea surface temperature(averaging 26.6 degrees), favourable wind shear and vertical profile of humidity, contributing to the high frequency formation of depression systems. In the Mozambique channel specifically, this is reflected in local parameters, such as high sea surface temperature (SSTs) with an average of 26.6 degrees Celsius, a southerly wind shear with height, and below-normal geopotential height anomalies at 500 hPa. In the Mozambique channel, 3 to 12 cyclones form every year. Cyclone season in Madagascar typically occurs between November and march, with an average of 1.5 cyclones yearly the height number on the Africa continent. In Mozambique, on the other hand, the cyclones season spans November to April and the area is estimated to suffer 1.16 cyclones every year on average. Since mid-March 2022, it has been estimated that around 960,000 people have been affected by the five extreme tropical weather events that occurred in the Mozambique channel and left displaced people in need of health, housing, and alternative livelihoods. Estimating the impacts of tropical weather events in context of increases in their frequency is therefore crucial for developing climate adapted solutions (Schoenmakers, 2023).

Over the past decade, Malawi has been frequently hit by natural calamities as witnessed by significant number of tropical cyclones, each leaving a distinct mark on the landscape and its people. These tropical cyclones have become more frequent due to the effects of climate change (K.J.E Walsh, 2019). This research serves to study the tropical cyclones that hit Malawi through the Mozambique channel focusing on their intensity and respective magnitude effects to the nation from 2004 to 2023. Tropical cyclone

intensity is based on wind speeds and pressure, relationships between winds and pressure are often used in determining intensity of a storm. This study is of importance in the following ways; inform mitigation strategies, policymakers and urban designers need cyclone intensity analysis to assess the risk posed by cyclones on communities and infrastructure, this information helps in developing strategies to mitigate the impacts of cyclones through measures such as building resilient infrastructure, implementing zoning regulations and developing early warning systems. The second point is Climate change adaptation, studying cyclone intensity provides valuable insights into how storms may evolve in the future, allowing nations to adapt their policies and infrastructure to changing climate conditions and the last significant is impacts on economy and livelihoods, understanding cyclones intensity helps policy makers assess economic risks associated with storms and develop strategies to minimise the impacts on livelihoods. The research aims at assessing the intensity of tropical cyclones that hit Malawi from 2004 to 2023 but it will delve much on comparing intensity of tropical cyclones, determining high intense tropical cyclones, evaluating damage and losses caused by tropical cyclones and assessing climate change impacts on the cyclogenesis of tropical cyclones over the oceans, by doing this the study will address these issues to the nation, informing mitigation strategies, climate adaptation and economic resilience planning.

1.2 PROBLEM STATEMENT

Over recent years, Malawi's Southern region has been frequently impacted by tropical cyclones originated and those which pass through Mozambique channel posing significant risks to communities. Cyclone intensity, a key determinant of damage and loss of life, remains challenging to understand due to its complex drivers. Despite advances in Meteorological research, there is limited knowledge about the tropical cyclones that affect Malawi. This study seeks to address these gaps by providing a comprehensive understanding of tropical cyclones in the Mozambique channel improving the ability to predict and prepare for intensifying cyclones. Insights from this research will enhance early warming's systems, inform disaster response strategies and ultimately reduce the impacts of tropical cyclones on vulnerable communities.

1.3 OBJECTIVES

1.3.1 MAIN OBJECTIVE

The main objective was to analyse tropical cyclones from the Mozambique channel impacting Malawi, focusing on their frequency, intensity and associated effects.

1.3.2 SPECIFIC OBJECTIVES

- To identify frequency of tropical cyclones occurrence in Malawi.
- Determine the trends of climatic parameter (rainfall and temperature) over the period 2014-2023
- Identify influencing factors of tropical cyclones formation (Cyclogenesis)
- Evaluate impacts to tropical cyclones on communities in Malawi

1.4 RESEARCH QUESTIONS

I. What is the frequency of tropical Cyclone occurrence?
II. What are the trends of climatic factors over the period of 2014 to 2023?
III. What are the factors influencing cyclogenesis?
IV. What are impacts of tropical cyclones on Malawi?

1.5 SIGNIFICANCE OF THE RESEARCH

Researchers, this study provides a robust scientific foundation for understanding tropical cyclones. The literature, theories and concepts discussed will serve as valuable resources for future researchers, enabling them to improve the quality of their work and advance knowledge in this field.

Policymakers, the study's analysis of cyclone intensity trends offers vital insights for policy makers about potential risks posed by future cyclones. This knowledge will aid in developing effective disaster management policies and allocating resources for preparedness, response and loss recovery efforts.

Impacts on infrastructure and management, tropical cyclones can cause severe damage to infrastructure, agriculture, and economies. Researching cyclone intensity helps estimating potential economic losses and inform planning for resilience infrastructure.

Furthermore, understanding cyclone impacts enables economists and policymakers to devise strategies to mitigate economic damage, including the destruction of supply chains and loss of productivity (The economic impact of tropical cyclone, 2023)

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Tropical cyclones(TCs) affect millions of people annually across the globe causing significant damage to life and property because of strong winds, heavy precipitation, and storm surge in which global warming has increased the intensity and frequency. Tropical cyclones are one of the most intense and impactful weather systems in the world, they are extremely important for the weather and climate of many tropical countries since they bring much of the annual rainfall to many tropical regions. However, they can also produce periods of extremely heavy rain, which can result in flooding and landslides, particularly in complex terrain along with high winds, as a consequence, it is important to understand how the behaviour of Tropical Cyclones such as their frequency and intensity and their physical impacts will change due to changes in the climate(*Tropical_Cyclone_Exposure_in_the_North_Indian_Ocea*, n.d.).

Tropical cyclones are among powerful and destructive weather systems on earth. At peak intensity, surface winds around the inner core have been observed to exceed 90m/s (Kimberlain, 2016). In addition to the violent surface winds, tropical cyclones bring with them additional hazards of torrential rains and storm surges, which individually may pose even greater threats than the wind, especially to those living along the coast (Rapperpot, 2015). Land falling Tropical Cyclones can produce several different physical hazards, notably storm surges, strong winds, heavy rain, flooding and related mud/landslide, the damage caused by tropical cyclone to marine interests both over open ocean and near coastal habitats has been recognised for hundreds of years. Storm surges, strong winds and flooding can produce considerable loss of life and damage to properties every year in the affected regions(*Tropical_Cyclone_Exposure_in_the_North_Indian_Ocea*,n.d.).Different scholars have come up with different definitions of tropical cyclone, but until today

there is no concise definition. Arguably it has different meanings depending on geographical location. According to (Society, 2000), tropical cyclone is generally defined as a cyclone that originate over the tropical ocean. Technically it is defined as a non-frontal synoptic scale low-pressure system over tropical and sub-tropical waters with organised convection and a closed cyclonic low level wind circulation. This phenomenon is called tropical depression, tropical storm or hurricane depending on the intensity of the cyclone where as those in Asia used the term typhoon to describe the tropical cyclone that has reached the hurricane intensity.

Knowledge of the global and regional characteristics of tropical cyclone activities, includes where and when they form, their intensities and tracks, requires careful documentation and planned coordination from government agencies around the world. In 1972 the world meteorological organization (WMO) established the tropical cyclone project, a predecessor to the tropical cyclone programme currently in operation, in response to the disastrous 1970 Bangladesh cyclone. TCP has established six regional specialised meteorological centres which are responsible for providing with information such as a tropical cyclone location, size, present and forecast movement and intensity, as well as archiving best estimate of location and intensity into historical datasets knowns as best track data. The best track data are used widely in studies of the regional and global impacts of climate variabilities and change on tropical cyclones (Mc Taggart-Cowan, 2006). Tropical cyclones form in equatorial regions where sea surface temperature (SSTs) exceed 26-27 degrees, but rarely within less than 4-5 degrees from the Equator. Several Others have listed several conditions favouring genesis of cyclones some of them are large values of low level relative vorticity, weak vertical and horizontal wind shear, conditional instability through a deep atmospheric layer, large relative humidity in the lower and middle troposphere, all of which are fulfilled within the inter-Tropical Convergence Zone (ITCZ) and a deep oceanic mixed layer. Some have studied cyclone genesis region-wise, using data from 1968-1997. They found that most cyclones of maximum sustained wind exceeding 17 meter per second are formed in the North-West Pacific (27 out of a total of 86 per annum). In that region, cyclones are relatively frequent throughout the year with four cyclones reaching "super-typhoon intensity". In the South-West Indian Ocean, cyclones are generated mainly between November and April, with an average of 12 per year. Gray (1975) has investigated the

period 1952-1971, reporting a global average of 80 cyclones per year. However, data before the satellite era must be regarded as relatively unreliable. Cyclone activity i.e. frequency and intensity, may depend on natural cycles such as the El Nino-Southern Oscillation (ENSO) the Quasi-Biennial zonal wind Oscillation and the Madden-Julian Oscillation. El Nino is known to cause increase cyclone activity in the south and in the North-East pacific, but decrease activity in the North Atlantic and in the North-West Pacific as expected with regard to the deviation in SSTs. An east phase QBO seems to reduce activity in the North Atlantic. The MJO has been associated with higher frequency in the Pacific(*Ajol-File-Journals_180_articles_56672_submission_proof_56672-2149-97057-1-10-20100716 (4)*, n.d.). Trends in cyclones frequency and intensity have been studies by several authors some has emphasized a substantial increase in the intensity over the past 50years and others have found that 100% increase in the number of the most intense cyclones using data from 1974-2005. However, there are some doubts concerning the quality of the longer series, particularly concerning the intensity. Some authors underline the uncertainties, claiming that a link between increasing intensity and higher SSTs cannot be shown and others emphasis that increasing SSTs feed more intense cyclones. The climatology of SWIO cyclones has been investigated in a number of studies some reports shows an increase in frequency in cyclone formation during the east phase of QBO, when upper level westerlies are weakened. El Nino years have lower frequencies, as explained by increase subtropical upper-level westerlies, some have indicated that El Nino years are simultaneous with increased frequency/ genesis of tropical cyclones west of 75 degrees east but decrease east of 75 degrees east, all this vice versa during La Nina. The largest cyclone activity was found in phase 2-4 of the MJO (about 10 cyclones in 100 days), while there is lower activity during other phase. The series from JTWC (Joint Typhoon Warning Centre) for the years 1979-2004, but have included a comparison with the LR-RSMC (La Reunion- Regional Specialised Meteorological Centre). An increase cyclone frequency between 85-105 degrees east during La Nina years compared to El Nino. Bessafi and Wheeler (2006) have in turn found significantly increase frequency of tropical cyclone formation during the active phase of MJO(*Ajol-File-Journals_180_articles_56672_submission_proof_56672-2149-97057-1-10-20100716 (4)*, n.d.)

According to other studies landfall over Mozambique using observation and model integration. They have employed a cyclone record from Neumann (1993), the zonal wind from the National Centre for Environment Prediction (NCEP) reanalysis and SSTs to identify predictors and potential physical mechanisms responsible for landfall. Landfall is common during La Nina years, simultaneous with a negative zonal mean flow (averaged for 850-200 hPa). El Nino years have fewer landfall and positive zonal mean flow.

Forecasting these phenomenon is very crucial for mitigating social-economic impacts. Malawi through the Mozambique channel has experienced tropical cyclones which affected the country in several sectors more especially in the southern region. The Mozambique channel is a narrow body of water located between the southern coast of Africa and the island of Madagascar. It serves as a crucial pathway for maritime traffic and connects the Indian ocean to the south-western part of Indian ocean. The North Indian Ocean (NIO) is a relative small tropical cyclone basin bounded by Africa to the West, Asia to the north and east, and the equator to the south, it is divided into the Arabian Sea and the Bay of Bengal, annually an average of 12-13 Tropical Cyclones (TCs) form in the Southwest Indian Ocean (SWIO) basin, which accounts for approximately 14% of the global total, the Mozambique channel located on the western edge of the SWIO experience a subset of these Cyclones. From 1948-2010, a total of 94 Tropical cyclones formed within the Mozambique channel this averages to about 1.5 Cyclones per year. The formation frequency varied over the years, with some years experiencing no cyclones and others experiencing three or more formation, approximately 50% of the tropical cyclones that form in the Mozambique Channel make a landfall, these landfall predominantly affect Mozambique and Madagascar causing significant damage and disruption, for instance cyclone such as Eline(2000), Dera(2001) and Favio(2007) have caused widespread devastation in Mozambique, the impacts included structural damage, flooding and displacement of population(Matyas, 2014). The climate is dominated by monsoonal regime driven by the strong heating between the land and the ocean, during the winter from October to April, strong north-easterly winds dominate the region. From May to October, the winds reverse direction to prevailing south-westerly winds, up to 80% of the total annual rainfall can fall in the region during the summer monsoon, the climate variation of sea surface

temperature (SSFs) is an important predictor of rainfall in the monsoon season. The monsoon season divides into three monsoon periods: the pre-monsoon (February-May), Monsoon (June-September) and post-monsoon (October-January) periods. The pre-monsoon period is mostly devoid of TCs, although many monsoon depressions form in the northern part of the Bay of Bengal during May, more frequent and stronger TCs develop during the early monsoon and post-monsoon periods compared to the main monsoon period. on average approximately 5.5 TCs develop in the North Indian Ocean annually with four in the Bay of Bengal and one and a half in the Arabian, and this comprises about 7% of the global annual total TCs. The frequency of TCs in the North Indian Ocean basin is not high compared with the western North Pacific basin, in part because the ocean area is small. However, the large amount of land exposure means that a large percentage of the TCs that form in the NIO make landfall in the region(*Tropical_Cyclone_Exposure_in_the_North_Indian_Ocea*, n.d.). According to(*Variability-of-Upper-Ocean-Characteristics-and-Tropical-Cyclones-in-the-South-West-Indian-Ocean*, n.d.) the South West Indian Ocean tropical storm (including tropical cyclones) are generated mainly from late November to April with on average 10 per season and typically peak during the months of January and February. Although there have been significant strides in the TC track forecast over the last 30 years, skills in TC intensity prediction still lag behind. Similar to cyclones in other tropical ocean basins, tropical cyclones in the South West Indian Ocean also cause significant social and economic damage in southeast Africa and Madagascar. There have been marked cases in the South West Indian Ocean in the last two decades where sudden intensification of storms has caused loss of life and major damage to property in Mozambique and Madagascar. The channel is prone to tropical cyclones and tropical storms which cause significant damage to the surrounding areas. It provides favourable environment for the development of tropical storms and cyclones. The warm waters in the Mozambique channel provide the necessary energy for the formation and intensification of cyclones.(www.MozambiqueExpert.com).

2.2 TROPICAL CYCLONES IN MALAWI

Malawi has faced significant impacts from several tropical cyclones passing through the Mozambique Channel in recent years. Notable examples include Cyclone Chedza in

2015; Cyclone Idai and Kenneth in 2019; Cyclone Ana and Gombe in 2022; and Cyclone Freddy in 2023. These cyclones, originating over the Indian Ocean, derive their energy from the warm ocean waters serve as a critical driver for their formation and intensification.

Tropical cyclones affecting Malawi not only bring intense rainfall and flooding but also cause widespread displacement, destruction of infrastructure and loss of livelihoods. For instance, Cyclone Idai in 2019 was one of the deadliest on record, highlighting the regions vulnerable to such events. The warm sea surface temperature in the Indian Ocean, linked to global climate change, may contribute to the increased frequency and intensity of these cyclones, posing growing risks to communities in the region.

Efforts to mitigate the impacts of tropical cyclones including enhancing early warning systems improving disaster preparedness and implementing climate adaptation strategies. Regional collaboration between countries bordering the Mozambique Channel is also vital in addressing these challenges effectively.

2.2.1 TROPICAL CYCLONE CHEDZA

Tropical cyclone Chedza originated in the Mozambique channel on 11 January 2015,fuelled by the warm sea surface temperatures characteristic of the region (Ramontsheng S. Rapolaki, 2018). The cyclone rapidly intensified, leading to widespread flooding across Malawi, Mozambique and Madagascar, with devastating consequences. An impact assessment conducted by the World Bank revealed extensive damage to property, infrastructure and agriculture across several regions in south-eastern Africa, compounded by significant loss in life.

Southern Malawi and northern Mozambique bore the brunt of rainfall during the cyclones early stages, experiencing prolonged downpours that overwhelmed local drainage systems and river basins. In Malawi, the flooding displaced thousands of families, destroyed crops and exacerbated food insecurity in vulnerable communities. Similarly, northern Mozambique faced critical infrastructure losses, including damaged roads and bridges, which hindered emergency response efforts.

Tropical Cyclone Chedza highlights the pressing need for enhanced disaster preparedness and climate adaptation measures in the region. Strengthening early

warning systems, improving infrastructure resilience and fostering regional collaboration can mitigate future impacts of such climate-related disasters. The event also underscores the importance of addressing underlying factors such as poverty and environmental degradation, which amplify vulnerable to extreme weather events.

2.2.2 TROPICAL CYCLONE IDAI

Tropical cyclone Idai originated from a tropical depression that formed in the Mozambique channel on 4 March 2019. This depression rapidly intensified into a tropical storm as the atmosphere and oceanic conditions of the channel, particularly warm sea surface temperature, favoured cyclogenesis. Winds accelerated to speeds of 175 km/hr and after briefly weakening the cyclone re-intensified into a category 4system. It made its initial landfall in Beira, the second-largest city in Mozambique, causing catastrophic (Charrua, Padmanban, Cabral, Bandeira, & Romeiras, 2021).

Cyclone Idai became one of the worst weather-related disasters in Africa, making a landfall twice in Mozambique. Its destructive wind and extreme rainfall led to widespread flooding, landslides and substantial damage across southern Africa. It was the third deadliest tropical cyclone ever recorded in the southern Hemisphere. Claiming over 1000 lives and affecting at least 2.98 million people in Mozambique, Zimbabwe and Malawi (Peng Yu, 2019). Beyond human losses, entire communities faced collapsed infrastructure, disrupted livelihoods and prolonged suffering.

In Malawi, the cyclone compounded the effects of a year-long drought in 2018, particularly in the southern and central regions. The Malawian Government estimated that cyclone Idai and its associated flooding affected over 975,600 people, displaced 86,976 residents and caused 60 fatalities. Additionally,288,371 houses were reported as damaged or destroyed (Malawi, Malawi 2015 Floods Post Disaster Needs Assessiment, 2015). Cyclone Idai trajectory passed between southern Mangochi and northern Nsanje between the 6 and 8 March 2019, leading the government to declare a state of disaster on 8 March.

Rainfall data emphasizes the severity of the event. During the first 10 days of March 2019 Nsanje recorded over 200mm of rainfall and Mangochi received over 150mm. significantly exceeding the respective 40-75mm and 30mm recorded during the same period in March 2018. Additionally, February 2019 had been marked by a period of

no rainfall in Nsanje and less than 30 mm in Mangochi, underscoring the abrupt transition to extreme conditions caused by Idai.

A defining feature of cyclone Idai was its unusual behaviour: after dissipating over land, it returned to the Indian ocean, regained strength and stuck the Mozambique coast again with devastating effects. While the cyclone's core did not cross into Malawi during this second landfall, southern Malawi continue to experience heavy rainfall between 11 and 20 March, with Nsanje receiving an additional 40-100 mm of precipitation over the period.

Malawi 's history of extreme weather events, including recurrent floods and drought, reveals the country's vulnerability to climate variability. According to the Government's post-cyclone Idai needs assessment, Malawi has experienced 19 major floods and 7 significant droughts in the past 50 years. Many of these events are linked to weather systems such as the inter-Tropical Convergence Zone (ITCZ) and the Congo air mass. The worst flood in Malawi's history occurred in 2015, causing damages estimated at USD 335 million (Malawi, Malawi 2015 Floods Post Disaster Needs Assessiment, 2015).

2.2.3 TROPICAL CYCLONE GOMBE

Tropical cyclone Gombe was a significant weather event that severely impacted Malawi in 2022. Originally as a tropical disturbance off the coast of Madagascar, Gombe was first monitored by the Typhoon warning centre on March 6. The storm gradually moved westwards, intensifying into a tropical depression on March 9 and further developing into a moderate tropical storm. Gombe made its initial landfall in Madagascar on March 8, causing localized damage. in then entered the Mozambique channel, where it was upgraded to a tropical storm on march 9. The cyclone Continue to intensify rapidly, reaching its peak intensity on March 11 as the fourth intense Tropical cyclone of the year. At its peak, Gombe recorded maximum sustained winds of 185km/h and a minimum central pressure of 960 hPa.

On March 11, Gombe made landfall in Mossuril district, Nampula province, Mozambique, causing widespread devastation. In Nampula province alone, the storm affected 18,345 people, resulting in 20 injuries and 10 fatalities. Across both Nampula and Zambezia province, over 100,000 people were impacted, with 15 deaths, 50 injuries and 11,629 individuals displaced. The cyclone destroyed numerous houses,

health centres, classrooms, electricity poles and roads leaving communities in dire need of assistance. In Malawi, the cyclone resulted in the loss of at least seven lives and displaced hundreds of people. The storm exacerbated the vulnerability of communities already struggling from previous disasters, such as Tropical Storm Ana. The aftermath of Gombe highlighted the urgent need for humanitarian assistance, search and rescue operation and long term recovery efforts to address the extensive damage caused by the cyclone. The impacts of Tropical Cyclone Gombe underscored the growing vulnerability of the region to climate-related disasters. The storms aftermath revealed the need for enhanced disaster preparedness, early warning systems and resilient infrastructure to mitigate future risks. Recovery efforts in Malawi and Mozambique required significant resources to rebuild homes, restore essential services and support displaced population.

2.2.4 TROPICAL CYCLONE ANA

The 2021-2022 Southwest Indian Ocean season (November-April) brought devastating storms to Southern Africa, beginning with Tropical Cyclone Ana and followed by Tropical Cyclone Batsirai. These Cyclones, along with subsequent weaker storms-Dumako, Emnati and Gombe-caused widespread flooding, casualties and long-lasting socio-economic impacts across Madagascar, Malawi and Zimbabwe.

Tropical cyclone Ana originated as a tropical depression east of Madagascar on January 22, 2022. At the time, the region was already experiencing severe flooding and casualties from heavy rainfall associated with the annual southward migration of the Inter-Tropical Convergence Zone (ITCZ). These preceding conditions compounded the impacts of Ana. Although Ana weakened into a tropical disturbance upon exiting Madagascar on January 23, it regained strength as it moved across the Mozambique Channel. On January 24, Ana made landfall in Mozambique as a moderate tropical storm, bringing strong winds and heavy rains. Mozambique reported over 141,483 people directly affected, including at least 25 fatalities. In Malawi, Ana impacted approximately 945,728 people, including nearly 10,000 individuals living with disabilities and roughly 21,000 pregnant women. Tropical cyclone Batsirai followed Ana, making landfall on Madagascar's east coast on February 5,2022. The cyclone brought heavy rainfall and strong gusts, which persisted until February 7 as it moved southwest across the Island. Batsirai weakened into a remnant low but left behind significant damage. Its effects were primarily concentrated in Madagascar, where

preceding flooding events in the southern region exacerbated the humanitarian crisis. Both Ana and Batsirai caused severe humanitarian impacts, including deaths, injuries, infrastructure damage and socio-economic disruptions. The storms highlighted the vulnerability of affected communities, particularly in Madagascar, Mozambique, Malawi and Zimbabwe. Recovery efforts were further complicated by the cumulative effects of preceding flooding events and subsequent weaker storms.

2.2.5 TROPICAL CYCLONE FREDDY

According to African News by Richard Davies dated 14 March 2023, cyclone Freddy originated as a disturbance near Australia before crossing Indian ocean. It made a landfall in Madagascar on 21 February 2023 crossing the entire south Indian ocean after travelling more than 8,000 kilometres affecting Mauritius and La Reunion. Before second landfall, Freddy caused floods, mudslides and damage in parts of Malawi. The storm spent several days tracking over Mozambique, bringing heavy rains and flooding. It looped back towards Mozambique channel and picked up energy from the warm waters and moved towards the south western coast of Madagascar, causing further flooding and damages on 02 March before returning back towards Mozambique for the second time and then to the Malawi.

Of all the cyclones that have ever hit Malawi through Mozambique channel, Freddy was a deadliest and most devastating cyclone as it caused landslides and floods in affected areas. It caused extensive damage infrastructure, crops and homes, and resulted in the death of people. The cyclone brought winds and torrential rains leading to widespread flooding and destruction. More than 500 people were found dead and about 550 people were missing with thousands of homes destroyed and people were displaced. (Mpheza, 2023)

According to (W.J. Wouter Botzen, 2019) natural disaster have both direct and indirect by a natural disaster, with the losses occurring at the time of the disasters or shortly thereafter. Examples of direct economic losses include the destruction of residences, business, productive capitals, infrastructure, crops, live stocks and physical and mental health impacts. These direct losses are generally estimated using catastrophe model and measured using empirical data losses. The direct impacts can lead to indirect impacts, which refer to changes in economic activities that follow the disaster. These includes

interruption of economic activities as well as any spill over effects due to the substitution of production and the demand for reconstruction. Thus the indirect impacts capture the short-and long-term economic losses in economic production and consumption and any related economic recovery paths.

Tropical cyclone Freddy in march 2023 mainly affected the southern part of Malawi. Flash floods and severe mudslides were the main cause of death and destruction of homes, buildings and other infrastructure (Maxwell JT, 2021) of note is that Freddy occurred a midst of cholera outbreak which started almost 2 month prior to the cyclone and had already put strain on the health system. In additional Freddy was a new experience for most Malawians and the government in terms of its strength location and consequences. Thus, the government and health system were not prepared for the scale of the devastation.

As of 25th march 2023 the department of disaster management (DoDMA) reported that 126577 people were displaced as a result of winds, floods and landslides. The death toll had risen to 511 while 533 people were missing and 1724 were injured. The DoDMA noticed the damage to the water supply system and 918 boreholes were totally submerged, with an estimate 1008976 people in urgent need of access to clean water and sanitation. The disruption of lives and livelihoods was huge and included primary health care. Firstly, access to health care was hampered because of destruction of road network and bridges. The referral hospital was overwhelmed from the huge demand for health care service. There was a reported shortage of medicine supplies and in adequate medical personnel to cover the needs of note, was the urgent need for maternal and child health service in the midst of the disaster yet these were barely accessibly. Secondly, IDPs, faced a number of health challenges a rising from poor sanitation and overcrowding. An escalation of water-borne and respiratory disease, including cholera was anticipated especially among the most vulnerable such as children and elderly, families faced acute hunger as they were already living in poverty and now lost their livelihoods. Furthermore, there was a risk of sexual assaults in the camps IDPs. The high levels of grief and loss were a recipe for mental health disorder, both for victims and health care workers and the need for mental health service was unmatched. It is therefore evident that these health challenges were overwhelming especially for a

health care system that was already battling a severe cholera outbreak (Malawi, Tropical cyclone Freddy emergency responce plan, 2023). Despite the disruption, life must eventually return to some form of normalcy. Internal displaced people must be decamped and learn. Such loss and damage as a result of climate change in low-income countries that have not contributed to the problem should be compensated for from high-income countries that are responsible for emission (Atwoll L, 2022). While the needs are enormous, the depending on external donations must be tempered by local measures, built on deep knowledge of the context and resilience of locals. Malawi must do her homework and implement its own sustainable solutions based on local capacity and resources.

CHAPTER 3; METHODOLOGY

3.1 STUDY AREA

The research focused on southern region of Malawi which is the most populated region with a wide variety of landscape including the highest and lowest points in the country. The Southern Region of Malawi experience a subtropical climate characterized by distinct wet and dry seasons, the rainy season occurs from November to April, influenced by the inter-Tropical Convergence Zone (ITCZ) and tropical cyclones, while the dry season lasts from May to October. The region generally has warm to hot temperatures throughout the year, with mean annual temperature ranging from 20 degrees to 26 degrees. Higher elevations, such as the Shire Highlands, experience slightly cooler conditions, southern Malawi receives annual rainfall ranging from 600mm in low-lying areas like the Shire Valley to over 1200mm in higher altitude regions. In recent decades, the region has experienced increasing climate variability, including erratic rainfall, prolonged dry spells, droughts and extreme weather events such as tropical storms and Floods. Climate change has intensified weather extremes in the region affecting agriculture, water availability and infrastructure, the agriculture sector which is heavily rain fed remains highly vulnerable to shifting climate conditions. It's an area which falls on 15°40'S and 34°58'E. The region borders Mozambique to the east, south and southwest. It also borders Salima, Dedza and Ntcheu district to the north. It comprises 13 districts which are; Blantyre, Balaka, Machinga, Zomba, Mangochi, Neno,

Mwanza, Phalombe, Chiradzulu, Thyolo, Mulanje, Nsanje, and Chikwawa covering an area of 31,780 km^2 . (Office, 2018) This region experiences tropical cyclones which move inland and which cause damage of property, loss of life among those people living in this region.

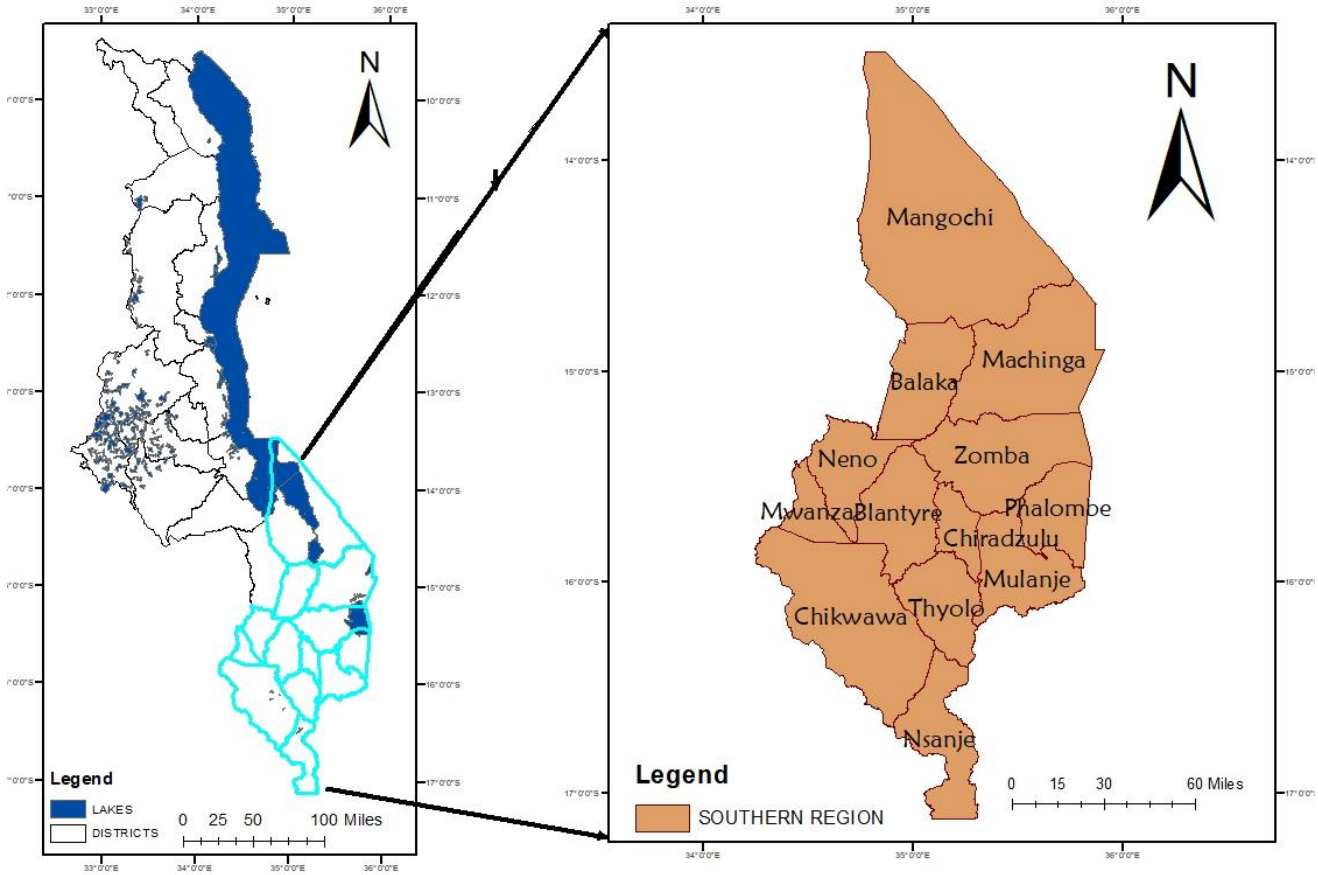


Figure 1 Map of study area

3.2 RESEARCH DESIGN

The study adopted a quantitative method approach. It is an approach that emphasizes using numerical measurements and statistical analysis to understand phenomena, the method involves collecting data that can be quantified and subjecting to various statistical techniques to test hypothesis or explore relationship between variables for comprehensive analysis. This research will make use of secondary data which is the data that is collected by someone other than the primary user. This is the type of information or statistics that researchers have already collected through their primary sources. In this project retrospective observational study design will be utilised for analysing historical data on cyclones and their impacts. Additionally, a prospective component will involve exploring future cyclone risks using cyclone trend.

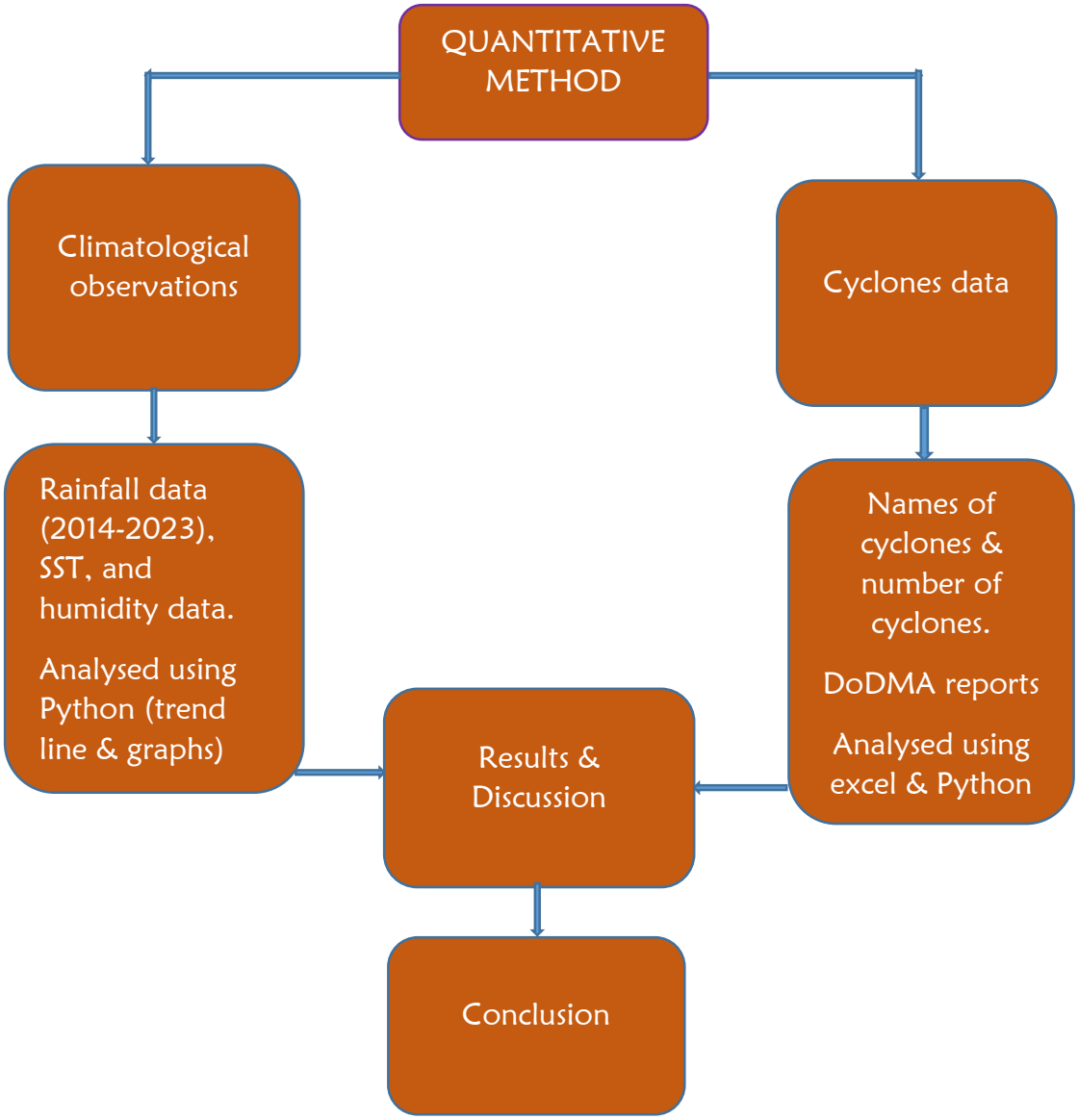


Figure 2. Showing Conceptual Framework

3.3 METHODS

3.3.1 DATA SOURCES

Cyclones data were collected from NASA; they are cyclones which occurred through Mozambiquican channel.https://www.ncei.noaa.gov/products/international-best-track-archive

The historical Meteorological and climatological data were collected from the Department of Climate Change and Meteorological services (DCCMs) which included rainfall, temperature, wind speed and humidity data.

Post-disaster reports were collected Department of Disaster Management Affairs (DoDMA). The reports comprise the loss and damage which occurred during Cyclones events.

Sea Surface Temperatures were also collected. https://power.larc.nasa.gov/data-access-viewer/

3.3.2 MATERIALS AND METHODS

The data collected in this research was analysed using Python (JupyterLab environment) and excel. Python was used to conduct Mann-Kendall trend test, including producing graphs of different datasets to observe the relationships. Excel was used also used to produce pie charts and bar graphs. The climatological data was analysed using the Mann-Kendall trend test and relationship between the observed cyclone events and the climatic parameters has been clearly demonstrated by proper graphs and pie charts.

3.3.2.1. PYTHON (JUPYTERLAB)

To achieve objective one, Python was used to produce a graph using Cyclone data. The Python codes were executed in JupyterLab environment which produced the graph showing how the cyclones had been occurring in each year from 2014 to 2023.

3.3.2.2. MANN-KENDALL TREND TEST

To achieve objective two, the Mann-Kendall trend test was used. This method gave the trends of annual rainfall amounts, average maximum and minimum temperature, wind speed, and humidity. The Mann-Kendall test was used to statistically access if there is a monotonic upward or downward trend of the climatological data over a period of ten years from 2014 to 2023. The null hypothesis, *H*0, states that there is no monotonic trend, while *Ha* (alternative hypothesis) means that there is either an upward monotonic trend or downward monotonic trend series (Mann-Kendall et al., 2022). It is a good method for trend test in climatological time series analysis because it does not assume that data is distributed according to any particular rule, it is not affected by unavailable data and it is not affected by the length of the time series (Kendall et al., 2022).

The following method is used to calculate Mann-Kendall statistics.

$$S = \sum_{i-1}^{n-1} \sum_{j-i+1}^{n} Sgn(x_j - x_i)$$

Where Sgn is a function that returns:

- 1 if $x_j > x_i$
- 0 if $x_j = x_i$
- -1 if $x_j < x_i$

x_i and x_j are the sequential data values of the time series in the years i and j (j > i), N is the length of the time series and $sgn\ (x_j - x_i)$, is the sign function. Positive value of S shows an increasing trend while the negative value of S shows a decreasing trend while zero shows neither an increasing nor decreasing trend. To get to the standardized Mann-Kendall statistic, the variance must be computed first.

$$\sigma^2 = \frac{1}{18}\left[n\ (n-1)\ (2n+5) - \sum_{t=1}^{g} nt(nt-1)(2nt+5)\right]$$

where t is the number of tied groups in the data set, that is a set of sample data with the same values (Al-Mukhtar & Qasim, 2019). It is the number of data points in the j th tied group. Upon computing the variance then the standardized Mann-Kendall statistic, Zmk is computed as follows:

$$\text{Zmk} = \begin{cases} \frac{S-1}{\sigma} & if\ S > 0 \\ 0, & if\ S = 0 \\ \frac{S+1}{\sigma} & if\ S < 0 \end{cases}$$

A positive Zmk value indicates an upward trend while a negative value indicates a downward trend. When the $|zmk| > z\alpha/2$ then the null hypothesis is rejected (Kendall et al., 2022). This test was conducted at an alpha value of 0.05, in this case the value of $z\alpha/s2$ was 1.96. The P value is used to see whether the trend is significant or not. A P value of less than 0.05 shows that there is a significant trend either a significant increasing trend or a significant decreasing trend.

3.3.2.3. INFLUENCING FACTORS FOR CYCLOGENESIS

The influencing factors for Cyclogenesis were determined by comparing SSTs and threshold temperature at which Cyclones form. The SST dataset was used to calculate annual mean temperature. The Python codes were executed using JupyerLab to calculate annual mean temperature for each year from 2014 to 2023. The produced graph shows variation in SST in Mozambiquican channel and in south east Indian Ocean.

3.3.2.4 EXCEL

Excel was used to produce bar graphs and pie charts where impacts of tropical Cyclones were demonstrated. Variation of impacts of Cyclones events were clearly shown where Cyclone Freddy and Cyclone Ana were scrutinized in terms of effects to communities.

CHAPTER 4. RESULTS AND DISCUSSION

4.1. INTRODUCTION

This chapter covers data analysis and discussion, and it responds to the objectives of the study. The main objective of the objective of the study was to assess tropical that have affected Malawi through Mozambique channel in the past decade (2014-2023) to see how climatic parameters (rainfall and temperature) have been affected by cyclones events.

4.2. CYCLONES OCCURRENCE FREQUENCY

This sections gives analysis of frequency of occurrence of tropical cyclones from 2014 to 2023 using cyclones data that was obtained from NASA

Table 1. Tropical cyclone (2014-2023)

NUMBER	NAME OF CYCLONE	INTENSITY	MONTH & YEAR OF OCCURRENCE
1	Deliwe	85km/hr	January 2014
2	Hellen	240km/hr	March 2014
3	Chedza	85km/hr	January 2015
4	Fundy	55km/hr	February 2015
5	Daya	95km/hr	February 2016
6	Bonozo	55km/hr	February 2016
7	Boneo	160km/hr	February 2017
8	Dumazire	110km/hr	March 2018
9	Desmond	85km/hr	January 2019

10	Idai	205km/hr	March 2019
11	Kenneth	220km/hr	April 2019
12	Amara	100km/hr	January 2020
13	Herold	85km/hr	February 2020
14	Jobo	85km/hr	March 2020
15	Klans	55km/hr	April 2020
16	Lokadia	85km/hr	November 2020
17	Ana	120km/hr	January 2021
18	Batsirai	180km/hr	February 2021
19	Chiara	85km/hr	March 2021
20	Dumako	55km/hr	March 2021
21	Eloise	180km/hr	January 2021
22	Glory	55km/hr	April 2021
23	Ibrahim	100km/hr	December 2021
24	Gombe	175km/hr	March 2023
25	Freddy	85km/hr	March 2023
26	Jangmi	55km/hr	April 2023
27	Lisa	130km/hr	April 2023
28	Kamil	50km/hr	November 2023

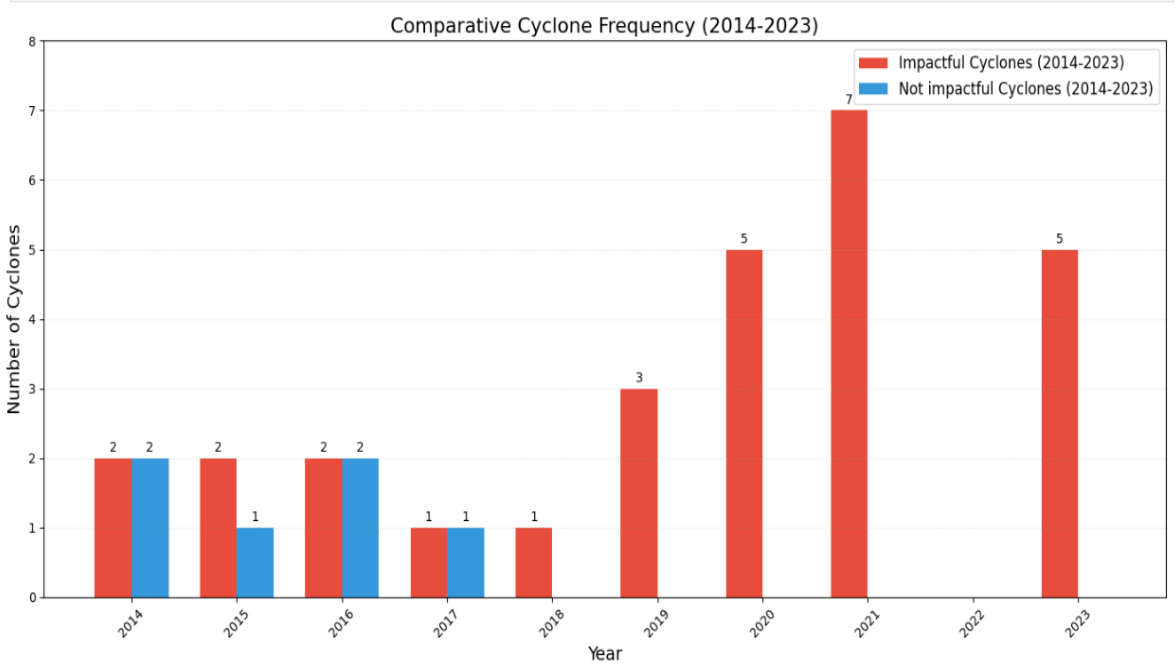


Figure 3. Graph Showing Frequency of Tropical Cyclones

The comparative analysis of tropical cyclone frequency (2014-2023) in the South western Indian Ocean reveals distinct patterns through dual-dataset visualization, where blue bars (Dataset 1: 28 cyclones) show peak activity in 2021 (7 cyclones) with cyclical increases during 2016-2017 and 2019-2021, correlating with positive IOD phases and ENSO-modulated convection, while red bars (Dataset 2: 6 cyclones) demonstrate methodological discrepancies in overlapping years (2014-2017) due to varying classification criteria. The graph highlights 2021's exceptional activity (3 intense cyclones >120 km/h and 4 moderate systems) against a backdrop of regional climate trends (+0.022°C/year SST warming, poleward track migration, and +0.036 g/kg/year humidity increases), though limitations include inconsistent data protocols and potential underreporting of weaker systems, emphasizing the need for standardized monitoring to inform climate adaptation strategies.

4.3 FACTORS INFLUENCING CYCLOGENESIS (CYCLONE FORMATION)

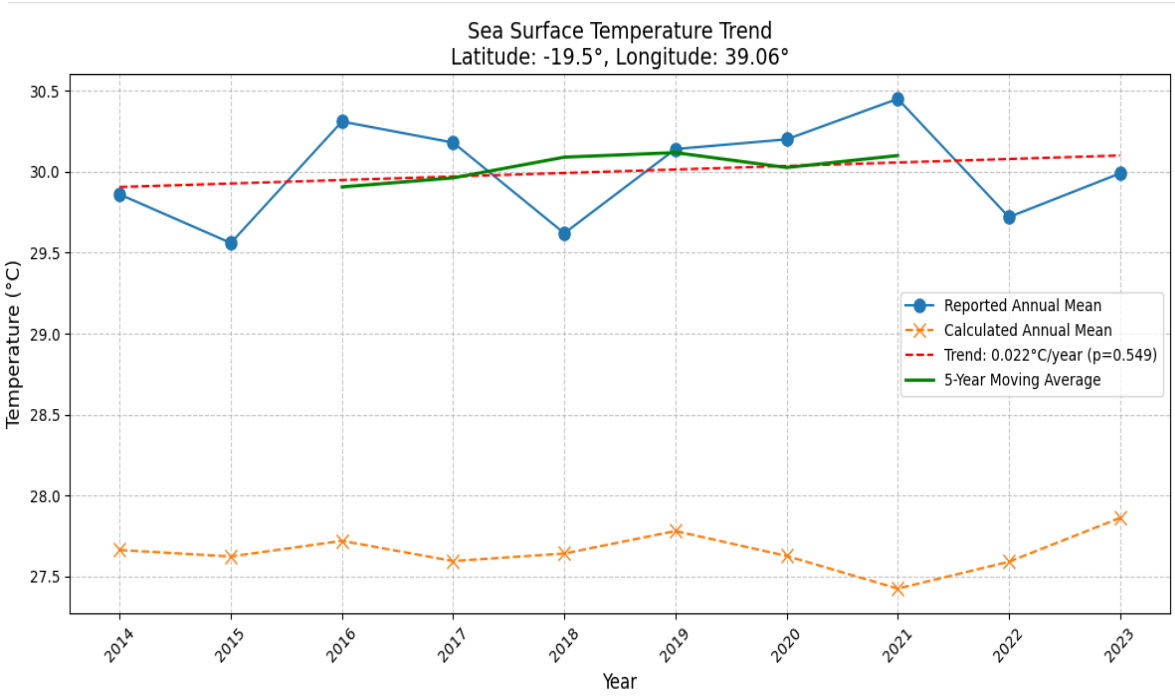


Figure 4. Graph Showing Sea Surface Temperatures Trend (2014-2023)

Globally, more than 93% of cyclone formations occur at Sea Surface Temperature values exceeding 26.5 and more than 98% occur at Sea Surface Temperature values exceeding 25.5. (McBride, 2011). Based on calculated annual mean SST indicated in the graph, it is clear that during all the years SST surpassed the threshold temperature for cyclogenesis with the least annual mean SST in 2021 and the peak annual mean temperature in 2023.

The Sea Surface Temperature (SST) trend analysis from 2014 to 2023 at -19.5° latitude and 39.06° longitude (Mozambique channel) reveals a gradual warming of 0.022°C per year (P-value=0.549). Variability in SST in south-east of Indian Ocean has demonstrated to be the influencing factor in the cyclogenesis.

However, comprehensive risk assessment requires integrating additional factors like wind shear and atmospheric instability alongside SST trends.

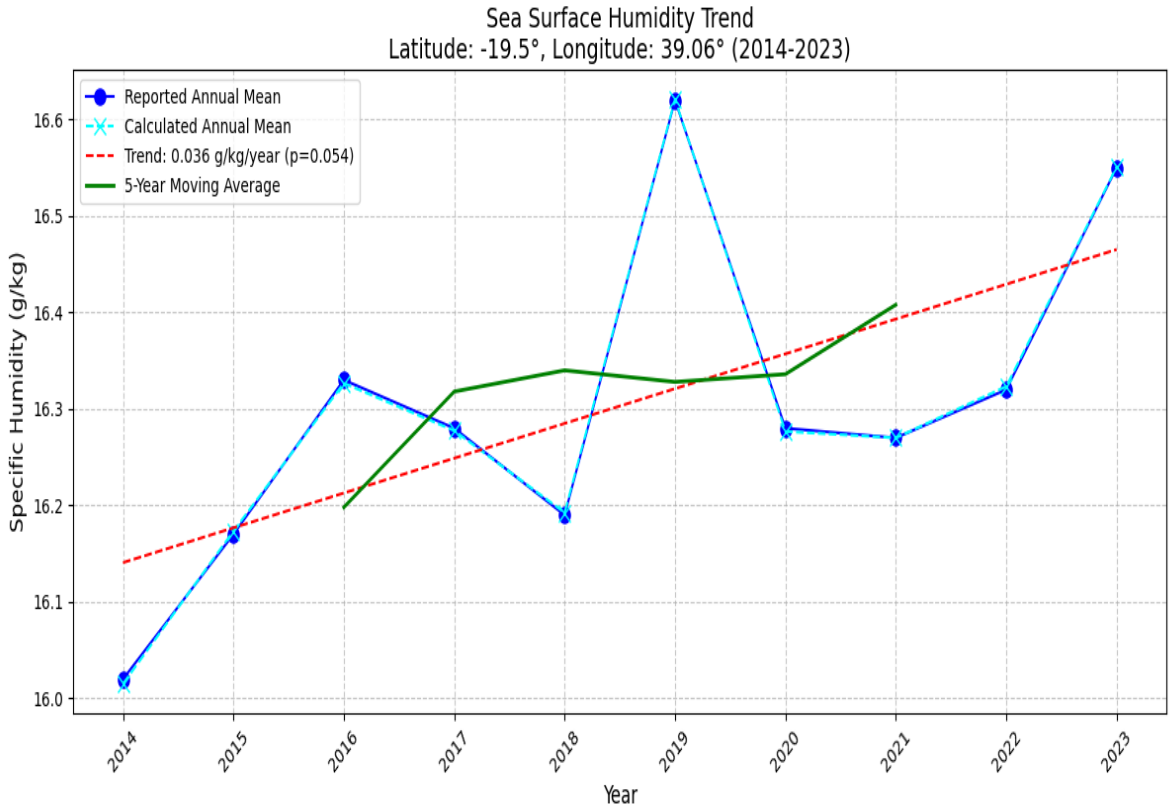


Figure 5. Graph Showing Sea Surface Humidity Trend

The sea surface humidity trend analysis from 2014 to 2023 at -19.5° latitude and 39.06° longitude (Mozambique Channel) reveals a statistically marginal increasing trend of +0.036 g/kg/year (p=0.054), with peak humidity levels coinciding with major cyclone events such as Fantala (2016) and Eloise (2021). The 5-year moving average shows cyclical patterns that correlate with periods of enhanced cyclone activity, as elevated humidity (>16.4 g/kg) provides crucial moisture for tropical cyclone intensification through enhanced latent heat release. While the trend's borderline significance (p=0.054) suggests natural variability dominates this decadal period, the consistent humidity levels above 16 g/kg - well beyond the typical 14 g/kg threshold for cyclogenesis - created persistently favourable conditions for storm development. The humidity peaks in 2016-2017 and 2020-2021 align precisely with the most intense cyclones in the region, demonstrating how interannual humidity variations modulate cyclone energy potential, even as the gradual upward trend may reflect broader climate change influences on marine atmospheric moisture content.

4.4. MANN KENDALL TREND TESTS FOR RAINFALL

Table 2. Mann Kendall test results for rainfall

STATION	S	VARIANCE	Z SCORE	P-VALUE	TREND
Bvumbwe	19	125.0	1.6100	0.1074	NST
Chichiri	13	125.0	1.0733	0.2831	NST
Mimosa	-13	125.0	-1.0733	0.2831	NST
Ngabu	-1	125.0	0.0000	1.0000	NST

Where **NST** means that the trend is not significant.

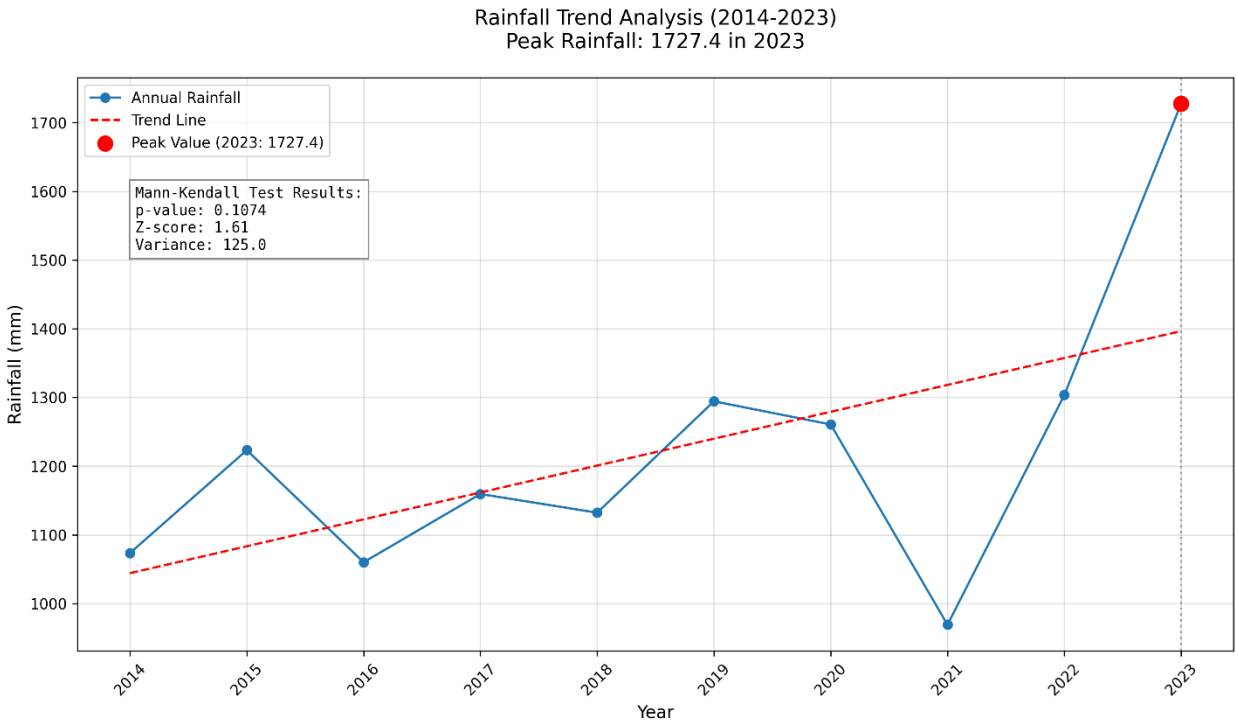


Figure 6. Graph Showing Rainfall Trend Bvumbwe Station

The rainfall values range from 1000mm to 1800mm in graph. This range suggests annual rainfall fluctuations; though incomplete data points indicate potential truncation. The upward trend line culminates in the 2023 peak, highlighting a significant increase compared to prior years. The P-value of 0.1074 is indicating that the observed rainfall trend in the period of 10 years (2014-2023) at Bvumbwe is not statistically significant at the commonly used 95% confidence level of 0.05, and variance of 125.0 underscores the high interannual variability in rainfall at Bvumbwe.

The 2023 peak aligns with Cyclone Freddy, one of the longest-lived cyclones on record in Malawi, which devastated even neighbouring countries including Mozambique and Madagascar on February to March 2023. It remnants triggered catastrophic floods to southern region of Malawi leading to anomalous rainfall spike.

This graph implies that tropical cyclones play a pivotal role in shaping Malawi's rainfall variability, particularly during peak events.

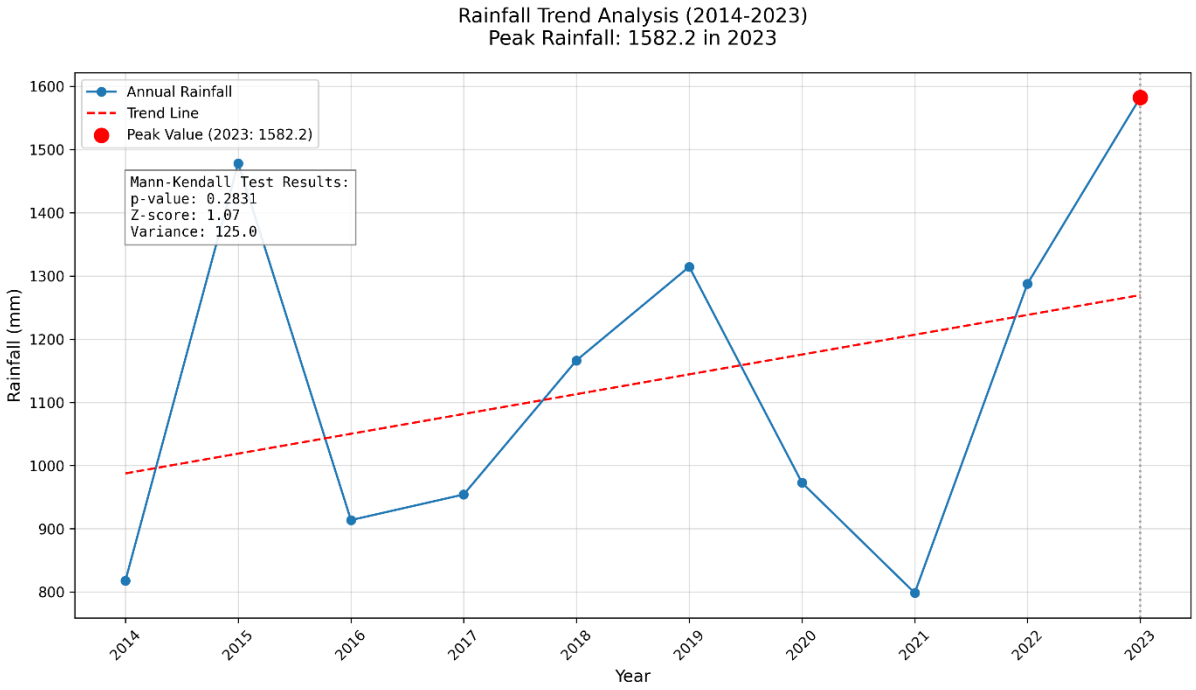


Figure 7. Graph Showing Rainfall Trend Chichiri Station

The graph shows an upward trend in rainfall at Chichiri (culminating in 2023). This suggests increasing precipitation variability. Warmer Indian Ocean temperatures intensity cyclones, increasing their moisture content and rainfall intensity when they make landfall in Malawi. The graph highlights Malawi's increasing exposure to climate-driven hydro-meteorology hazards, with cyclones playing a role a pivotal role in shaping extreme rainfall trends. Rising cyclone frequency and intensity under climate change could exacerbate Malawi's vulnerability to extreme rainfall, threatening agriculture, infrastructure, and livelihoods. The 2023 peak underscores the urgent for adaptive strategies in disaster-prone regions.

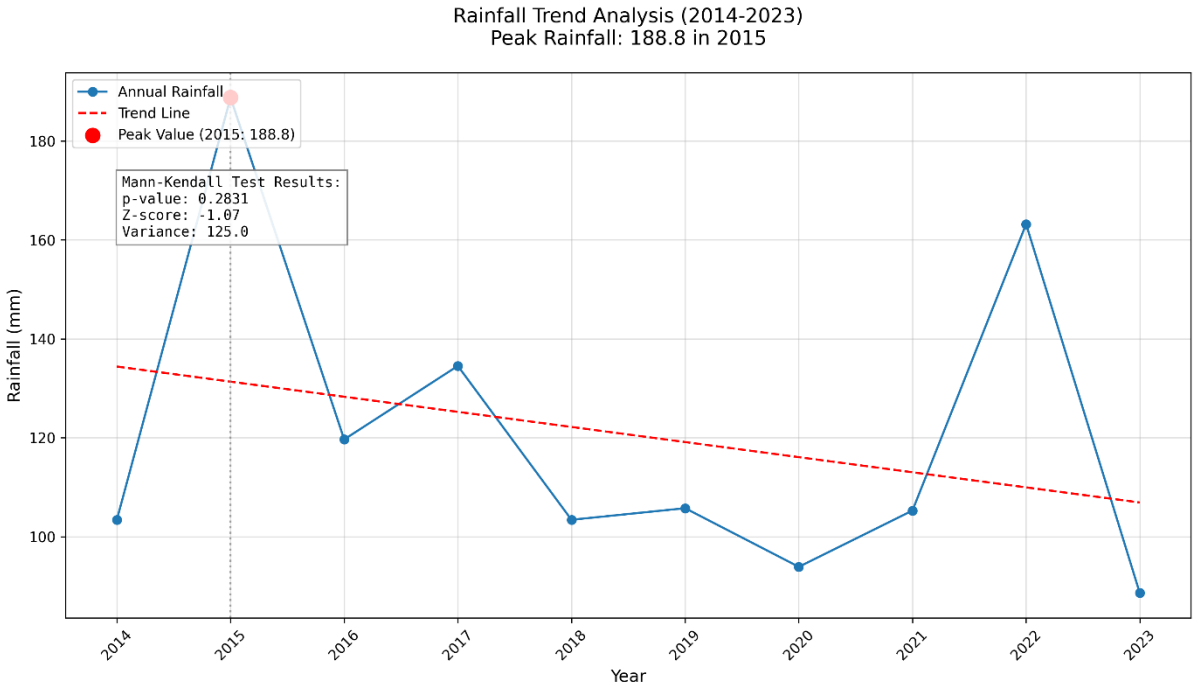


Figure 8. Graph Showing Rainfall Trend Mimosa Station

The rainfall graph for Mimosa depicts annual rainfall trends in Malawi (southern region) over a decade, with a notable peak of 188.8mm in 2015. The trend test shows a P-value of 0.2831, indicating no statistically significant trend in rainfall over the period. The variance is 125.0 which is reflecting moderate year-to-year rainfall variability. There is lack of significant trend, and P-value of 0.3831 indicates no clear upward or downward rainfall trend. In 2015 rainfall anomaly reflects complex climatic interactions rather than direct cyclone activity. However, cyclones remain a critical factor in Malawi's rainfall extremes, as seen in later years for example 2023. The graph emphasizes the need for adaptive strategies addressing both cyclone-driven and climate-influenced rainfall risks.

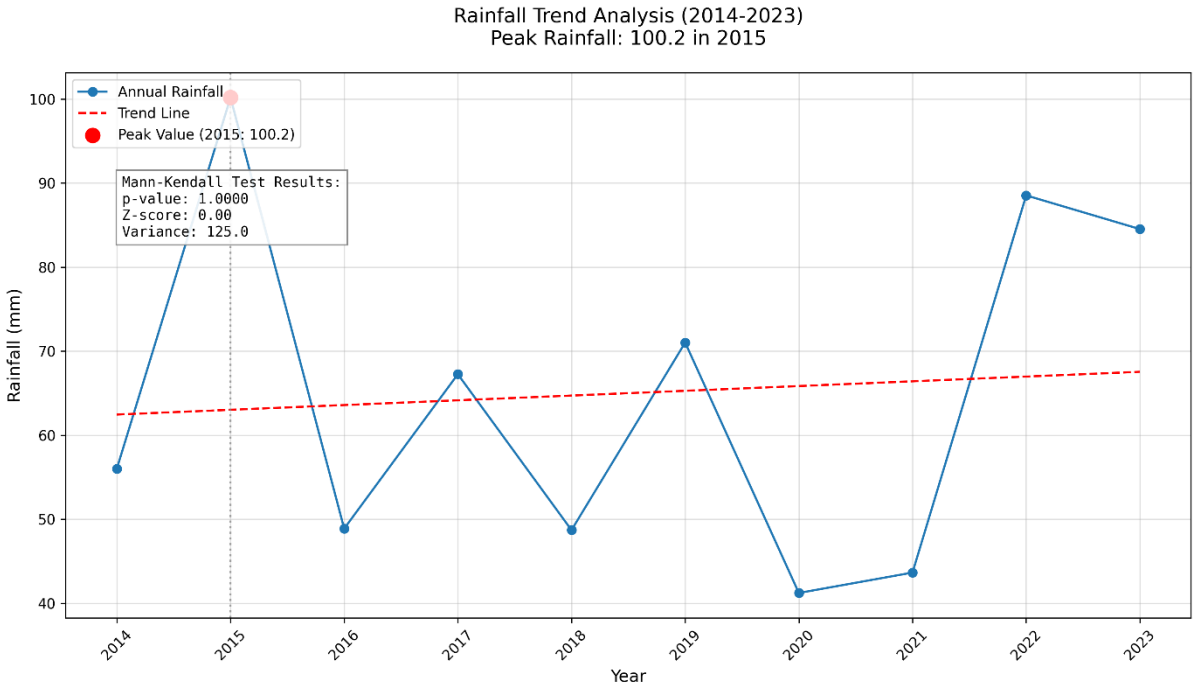


Figure 9. Graph Showing Rainfall Trend Ngabu Station

The p-value of 1.0000, indicating that there no statistically significant trend in rainfall. (assuming the significant threshold is 0.05). The variance is 125.0 reflecting a moderate variability between years.

4.5. IMPACTS OF TROPICAL CYCLONES

Tropical Cyclones accompany with them the strong winds, torrential rainfall which cause landslides, mudslides, and flooding in affected areas. The tropical Cyclones which occurred from 2014 to 2023 mostly affected the southern region of Malawi. This is where significant impacts of tropical Cyclones are reported. These events pose mostly negative effects to almost all sectors of government including healthy, education, energy, and agriculture. The Department of Disaster Management Affairs (DoDMA) on situation report number 6 of Cyclone Freddy, reported that during Cyclone Freddy in 2023, a total of 86,604 households were displaced from their usual residence in southern Malawi districts, and a total of 362,928 people were displaced following the event. During this time people lost their property due to flooding that carried away the property including animals, farm fields, and their houses were washed away.

4.5.1. IMPACTS OF CYCLONE FREDDY

Table 3Showing number of displaced households and people

HOUSEHOLDS DISPLACED	PEOPLE DISPLACED
86,604	362,928

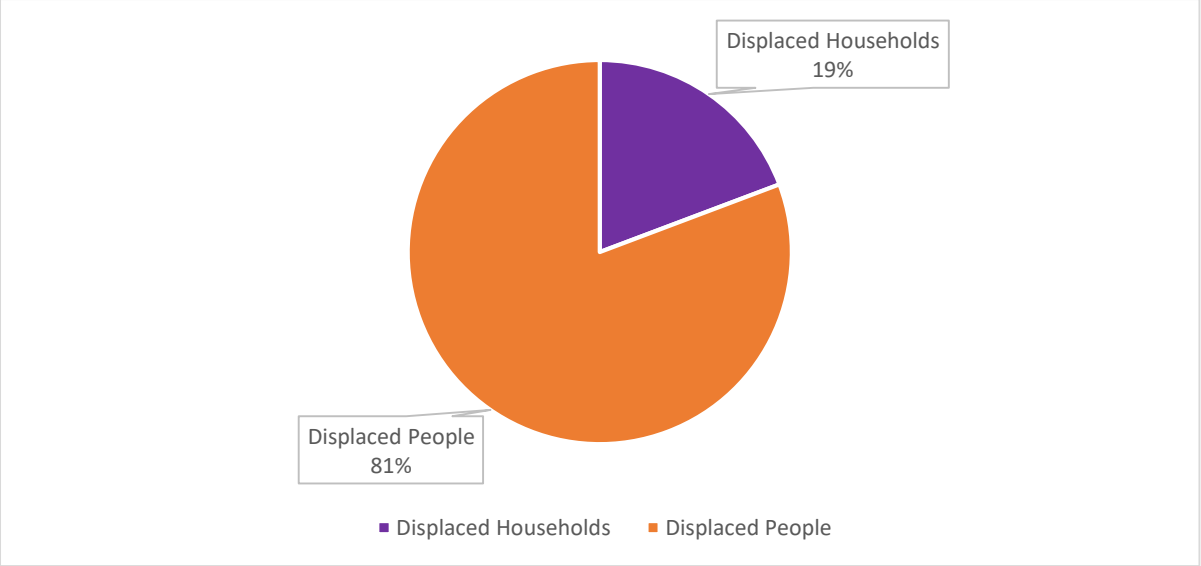


Figure 10. Chart Showing Number Percentage of Displaced Households and People

In the chart above, 81% represents the number of people were displaced during cyclone Freddy event and 19% represents the number of households which were displaced due to the effects of cyclone Freddy. It shows that a number of had gone homeless and hopeless with no food to eat and no place to stay. Their livelihoods were no more in existence leading to poverty on displaced households.

Table 4Showing number of people affected by Cyclone Freddy

MISSING PEOPLE	TOTAL DEATHS	TOTAL INJURIES
282	445	918

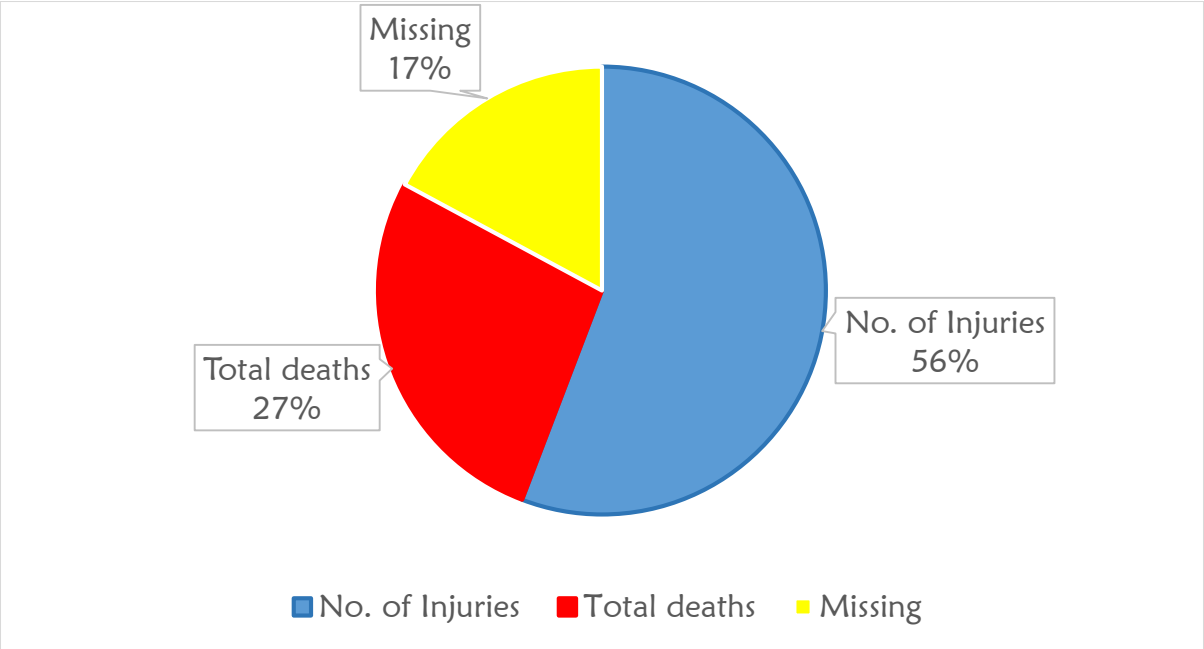


Figure 11. Chart Showing Percentage of People affected by Cyclone Freddy

Cyclone Freddy took lives of many people with significant number of injuries while others remained undiscovered. The DoDMA reported indicated that a total of 282 people went missing representing 17 % of people who were directly affected, a total of 445 people who were dead representing 27% of people who were directly affected, and 918 injuries were reported during the same period representing 56%.

Following the passage of Tropical Cyclone Freddy across southern Malawi. the districts of Blantyre (including city), and the districts of Chikwawa, Chiradzulu, Mulanje, Mwanza, Nsanje, Phalombe, and Zomba (including city) had been severely hit by torrential and persistent rains, and causing devastating floods and mudslides.

Education sector, due to Cyclone Freddy, a total of 253 schools were affected negatively; the school blocks were used as camps for displaced communities and due to large number of the displaced 136 camps were in schools where learning classes were occupied. A total of 110,710 learners (54,307 boys and 63,670 girls) were affected during Cyclone, 195 teachers were also affected with the death of 9 learners.

Transport sector, due to Cyclone Freddy, road access was severely limited in the southern region from the effects of heavy rains and resulting riverine flooding. As of 18 March 2023 Chikwawa district was accessible via the M1 from Blantyre, but access

remained extremely restricted in the southern portion of the district. There were multiple road damages which were reported in Nsanje, Chiradzulu, Phalombe, and Mulanje districts which prevented access to transportation.

Social impacts, the cyclone event resulted in overcrowding displaced women, adolescent girls, and children in shelters which increased the risk of sexual violence. Separation and orphaned children in camps; collapsed community based childcare centres and disruption of children safe spaces.

4.5.2. IMPACTS OF CYCLONE ANA

Tropical Cyclone Ana caused damage to public and private infrastructure, and also caused deaths and injuries southern region districts and other districts in the central region.

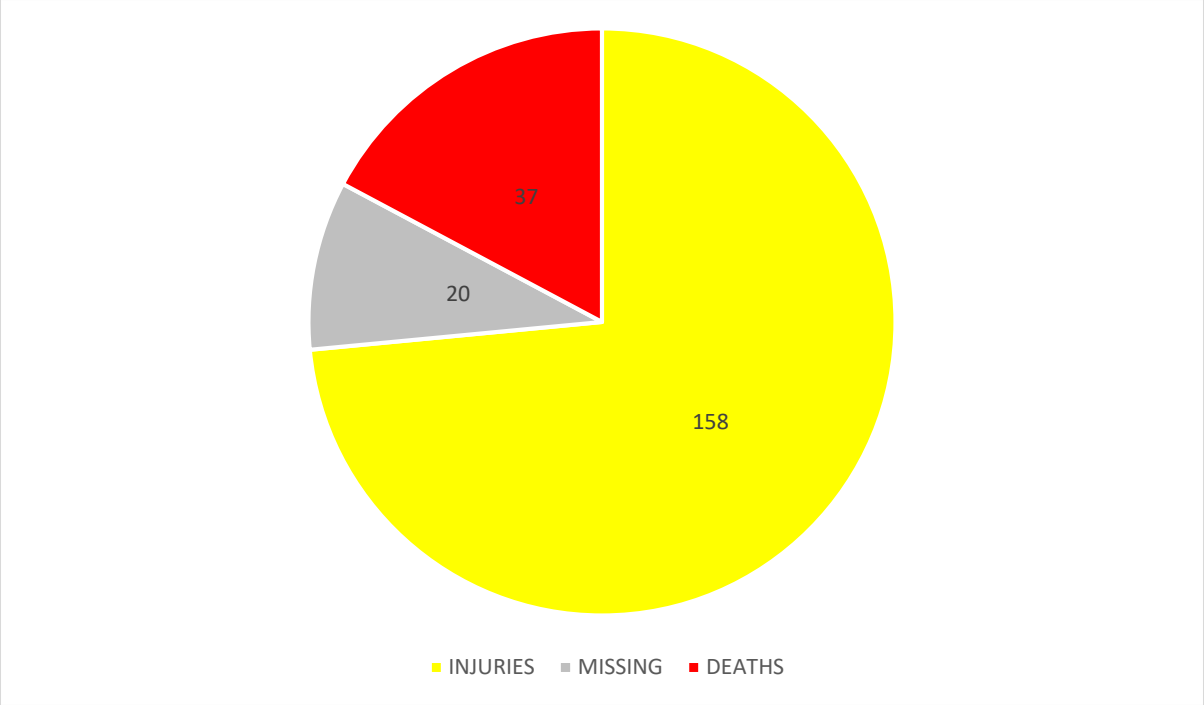


Figure 12. Chart Showing Number of People Affected by Cyclone Ana

Tropical Cyclone Ana caused deaths to 37 people, with 20 people missing, and 158 injuries were recorded due to the effects of the storm.

In 11 districts including Chikwawa, Nsanje, Mulanje, Balaka, Phalombe, Zomba, Blantyre, Thyolo, Mangochi, Mwanza, and Neno, households were displaced from their usual residence.

Table 5. Showing number of displaced households in districts

DISTRICT NAME	No OF HOUSEHOLDS DISPLACED
Chikwawa	10,159
Nsanje	6,096
Mulanje	2,678
Balaka	1,448
Phalombe	869
Zomba	424
Blantyre	197
Thyolo	179
Mangochi	179
Mwanza	113
Neno	22

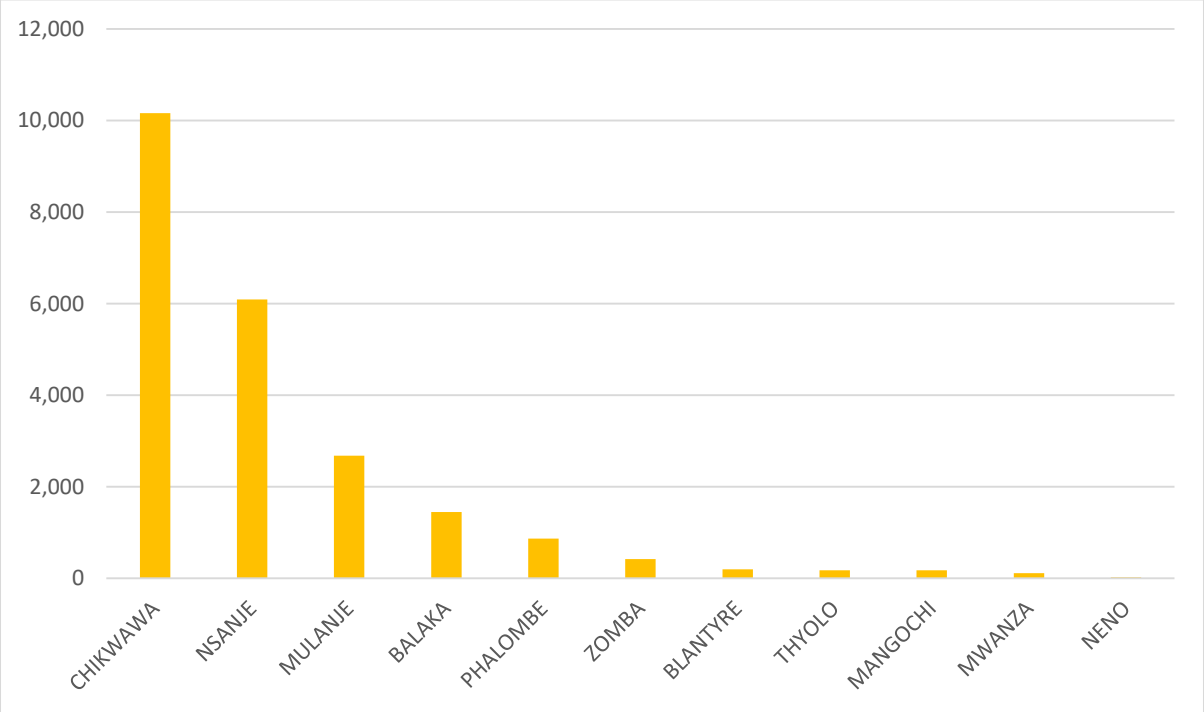


Figure 13. Graph Showing Districts and their Displaced Households

The tropical Cyclone Ana event resulted robust effects; vehicles were washes away by flood water, houses were blown off by winds, livestock got lost, houses and toilets collapsed, brick fences collapsed, road network was cut down, bridges were damaged.

There was also disruption in school programs, damage of power plant leading to disruption of power supply across the country, contamination of water resources like boreholes and wells, damage of learning and teaching materials, and damage of private and public infrastructure.

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The study has indicated the escalating threat of tropical cyclones in the Mozambique Channel to Malawi, driven by climate change-induced factors such as rising Sea Surface Temperatures(SSTs) and atmospheric humidity. Between 2014 and 2023, Cyclones like Idai, Ana, and Freddy demonstrated heightened intensity and destructive potential, correlating with SST warming trends (0.022°C/year) and increased humidity (+0.036g/kg/year). These Cyclones caused catastrophic socio-economic impacts, including over 500 fatalities, displacement of 36,928 people, and widespread damage to infrastructure, agriculture, and public services.

Southern Malawi, with its high population density and climatic vulnerability, bore the brunt of these events. While rainfall variability was linked to Cyclone activity, the long-term trends were not statistically significant, highlighting the complexity of regional hydro-meteorological dynamics. The findings emphasize Malawi's urgent need to address systemic vulnerabilities exacerbated by climate change, poverty, and inadequate infrastructure.

5.2 LIMITATIONS

The research used data which is of only 10 years which is just short period of time. This could not give clear results according to the nature of this study. It needed dataset for at least 30 years.

5.3 RECOMMENDATIONS

The following are the recommendations that have been made from the study:

Strengthening early warning systems, there is a need to invest in advanced meteorological technologies to improve Cyclone tracking and public alerts, ensuring timely evacuations and preparedness.

Building Climate-Resilient Infrastructure, prioritization of Cyclone-resilient designs for schools, hospitals, and roads, particularly in high-risk southern districts is very imperative

Integrating Climate Adaptation into policy, mainstreaming climate resilience into national development plans, focusing on sustainable agriculture, water management, and ecosystem restoration

Community Empowerment and Education, by launching grassroots campaigns to educate vulnerable communities on disaster preparedness, emergency response, and livelihood diversification to enhance resilience on climate sensitive sectors

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