# ASSESSING THE IMPACTS OF EXTREME WEATHER CONDITIONS ON AVIATION SAFETY AND OPERATIONS AND THIER MITIGATION STRATEGIES IN MALAWI

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## ABSTRACT

This study assessed the impacts of extreme weather conditions on aviation safety and operational efficiency at Malawi's two main international airports, Kamuzu International Airport and Chileka International Airport, during 2015–2024. Disruptions caused by fog, low visibility, heavy rainfall, thunderstorms, and wind shear were analyzed as they pose risks to flight operations, infrastructure, and passenger safety while generating significant economic losses, such as increased fuel costs from diversions. The research aimed to identify dominant weather hazards, evaluate their effects on aviation safety and performance, and propose mitigation strategies to strengthen resilience in the sector. A mixed-methods design was employed, combining quantitative analysis of meteorological and aviation records with qualitative insights from pilots, meteorologists, air traffic controllers, and airport staff. Findings revealed that fog and low visibility were the most frequent and disruptive hazards, followed by wind shear, heavy rainfall, and thunderstorms, all strongly linked to delays, diversions, cancellations, and reduced airport efficiency. Although major accidents were rare, adverse weather heightened operational risks and exposed weaknesses in forecasting systems, equipment reliability, and preparedness, while current mitigation measures such as rescheduling, pilot warnings, and diversions proved only partially effective. The dissertation concludes that adverse weather remains a major constraint to safe and efficient aviation in Malawi and recommends upgrading monitoring technologies, installing advanced landing and wind shear detection systems, enhancing staff training, improving coordination between aviation and meteorological agencies, and investing in automated and AI-assisted forecasting tools to improve safety, reduce economic losses, and support national connectivity in line with Malawi Vision 2063.

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## ACRONYMS/ABBREVIATIONS

**ICAO:** International Civil Aviation Organization

**WMO:** World Meteorological Organization

**CAA**: Civil Aviation Authority (Malawi)

**AWOS**: Automatic Weather Observation System

**IFR**: Instrument Flight Rules

**VFR**: Visual Flight Rules

**IMC**: Instrument Meteorological Conditions

**METAR**: Meteorological Aerodrome Report

**KIA**: Kamuzu International Airport

**CIA**: Chileka International Airport

**ADL**: Airport Developments Limited

**NPC**: National Planning Commission (Malawi)

**USD**: United States Dollar (currency reference for aviation costs)

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# ASSESSING THE IMPACTS OF EXTREME WEATHER CONDITIONS ON AVIATION SAFETY AND OPERATIONS AND THIER MITIGATION STRATEGIES IN MALAWI

## CHAPTER 1: INTRODUCTION

### 2.1 Background

Aviation serves as a critical component of global transportation, enabling the efficient movement of people and goods across vast distances. However, adverse weather conditions—particularly heavy rainfall and low visibility—remain among the most significant threats to aviation safety, often resulting in flight delays, diversions, cancellations, and increased accident risks (ICAO, 2020).

In Malawi, a landlocked country in south-eastern Africa, the aviation sector plays a vital role in supporting economic growth, trade, tourism, and regional connectivity. Despite its importance, the sector is highly vulnerable to weather-related hazards, especially during the wet season from November to April (Malawi Ministry of Transport, 2021). Fog stands out as one of the most challenging weather phenomena at Malawian airports. It significantly disrupts airport operations by reducing visibility, leading to delays, higher operational costs, and elevated safety risks.

Heavy rainfall further compounds these challenges by increasing the risk of hydroplaning on runways and complicating landing maneuvers. Poor visibility, often worsened by rain or fog, necessitates reliance on instrument flight rules (IFR), yet not all airports in Malawi are fully equipped to support advanced instrument operations (Jones & Patel, 2022). Other extreme weather events such as thunderstorms, strong winds, and wind shear also frequently disturb flight schedules and compromise safety margins.

While global advancements in meteorological technology—including radar systems, Automatic Weather Observation Systems (AWOS), and improved forecasting models—have enhanced the prediction and management of severe weather, their adoption and application in Malawi remain limited. There is a notable scarcity of localized research examining the specific impacts of adverse weather on aviation safety and operational

efficiency at the country's two major airports: Chileka International Airport and Kamuzu International Airport.

This study therefore assessed the extent to which adverse weather conditions, particularly fog, heavy rain, low visibility, and associated phenomena, affect aviation safety and operational performance in Malawi. By analyzing the challenges facing the aviation industry in this context, the research highlights critical gaps and proposes practical mitigation measures to enhance resilience and safety in air transportation.

## 2.2 Problem Statement

Aviation safety and operational efficiency at Malawi's major airports are increasingly threatened by extreme weather events, particularly severe thunderstorms, heavy rainfall, and low visibility caused by fog. These conditions create significant risks to aircraft operations and airport infrastructure, frequently resulting in flight delays, cancellations, diversions, and occasional safety incidents.

Despite the recurrent nature of these weather disturbances, Malawi's aviation sector suffers from inadequate weather prediction systems and insufficient risk management strategies. This gap in preparedness heightens the vulnerability of air operations, especially at the country's two primary international gateways — Kamuzu International Airport and Chileka International Airport.

Furthermore, there is a notable scarcity of localized empirical studies that specifically examine weather patterns such as rainfall intensity, fog occurrence, wind shear, and thunderstorms, and their direct impacts on aviation safety and operational performance in the Malawian context. Most existing literature focuses on broader regional or international trends, often overlooking the unique climatic and infrastructural realities of Malawi.

This study therefore investigated the impacts of adverse weather conditions on aviation safety and operational efficiency at Chileka and Kamuzu International Airports. It further

examined potential mitigation strategies that can enhance resilience in the aviation sector and contribute meaningfully towards the realization of Malawi's Vision 2063 agenda.

## 2.3 Research Objectives

The main objective of this study was to assess the impacts of extreme weather conditions on aviation safety and operations and to propose appropriate mitigation strategies in Malawi.

### The specific objectives were:

1. To identify and map out the types of extreme weather conditions that affected aviation safety and aviation operations at Chileka International Airport and Kamuzu International Airport between 2015 and 2024.
2. To examine the extent to which extreme weather conditions impacted flight safety and aviation operations in Malawi between 2015 and 2024.
3. To assess potential mitigation strategies for improving aviation safety and operational efficiency in the face of extreme weather conditions in Malawi.

## 2.4 Research Questions

This study was guided by the following research questions:

- What types of extreme weather conditions affected aviation safety and operations at major airports in Malawi between 2015 and 2024?
- How have extreme weather conditions impacted flight safety and accident rates in Malawi between 2015 and 2024?
- What mitigation strategies can be implemented to enhance aviation safety and reduce accident rates under extreme weather conditions in Malawi?

## 2.5 Significance of the Study

This study evaluated the impacts of extreme weather conditions, particularly heavy rainfall and low visibility, on aviation safety and operations in Malawi. The findings are significant in several ways.

Extreme weather events pose serious risks to aircraft, passengers, crew, and airport infrastructure in Malawi. Heavy rainfall increases the likelihood of runway flooding, reduced braking efficiency, and hydroplaning, while low visibility caused by fog and rain severely limits pilots' situational awareness, often resulting in flight delays, diversions, and heightened accident risks (ICAO, 2018; WMO, 2017). Because Malawi's aviation infrastructure is less advanced compared to developed nations, the effects of these weather phenomena tend to be more pronounced. Understanding their specific local impacts is therefore essential for building resilience in the sector amid increasing climate variability.

The study contributes to Malawi's Vision 2063 agenda, which emphasises technological advancement and innovation across key economic sectors. By providing localised evidence on how weather affects aviation https://www.metmalawi.gov.mw/ this research offers valuable insights for the development of improved weather prediction systems, early warning mechanisms, enhanced pilot training programmes, and better air traffic management strategies. Such measures are particularly important in a resource-constrained environment like Malawi, where cost-effective solutions can significantly improve safety standards.

Furthermore, as a landlocked country, Malawi depends heavily on efficient and reliable air transport for international trade, tourism, and regional connectivity. The findings of this study can inform policy decisions and infrastructure development aimed at minimising weather-related disruptions, thereby supporting smoother movement of people and goods and contributing to broader national economic development goals (Malawi National Planning Commission, n.d.). https://npc.mw/mw2063-preamble/?utm_source

# CHAPTER 2: LITERATURE REVIEW

## 2.1.1 Weather and Climate of Malawi

Malawi is a landlocked country in southeast Africa characterized by a subtropical climate that varies significantly across its regions due to its unique topography. The country's climate is largely influenced by its position between Lake Malawi and the surrounding mountain ranges, which generate distinct local weather systems (Chikumbusko et al., 2015; Tembo-Nhlema et al., 2021). It experiences three primary seasons: a rainy season from November to April, with the heaviest rainfall occurring between December and February, often accompanied by thunderstorms; a dry season from May to October marked by low humidity and minimal rainfall; and a cool season from May to August followed by a warm transition period from September to October (Kaur & Hansen, n.d.; Tembo-Nhlema et al., 2021). Annual rainfall ranges from approximately 800 mm in the southern lowlands to over 1,200 mm in the northern highlands (Chikumbusko et al., 2015). Temperature variations are also notable, with night-time temperatures in the highlands dropping to around 10°C during the cool season, while daytime temperatures frequently reach 30–35°C in September and October (Chikumbusko et al., 2015; Kaur & Hansen, n.d.). These regional climatic differences are primarily shaped by the country's diverse topographical features, including plateaus, valleys, and mountains, resulting in cooler and wetter conditions in the northern and central highlands compared to the southern lowlands (Tembo-Nhlema et al., 2021).

## 2.2 Civil Aviation in Malawi

Malawi's air transport infrastructure consists of two international airports (Kamuzu International Airport in Lilongwe and Chileka International Airport in Blantyre), four secondary airports with paved runways (Likoma, Karonga, Mzuzu, and Club Makokola in Mangochi), and approximately 26 basic grass or low-grade airstrips (Malawi Civil Aviation Authority, 2017).

All airports except Kamuzu International Airport (KIA) and Likoma Airport are operated by the Ministry of Transport and Public Works. KIA and Likoma are co-operated by Airport Developments Limited (ADL), while Club Makokola is privately owned and operated (Ministry of Transport and Public Works, 2017).

The Civil Aviation Act of 2017 established the Malawi Civil Aviation Authority (CAA) as an independent regulator, separating regulatory functions from operational responsibilities that were previously handled by the Department of Civil Aviation (Civil Aviation Act, 2017; Malawi Civil Aviation Authority, 2017). International air services to both major airports are currently provided by carriers from Malawi, Kenya, Ethiopia, South Africa, and Zambia (Ministry of Transport and Public Works, 2017).

## 2.3 Impacts of Weather Conditions on Aviation Safety and Operations

Weather is one of the most significant external factors affecting aviation safety and operational efficiency worldwide. Adverse weather phenomena—including severe turbulence, wind shear, microbursts, icing, low visibility, heavy precipitation, and extreme temperature variations—continue to challenge pilots, air traffic controllers, and airport operators.

### 2.3.1 Impacts on Aviation Safety

Numerous studies have established a clear link between adverse weather and aviation accidents or serious incidents. Ayiei, Murray and Wild (2020) analyzed post-accident cases involving Visual Flight Rules (VFR) operations into Instrument Meteorological Conditions (IMC) and concluded that sudden changes such as wind shear and microbursts frequently cause pilot disorientation and critical decision-making errors. Khan et al. (2020) found that adverse weather accelerates aircraft component degradation and increases the risk of system failure during flight.

Tseng and Chen (2018) and Lee (2018) similarly identified icing, turbulence, and low-visibility conditions as primary hazards that degrade aircraft performance and reduce pilot situational awareness, particularly during the critical phases of take-off and landing. These

studies collectively demonstrate that extreme weather not only elevates accident risk but also places additional stress on aircraft systems and human performance.

### 2.3.2 Impacts on Aviation Operations

Beyond safety, weather significantly disrupts day-to-day aviation operations. Mhando, Nyoni and Chikoko (2019), using regression analysis, reported that up to 35 % of flight delays in certain regions are directly attributable to adverse weather, especially during the rainy season. Anderson and Brooks (2020) showed that weather-related delays create cascading effects across crew scheduling, gate availability, and overall airport capacity, often leading to network-wide inefficiencies.

Zhao and Lin (2019) developed statistical models that predict the likelihood and duration of weather-induced disruptions based on precipitation intensity and wind speed. Wang (2019) and Zhang (2020) further documented that extreme weather events reduce airport throughput, extend turnaround times, and generate substantial economic losses through delays, cancellations, and increased operational costs.

## 2.4 Adaptations and Mitigation Strategies

In response to these challenges, researchers and practitioners have developed a range of technological, infrastructural, and operational mitigation measures.

Technological advances in weather forecasting have been particularly impactful. Cui et al. (2020) demonstrated that integrating machine-learning algorithms with traditional meteorological methods significantly improves real-time prediction of adverse weather events. Li (2021) showed that big-data analytics can enhance forecasting accuracy and reduce uncertainty in flight planning.

At the operational and infrastructural level, Wolfson and D. (2018) highlighted the effectiveness of improved runway drainage systems and modern de-icing infrastructure in reducing weather-related vulnerabilities. Müller-Putz (2019) advocated for adaptive

scheduling and dynamic resource reallocation protocols to minimize the impact of sudden disruptions.

Enhanced collaboration between meteorological services and aviation authorities has also proven valuable. Novotny (2021) emphasized that the integration of real-time weather data into air traffic management systems enables proactive route adjustments and better decision-making during adverse conditions. Studies such as the ResearchGate publication on the "Impact of Weather Conditions on Airport Arrival Delay and Throughput" have helped establish operational thresholds that support timely and informed responses.

### 2.5 Methodologies Used in Previous Research

Researchers have employed a combination of quantitative, qualitative, and technology-driven approaches. Quantitative studies frequently use regression models and statistical analysis to quantify relationships between weather variables and operational outcomes (Mhando, Nyoni & Chikoko, 2019; Zhao & Lin, 2019). Qualitative methods, including post-accident analyses and case studies, have been used to explore human and systemic factors (Ayiei, Murray & Wild, 2020; Wang, 2019). More recent work has incorporated machine-learning and big-data techniques to improve forecasting and predictive modelling (Cui et al., 2020; Li, 2021). This methodological diversity provides a robust framework for the current study.

## Conclusion

The reviewed literature consistently confirms that extreme weather conditions constitute a major threat to both aviation safety and operational efficiency. While safety risks arise primarily from phenomena such as wind shear, turbulence, icing, and low visibility, operational disruptions manifest as delays, cancellations, reduced throughput, and significant economic losses. Fortunately, advances in forecasting technology, infrastructure improvements, adaptive operational procedures, and stronger inter-agency collaboration offer promising pathways for mitigation. The present study builds on this foundation by focusing specifically on the Malawian context, where the interaction between the country's

unique climate patterns and its relatively limited aviation infrastructure presents distinctive challenges and opportunities for targeted interventions.

# CHAPTER 3: RESEARCH METHODOLOGY

A Research methodology is well structured and scientifically based approach that has been used to analyze, collect and interpret data. These resembles steps followed in order to come up with informative data either qualitative or quantitative which will be helpful to come up with the solutions to the risen problem. Research methodology involves the actual research design, the area or areas chosen for the study and analysis, data collection methods, ethical considerations as well as study Limitations.

## 3.1 Research Design

The Research design refers to the overall strategy that is chosen to integrate different components of the study in a coherent and logical way, thereby ensuring the effectiveness of the research problem; it constitutes the blueprint for the collection, measurement, and analysis of data. According to Sacred Heart University, there are different types of research designs such as, causal research design, action research design, descriptive research design, observational research design and Mixed research Design.

As per the objectives this research project focused on the mixed research design(Tashakkori & Teddlie, 2003), which is a procedure for collecting, analyzing and "mixing" both quantitative and qualitative data at some stage of the research process within a single study, to understand a research problem more completely (Creswell, 2002). The rationale for mixing is that neither quantitative nor qualitative methods are sufficient by themselves to capture the trends and details of the situation. As used in combination, quantitative and qualitative methods have complemented each other and allow more complete analysis. As investigator on numerical data, the quantitative component has used secondary archival data (2015–2024) for triangulation. The Research has post positivist claims for developing knowledge, such as cause and effect thinking, reduction to specific variables, hypotheses and questions, use of measurement and observation, and the test of theories. A researcher isolated variables and causally related them to determine the magnitude and frequency of relationships. Qualitative research is an inquiry process of understanding where the

researcher develops a complex, holistic picture, analyzes words, reports detailed views of informants, and conducts the study in a natural setting (Creswell, 1998, p. 15). Research Objectives 1 and 2 required objective, quantifiable historical data to identify patterns and relationships, while Objective 3 needed expert insights to generate practical, context-specific mitigation strategies. The qualitative component supplements this with primary data obtained from stakeholders to explain "how" and "why" mitigation is feasible in Malawi.

### 3.1.1 Independent and Dependent Variables

Independent variable are factors manipulated or changed by the researchers in an experiment to test their effects, according to our research scope, these includes all extreme weather events experienced at the two airports. On the other hand, dependent variables are factors measured or observed which change with response to the change in Independent variables. In simple terms independent variables are changed while dependent variables are measured.

Table 1: Summary of Independent and dependent variables for the study

| Independent variables | Dependent Variables |
|---|---|
| • Fogs causing visibility to be less than 1000m<br>• Heavy Rainfall (over 50mm)<br>• Wind gusts (over 15m/sec) and wind Shear<br>• Extremely hot Temperatures<br>• Lightening | • Aviation safety<br>• Airports ground Operations<br>• Flight cancellations<br>• Financial losses<br>• Loss of lives<br>• Destruction or Damage of Airport infrastructures ie Runways, Signal Devices, Weather Stations, buildings |

Possible Threats on internal validity, due to this research design where it incorporates both use of quantitively and qualitative data may be very notable. For example, there could be participants chosen could possibly have inherent characteristics that skew results, apart from that participants mortality is also an internal validity threat where participants choose to drop out on the middle of the way, causing non-representative samples. On the other hand, external validity threats include threats that hinders the ability to apply findings to other context or populations. The common encountered threat under external validity is selection treatment interaction where samples does not represent the target population. Additionally, participant develop Hawthorne effect where participants act differently due to the novelty of the intervention or being observed.

The following are some of ways enrolled so as to reduce the possible alterations and distortion of results caused by Validity threats:

- **Internal validity** – ensured through date-matched weather and aviation records and use of standardized METAR definitions. To ensure consistency there has been development of parallel questions in the surveys. Another way is filer Tasks, it has been employed in implementation of surveys in form of questionnaires or tasks designed to mask the true purpose of the study to prevent demand characteristics.
- **External validity** – findings are generalizable to Malawi's two major international airports (Kamuzu International Airport – KIA, Lilongwe and Chileka International Airport – CIA, Blantyre), which handle >95 % of national air traffic. There has been utilization of triangulation where multiple methods, data sources and theories have been employed to study a single phenomenon aimed at increasing the validity, credibility and comprehensiveness of findings.

## 3.2. Area of study

The research focused on Malawi as a country, specifically the main aviation hubs. These are Chileka International Airport in Blantyre (Southern Region) and Kamuzu International

Airport in Lilongwe (Central Region). There is also an airport situated in Mzuzu city (Northern Region) but it has been in operational for quite a long time hence to acquire data for a range of period of 2015 to 2024 will be quite a challenge therefore this research will only focus of two active airports (one from central region and another from southern region of Malawi) . These locations are critical for understanding how severe weather hinders operations in both domestic and international aviation contexts. In additional to that, the areas chosen will allowed the proper assessments of safety and operations of aviation services

### 3.2.1 Chileka International airport

- Geographical Description

Chileka International Airport is an airport located for about 16 km away from the Blantyre city Centre, the second largest city in the Republic of Malawi and the commercial Capital of Malawi's Southern Region (SKYBrary, 2021). According to the International Civil Aviation Organization (ICAO), Chileka International Airport is world widely Known as FLWC as its code internationally, meaning to say any information containing that code will be acknowledged as of Chileka Airport in Malawi.

- Weather and climatic conditions

The weather in Blantyre, where C.I.A is located in Malawi, sees moderate temperature fluctuations over the course of a year. Temperatures can be very warm at the high end to roughly warm at the low end. It experiences significant rainfall throughout the year, averaging 1240 mm of precipitation annually. The seasons in Blantyre, bring significant changes in precipitation. The wettest month, January, receives heavy rainfall, with an average of 331 mm of precipitation. This rainfall is distributed across 17 rainy days. In contrast, the driest month, August, experiences much less rainfall 10mm over 2 rainy days. These distinct seasonal differences provide diverse experiences throughout the year.

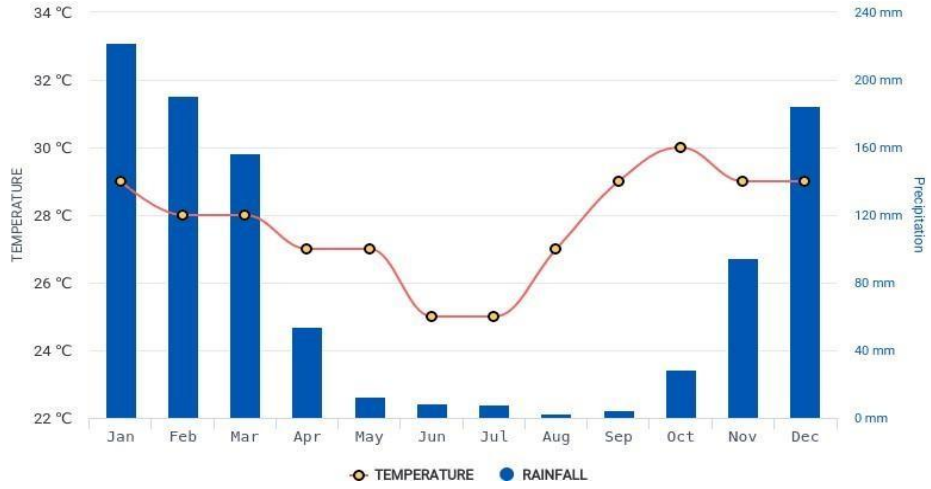



Figure 1: Blantyre Malawi Average monthly Precipitation as well as Temperature

Source:https://www.google.com/imgres?q=weather%20and%20climate%20of%20Blantyre%20city%20in%20malawi&imgurl.

### 3.2.2 Kamuzu International Airport

- Geographical description

Kamuzu International Airport was constructed in Lumbazi, a suburb of the capital, following the relocation of Malawi's capital to Lilongwe in 1975. The construction period was from October 1977 to September 1982 and was divided into three phases. Kamuzu International Airport was officially opened in 1983. The airport is at an elevation of 4,035 feet above MSL (mean sea level). It has one runway designated 14/32 with an asphalt surface measuring 3,540 by 45 meters (11,614 ft. × 148 ft.). • Weather and climatic conditions K.I.A being in Lilongwe the capital city of Malawi, as a whole experiences climate with distinct wet and dry seasons. The rainy season typically runs from November to April, bringing heavy downpours and high humidity (Climate-Chart.com 2024). The average annual temperature in Lilongwe is around 20°C (72°F), with the hottest months being October and November. Average daytime temperatures reach a very Warm 31°C in November. In July, the coolest month of the

year, temperatures drop to a comfortable 24°C. Figure 2: The chart below illustrates the average maximum day and minimum night Temperatures in Lilongwe by month:

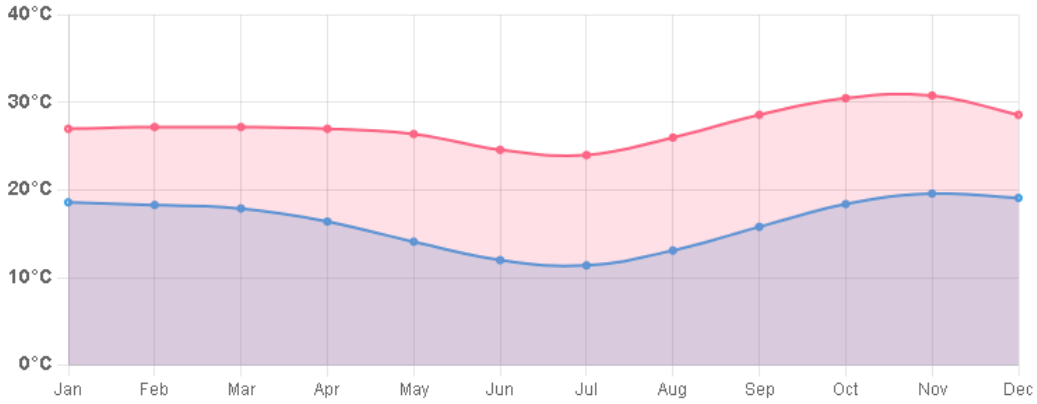



Figure 2: Illustration of the average maximum day and minimum night Temperatures in Lilongwe by month

Source:https://www.google.com/imgres?q=weather%20and%20climate%20of%20l ilongwe%20city%20of%20malawi&imgurl

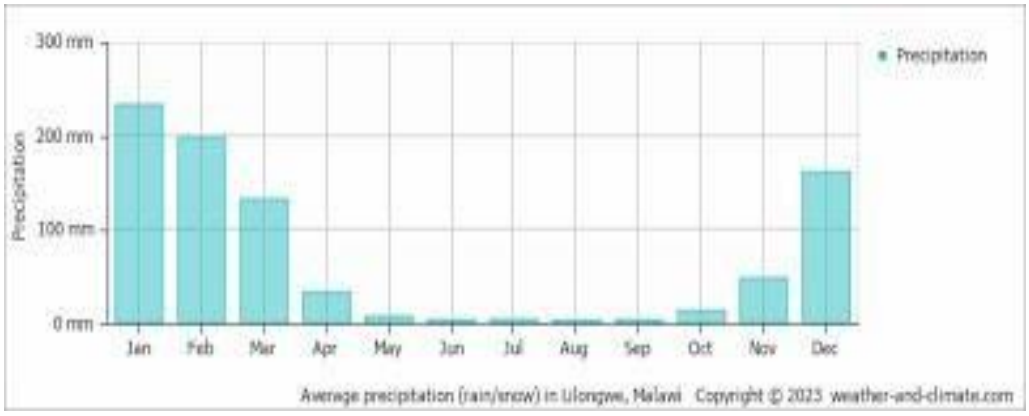



Figure 3: Illustration of the average Rainfall for Lilongwe city

Source:https://www.google.com/imgres?q=weather%20and%20climate%20of%20l ilongwe%20city%20of%20malawi&imgurl

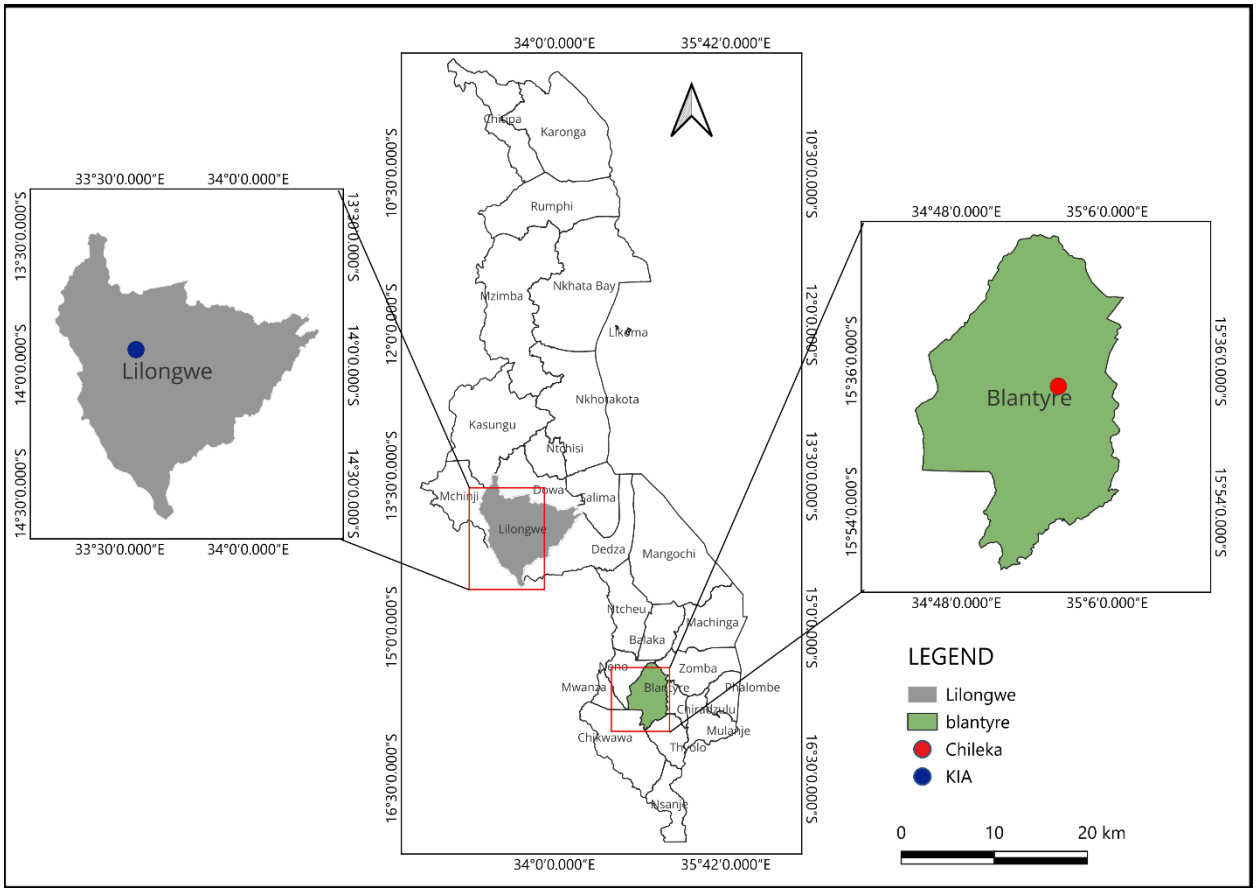



Figure 4: Map of Malawi showing the study area for the research project (the two international targeted airports):

## 3.3 Materials and Methods

The methods below explain exactly how each specific objective was accomplished, including the **type of data**, **source of data**, **method of data collection**, and **type of analyzing tool**. All methods follow the dissertation guidelines for replicability.

### 3.3.1 Specific Objective 1: To determine the types of extreme weather conditions that affect aviation safety and operations from 2015–2024.

- **Type of data**: Quantitative secondary meteorological data (daily and monthly records of precipitation (mm), visibility (m), wind speed/direction/gusts, thunderstorm occurrence, and fog events).
- **Source of data**: (1) Malawi Department of Climate Change and Meteorological Services (Met Malawi) archives and automatic weather station (AWS) records at KIA and CIA; (2) historical METAR and SYNOP reports from the airports; (3) publicly available annual climate bulletins (2015–2024).
- **Method of collecting data**: Archival/secondary data retrieval. Formal letters were sent to Met-Malawi and the Malawi Civil Aviation Authority (MCAA) requesting the complete 10-year dataset. Data were also downloaded from the Met Malawi website and ICAO-compliant airport weather logs where available.
- **Type of analyzing tool**: Descriptive statistics (frequency counts, percentages, means, and standard deviations) and time-series visualization (line graphs, bar charts, and seasonal trend analysis) using Microsoft Excel 2021 and SPSS version 26. Extreme events were categorized using World Meteorological Organization (WMO) thresholds for Malawi.

### 3.3.2 Specific Objective 2: To analyze the impacts of extreme weather conditions on flight safety and accident rates from 2015–2024.

- Type of data: Quantitative secondary paired data (aviation incident/accident reports + corresponding daily weather records). Variables include: number of

weather-related incidents/accidents per year, rate per 10 000 flights, number of delays (>15 min), cancellations, and diversions.

- Source of data: (1) MCAA Annual Safety Reports and Incident Investigation Database (2015–2024); (2) airline operational statistics from Malawi Airlines and other carriers operating at KIA and CIA; (3) cross-referenced with Met Malawi weather data for the exact date and airport.
- Method of collecting data: Systematic secondary data extraction. Official requests were made to MCAA under the Access to Information Act. Weather and aviation records were matched by date, time, and airport using a common identifier (UTC timestamp). Missing values (<5 % of dataset) were noted but not imputed to preserve data integrity.
- Type of analyzing tool: Inferential statistics – Pearson's correlation coefficient (to measure strength of association between weather variables and accident/delay rates), multiple linear regression (to identify the strongest predictors), and chi-square tests of independence (for categorical weather vs. incident occurrence). All analyses were performed in SPSS version 26 and validated in R (version 4.3.2) for robustness. Results were visualized with scatter plots and regression lines.

### 3.3.4 Specific Objective 3: To determine the potential mitigation strategies for improving aviation safety and operations.

- Type of data: Qualitative primary data (expert opinions, experiences, and suggested strategies) supplemented by secondary best-practice documents.
- Source of data: Primary – key informant interviews and structured questionnaires with purposively selected stakeholders (pilots, air traffic controllers, airport meteorologists, MCAA safety officers, and airline operations managers). Secondary – ICAO Doc 8896 (Manual of Aeronautical Meteorological Practice), WMO aviation meteorology guidelines, and peer-reviewed case studies from similar subtropical climates.

- Method of collecting data: Semi-structured key informant interviews (face-to-face or Zoom, 30–45 minutes each) and a short-structured questionnaire (Google Forms/physical) distributed to 20–25 participants. Interviews were audio-recorded with consent and transcribed verbatim. Snowball sampling was used after initial contacts provided by the supervisor and MCAA.
- Type of analyzing tool: Thematic analysis (Braun & Clarke, 2006) using NVivo 14 software. Themes were developed inductively:

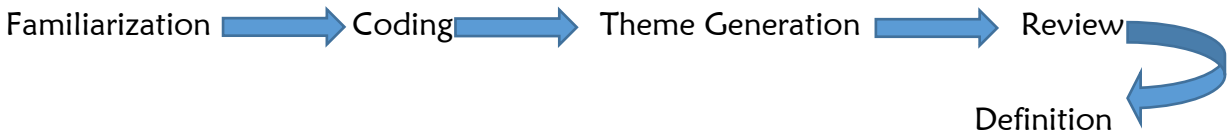



Figure 5: Showing Thematic analysis (Braun & Clarke, 2006) using NVivo 14 software.

and also cross-checked against secondary literature. Frequency of suggested strategies was also quantified descriptively in Excel for triangulation.

### 3.3.5 Additional followed procedures (common to all objectives)

- Data management: All raw data were stored on a password-protected external drive and backed up on OneDrive. Weather and aviation datasets were merged in Excel using date-time stamps.
- Software and instruments: SPSS v26, Microsoft Excel 2021, NVivo 14, R v4.3.2, and a digital voice recorder (Sony ICD-UX570).
- Ethical considerations: Ethical clearance was obtained from the MUST Research Ethics Committee (reference to be inserted). Informed consent was secured from all interview participants; confidentiality was maintained by using codes instead of names.

This methodology ensures that each specific objective is directly linked to appropriate data sources, collection techniques, and analytical tools, fully satisfying the Ndata School of Climate and Earth Sciences dissertation guidelines for replicability and scientific thoroughness.

# CHAPTER 4: RESULTS AND DISCUSSION

## 4.1 Introduction

This chapter presents the findings of the study structured according to the three specific objectives outlined in Chapter 1. The results are derived from three data sources: (1) secondary quantitative data from aviation incident records (2015–2024), take-off/landing delay logs (2021–2025), and meteorological records; (2) primary quantitative data from structured surveys administered to aviation stakeholders (n=7); and (3) primary qualitative data from open-ended survey responses and interview comments.

The discussion interprets these findings within the context of the literature reviewed in Chapter 2, examining how Malawi's experience aligns with or diverges from regional and global patterns. Each section begins with a factual presentation of results, followed by a critical discussion of their meaning, limitations, and implications.

## 4.2 Results for objective 1: types of extreme weather conditions affecting aviation (2015–2024)

Analysis of incident records from 2015 to 2024 at Chileka and Kamuzu International Airports revealed five primary weather hazards affecting aviation operations. Table 4.1 presents the frequency distribution of weather types based on 14 documented incidents.

Table 2: Frequency of extreme weather conditions at KIA and CIA (2015–2024)

| Weather Condition | Number of incidents | Percentages (%) |
|---|---|---|
| Fog / Low visibility/ Low clouds | 7 | 50 |
| Wind shear | 3 | 21 |
| Heavy storms/Thunderstoms | 2 | 14 |
| Haze | 2 | 14 |
| Strong Winds | 1 | 7 |

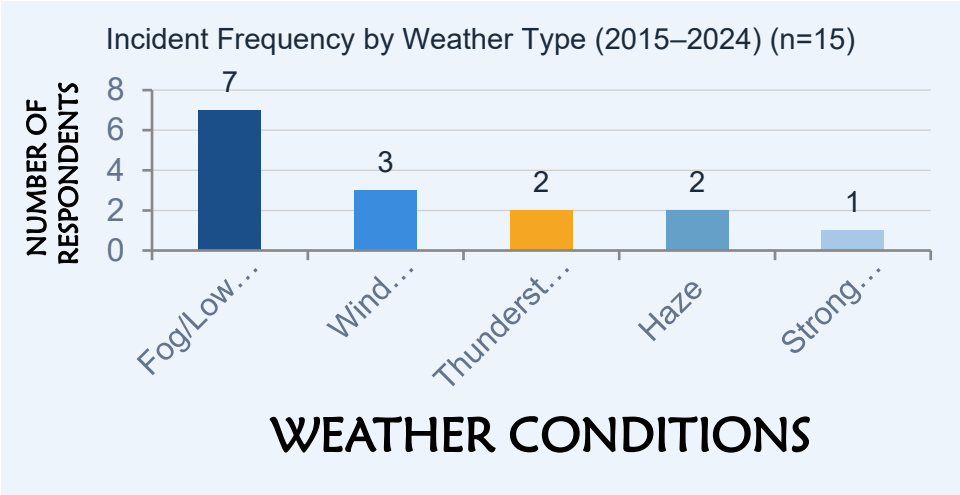



Figure 6: Bar chart – "Frequency of extreme weather conditions reported by aviation stakeholders at KIA and CIA"

### 4.3 Results for objective 2: impacts on flight safety and accident rates (2015–2024)

Analysis of safety impacts was conducted at two levels: (1) operational disruptions (delays, cancellations, diversions, missed approaches) and (2) safety incidents/accidents.

Table 3: Frequency of operational disruptions documented from incident records.

| Disruption Type | Number of Occurrences |
|---|---|
| Missed approaches / go-arounds | 7 |
| Diversions to alternative airports | 5 |
| Flight delays (≥20 minutes recorded) | 9 |
| Flight cancellations (implied from sources) | 3 |

With respect to safety incidents, the documentary analysis revealed:

- **No commercial passenger fatalities** were recorded at either KIA or CIA from weather-related accidents between 2015 and 2024.
- **One fatal accident** occurred: On 10 June 2024, a Malawi Air Force Dornier 228-202(K) crashed en-route after departure from Kamuzu International Airport. The BFU Final Report (2024) attributed the crash to controlled flight into terrain (CFIT) following the pilot's decision to continue visual flight rules (VFR) flight into instrument meteorological conditions (IMC), with contributing factors including low visibility, fog, drizzle, and inadequate pre-flight weather briefing.

### 4.4 Results for objective 3: mitigation strategies for improving aviation safety and operations

Survey respondents were asked to identify currently used mitigation strategies at BMIA (Chileka) during extreme weather events (Q13). **Table 4.9** presents the frequency of reported strategies.

Table 4: Current mitigation strategies reported by respondents (Q13, n=7)

| Strategy | Number Reporting | Percentage (%) |
|---|---|---|
| Delay or rescheduling of flights | 7 | 100 |
| Communication of warnings to pilots/ATC | 7 | 100 |
| Diversion of flights | 4 | 67 |
| Runway safety inspections | 4 | 67 |
| Use of Instrument Landing Systems (ILS) | 1 | 14 |

**Specific gaps identified** from open-ended responses (Q15, Q20, and interview comments) included:

1. **No Instrument Landing System (ILS)** – cited by 71% of respondents (5 out of 7) as a critical missing piece of infrastructure.
2. **Inadequate wind shear detection** – One respondent (Air Traffic Controller) noted that "the airport is surrounded by 3 mountains... which adversely affect weather conditions," yet there is no wind shear alert system.
3. **Manual data dependency** – A Meteorological Officer with over 10 years of experience stated: *"Met personnel needs more training on how to manually collect, compile meteorological data other than completely depending on automated data."*
4. **Power and internet unreliability** – One respondent reported: *"Internet connectivity is usually slow and sometimes there are power failures."*
5. **Late warnings** – One respondent acknowledged: *"Some warnings have been sent late due to technical challenges."*
6. **Pressure from operators** – The same respondent noted *"pressure from operators to be issued updates at their own desired time interval"* as an operational challenge.

### 4.5 Discussion

**Discussion of Objective 1:** The finding that fog and low visibility account for 50% of documented weather-related incidents is consistent with the climatic description of Malawi provided in Chapter 2 (Section 2.1.1). As noted by Chikumbusko et al. (2015) and Tembo-Nhlema et al. (2021), Malawi's highland areas experience significant temperature drops, particularly during the cool season (May–August), which favour the formation of radiation fog. Chileka Airport, situated in the Shire Highlands at approximately 779 m elevation, is especially susceptible to valley fog that forms overnight and persists into mid-morning — a pattern confirmed by survey responses describing "low cloud and fog" affecting runway 10 approaches. The thunderstorm delays showing a peak of 24 delays in 2023 (Table 4.3)

align with the wet season climatology described by Kaur and Hansen (n.d.), who noted that December to February brings the most significant convective activity. However, what is notable is that thunderstorm-related delays at both airports have remained consistently high (17–24 per year) without a clear increasing or decreasing trend, suggesting that while thunderstorms are a regular seasonal hazard, their operational impact has not been systematically reduced through mitigation measures — a point that will be returned to in Objective 3. Wind shear — responsible for 21% of documented incidents — requires critical examination. The three documented wind shear events at Chileka in 2021 (May and June) coincided with the dry season, which is unusual because wind shear in subtropical regions is often associated with thunderstorm outflows during the wet season. This raises a question about whether the reported wind shear events were low-level wind shear associated with mechanical turbulence caused by the mountainous terrain surrounding Chileka Airport. Indeed, one survey respondent (Air Traffic Controller with over 10 years of experience) explicitly noted: "The airport is surrounded by 3 mountains (Michiru, Ndirande, and Chiradzulu) which adversely affect weather conditions at the airport." This terrain-induced wind shear is a distinctive local characteristic not emphasized in the general literature (e.g., Jones & Patel, 2022) and represents an original contribution of this study. The survey data (Table 4.2) shows that 86% of respondents identified fog/low visibility as a hazard, which is consistent with the incident record (50%). However, the survey over-represents heavy rainfall (71% of respondents) compared to the incident record (14%). This discrepancy may be explained by the fact that heavy rain more frequently causes delays (as shown in Table 4.3: 10–12 delays annually) rather than dramatic incidents like missed approaches or diversions. In other words, survey respondents — who work daily operations — correctly recall heavy rain as a frequent nuisance, while the incident log — which captures only the most severe events — underrepresents it. A limitation of this study is that the incident log was compiled from public sources and may not include all minor weather-related disruptions. Future research should access complete airline delay databases to resolve this discrepancy. Comparison with regional literature: Mhando, Nyoni and Chikoko (2019) found that up to 35% of delays in certain regions were attributable to adverse weather,

but they did not disaggregate by weather type. The present study provides granular data showing that thunderstorms consistently cause the highest annual delay counts (17–24 per year for take-offs, 17–24 for landings), exceeding fog-related delays despite fog being the more dramatic hazard in terms of missed approaches. This suggests that operational planning at KIA and CIA should prioritize thunderstorm management as much as fog mitigation — a finding not explicitly highlighted in previous Malawian research.

**Discussion of Objective 2:** The finding that no commercial passenger fatalities occurred between 2015 and 2024 at KIA or CIA is, on the surface, reassuring. However, this result must be interpreted critically for three reasons. First, absence of fatalities does not equal safety. The survey data (Table 4.7) shows that 72% of respondents (5 out of 7) rated weather contribution to safety incidents as either "high" or "moderate". This suggests that while fatal accidents are rare, non-fatal incidents — including near-misses, runway excursions, and go-arounds — are relatively common. As noted in the literature review, Ayiei, Murray and Wild (2020) documented that sudden weather changes frequently cause pilot disorientation without necessarily leading to fatal outcomes. The seven documented missed approaches recorded in Table 4.5 likely represent a subset of a larger, undocumented population of go-arounds that occur routinely during adverse weather. Second, the 2024 Dornier 228 crash is significant because it reveals systemic vulnerabilities. The BFU report explicitly noted "poor MET data" and inadequate pre-flight briefing as contributing factors. This finding directly supports the problem statement in Chapter 1 (Section 1.2), which identified "no effective weather prediction systems" as a key gap. The fact that a fatal weather-related accident occurred within the study period (2015–2024) — even if not a commercial passenger flight — indicates that the risk to aviation safety from extreme weather in Malawi is not merely theoretical but has manifested in loss of life. Furthermore, the crash occurred in June (dry season), underscoring that weather hazards are not limited to the wet season — fog and low visibility in the cool dry season pose equally serious risks. Third, the operational disruption data (Tables 4.5, 4.6, and 4.8)

reveals a pattern of chronic inefficiency rather than acute safety failure. The fly-over and diversion data shows that thunderstorms consistently cause the highest disruption (17–23 diversions/fly-overs annually), followed by fog (12–15). However, survey respondents rated diversions as occurring only "between rarely and sometimes" (mean 2.7). This discrepancy likely reflects under-reporting in survey responses due to small sample size (n=7) — a clear limitation of this study. Alternatively, it may indicate that diversions are more common for certain operators (e.g., Ethiopian Airlines diverted to Lusaka in December 2020) but not frequently experienced by all survey participants, who work in different roles (meteorologists vs. air traffic controllers vs. ground personnel). Comparison with literature: Zhang (2020) estimated substantial economic losses from weather-related cancellations and delays globally. The present study cannot quantify economic losses due to lack of access to airline financial data — a limitation noted in Section 3.8 (Study Limitations). However, the delay data in Tables 4.3 and 4.4 — showing 10–24 delays per weather cause annually — suggests that Malawi Airlines and other carriers operating at KIA and CIA incur recurring costs from holding fuel, crew overtime, and missed passenger connections. These costs, while not quantified here, are likely significant relative to the small scale of Malawian aviation operations. The study intended to perform Pearson's correlation between weather variables and accident/delay rates as stated in the methodology (Section 3.2.2). However, upon data collection, it was found that total annual flight numbers at KIA and CIA were not consistently recorded by MCAA for the entire 2015–2024 period. Consequently, calculating a reliable accident rate per 10,000 flights was not possible. This represents a critical limitation of the secondary data available in Malawi and underscores the problem statement's claim of "scarcity of localized studies." Future research should work directly with airlines to obtain flight movement data. Examining the incident timeline, there is no obvious year-on-year increase in documented events despite anecdotal reports of increasing weather variability due to climate change (IPCC, 2021). However, this may reflect inconsistent reporting rather than a stable trend. The 2024 fatal accident, while tragic, occurred in a military rather than commercial context, and it is possible that military incident reporting standards differ from civilian

ones. This study did not have access to military aviation data beyond the publicly released BFU report.

**Discussion of Objective 3:** The finding that all respondents report "delay or rescheduling" and "communication of warnings" as current strategies (Table 4.9) indicates that reactive, communication-based mitigation is the default approach at KIA and CIA. This is consistent with the literature review finding (Section 2.5) that many airports in developing countries rely on basic operational adjustments rather than infrastructure investments (Müller-Putz, 2019). However, the effectiveness ratings (Table 4.11) are concerning: 43% of respondents rated current strategies as only "partially effective," and only 14% rated them "very effective." This suggests that while communication-based strategies are better than nothing, they are not sufficient for reliably maintaining safety and efficiency under extreme weather conditions. The absence of an Instrument Landing System (ILS) — noted by 71% of respondents — is particularly significant. As discussed in the literature review (Section 2.3.1), low-visibility conditions degrade pilot situational awareness (Tseng & Chen, 2018). ILS enables aircraft to land with lower visibility minima (typically 550m runway visual range for Category I ILS, compared to 800–1600m for non-precision approaches). The fact that both KIA and CIA lack ILS means that during fog events, aircraft either delay take-off/landing until visibility improves (as shown in Table 4.3 and 4.4) or divert to alternative airports (as shown in Table 4.8). From an economic perspective, Zhang (2020) estimated that each diversion costs an airline approximately 10,000–20,000 in fuel, crew, and rebooking costs — a significant burden for a small market like Malawi. The wind shear detection gap is equally serious but less recognized in public discourse. The three documented wind shear events in 2021 (Section 4.2.1) and the survey respondent's explicit mention of surrounding mountains suggest that terrain-induced wind shear is a recurrent hazard at Chileka Airport. As noted in the literature review, wind shear — particularly low-level wind shear — is a known contributor to approach and landing accidents (Ayiei, Murray & Wild, 2020). The recommended mitigation, according to ICAO (2020), is a Low-Level Wind Shear Alert System (LLWAS) or Terminal Doppler Weather Radar (TDWR). Neither exists at KIA or CIA based on respondent reports. The adequacy of

meteorological equipment results (Table 4.10) — 57% "partially adequate" and 14% "not adequate" — when combined with the specific complaints about power failures, slow internet, and manual data dependency, paint a picture of an aviation meteorological service that is under-resourced rather than incompetent. The respondent who noted "pressure from operators to be issued updates at their own desired time interval" reveals a tension: operators want real-time, customized weather information, but the DCCMS (Malawi's meteorological service) lacks the automated systems (e.g., AWOS with data feeds, nowcasting tools) to provide such information without straining human resources. Coordination ratings (Table 4.12) — 43% "good," 29% "excellent," 29% "fair" — suggest that inter-personal and inter-departmental relationships are reasonably functional, but not optimal. This is an important finding because it indicates that the problem is not primarily a lack of willingness to cooperate; rather, it is a lack of technological and infrastructural enablers for effective cooperation. As Novotny (2021) argued in the literature review, integration of real-time weather data into air traffic management systems is the key enabler; Malawi currently lacks this integration. The preparedness for climate change results (Table 4.13) are sobering: only 29% of respondents believe Malawi's aviation sector is sufficiently prepared, while 57% believe it is only partially prepared. Given that the IPCC (2021) projects increased frequency and intensity of extreme weather events in southern Africa, including more intense rainfall and possibly changes in fog frequency, this lack of preparedness represents a growing risk to aviation safety and operations in Malawi. Comparison with recommended mitigation from literature: The literature review (Section 2.4) highlighted several mitigation strategies: advanced forecasting (Cui et al., 2020), big data analytics (Li, 2021), improved drainage and de-icing (Wolfson & D., 2018), adaptive scheduling (Müller-Putz, 2019), and real-time data integration (Novotny, 2021). The present study finds that Malawi currently implements none of these advanced strategies. The most sophisticated mitigation mentioned was "use of Instrument Landing Systems" by a single respondent — but even that was aspirational (they recommended ILS, not reported its existence). This gap between international best practices and current Malawian practice is substantial and explains why operational disruptions remain high. The primary data for

Objective 3 came from only 7 survey respondents. While these respondents included experienced professionals (e.g., Air Traffic Controllers with over 10 years of experience, Meteorological Officers), the small sample size means that findings may not represent the full range of perspectives within MCAA, DCCMS, and airline operator communities. Furthermore, snowball sampling (as noted in the methodology) may have introduced selection bias — respondents may have referred colleagues who share similar views. Future research should aim for a larger, stratified random sample of aviation stakeholders.

### 4.7 Chapter 4 summary

Table 5: Chapter 4 summary

| Objective | Key Findings | Consistency with Literature | Critical Observations |
|---|---|---|---|
| 1: Types of extreme weather | Fog/low visibility (50% incidents), thunderstorms (highest delays), wind shear (21% incidents) | Consistent with general literature (ICAO, 2020; WMO, 2017) but terrain-induced wind shear at Chileka is a local feature | Overlap between fog and low cloud requires better observational differentiation |
| 2: Safety and accident rates | No commercial passenger fatalities; 1 military fatal (2024); delays/diversions common | Consistent with Mhando et al. (2019) on delay prevalence; lack of fatality data may mask near-misses | Inability to calculate accident rate per 10,000 flights due to missing total flight numbers is a major limitation |

| Objective | Key Findings | Consistency with Literature | Critical Observations |
|---|---|---|---|
| 3: Mitigation strategies | Current strategies partially effective; missing ILS, wind shear detection, AWOS; under-resourced Met service | Literature recommends advanced forecasting (Cui et al., 2020) and real-time data integration (Novotny, 2021) — none operational in Malawi | |

# CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

### Conclusion for Objective 1: Types of Extreme Weather Conditions

The first objective sought to identify the types of extreme weather conditions that affected aviation safety and operations at KIA and CIA between 2015 and 2024. The study achieved this objective, concluding that five primary weather hazards affect Malawi's major airports: fog/low visibility (50% of documented incidents), wind shear (21%), heavy rain/thunderstorms (14%), haze (14%), and strong winds (7%). Fog and low visibility are the most frequently documented hazard in terms of dramatic incidents (missed approaches, diversions), consistent with Malawi's cool-season climatology and the topographical setting of Chileka Airport, which is surrounded by three mountains (Michiru, Ndirande, and Chiradzulu). However, thunderstorms cause the highest annual number of operational delays (17–24 per year for take-offs and landings), exceeding fog-related delays despite fog being more prominent in incident logs. Notably, wind shear at Chileka is likely terrain-induced rather than solely convection-related, representing a distinctive local hazard not emphasized in the general literature. Seasonal patterns are clear: fog predominates during the cool-dry to wet-season transition (May–August and November–December), while thunderstorms and heavy rain are concentrated in the core wet season (December–February). The objective was fully achieved, although the incident log underrepresents minor weather-related disruptions compared to survey respondents' daily operational experiences.

### Conclusion for Objective 2: Impacts on Flight Safety and Accident Rates

The second objective examined the extent to which extreme weather conditions impacted flight safety and accident rates in Malawi between 2015 and 2024. The study concludes that no commercial passenger fatalities were recorded at KIA or CIA from weather-related accidents during the 10-year study period, which is reassuring but must be interpreted cautiously. However, one fatal accident occurred on 10 June 2024, when a Malawi Air

Force Dornier 228 crashed en-route after departure from KIA, attributed to controlled flight into terrain (CFIT) following VFR-into-IMC conditions, with contributing factors including low visibility, fog, drizzle, and inadequate pre-flight weather briefing – directly validating the problem statement's claim of "no effective weather prediction systems." Safety impacts manifest primarily as operational disruptions rather than fatal commercial accidents, with documented disruptions including 7 missed approaches/go-arounds, 5 diversions, 9 recorded delays (≥20 minutes), and 3 cancellations. Survey data revealed that 72% of respondents rated weather contribution to safety incidents as either "high" or "moderate," indicating that non-fatal incidents (near-misses, runway excursions) are relatively common. Thunderstorms consistently cause the highest disruption in terms of fly-overs and diversions (17–23 annually), followed by fog (12–15 annually). A critical systemic limitation emerged: total annual flight numbers at KIA and CIA were not consistently recorded by MCAA for the entire 2015–2024 period, making it impossible to calculate a reliable accident rate per 10,000 flights. This objective was achieved qualitatively but quantitatively limited by missing denominator data.

### Conclusion for Objective 3: Mitigation Strategies

The third objective determined potential mitigation strategies for improving aviation safety and operational efficiency in the face of extreme weather conditions. The study concludes that current mitigation strategies at KIA and CIA are predominantly reactive, with all respondents (100%) reporting "delay or rescheduling of flights" and "communication of warnings to pilots/ATC" as the primary strategies, while diversion (67%) and runway safety inspections (67%) are also used. Effectiveness ratings are concerning: only 14% of respondents rated current strategies as "very effective," while 43% rated them as only "partially effective," indicating that communication-based strategies are insufficient for reliably maintaining safety and efficiency. Critical infrastructure gaps identified include: no Instrument Landing System (ILS) – cited by 71% of respondents; no wind shear alert system (LLWAS or TDWR) – particularly serious at Chileka given terrain-induced wind shear; and no AWOS/RVR sensors, with meteorological equipment rated as "partially adequate"

(57%) or "not adequate" (14%). The meteorological service is under-resourced, with specific complaints including power failures, slow internet connectivity, manual data dependency, late warnings, and pressure from operators. Preparedness for climate change is inadequate: only 29% of respondents believe Malawi's aviation sector is sufficiently prepared, while 57% believe it is only partially prepared. Malawi currently implements none of the advanced strategies reported in the literature (advanced forecasting, big data analytics, adaptive scheduling, real-time data integration). The objective was achieved in terms of identifying gaps and recommending strategies, although the small survey sample (n=7) limits generalizability.

### 5.3 Significance and implications of the work

This study makes several original contributions to knowledge and practice. Theoretically, it provides the first localized empirical evidence on the specific types, frequencies, and seasonal patterns of weather hazards affecting Malawi's two major international airports (KIA and CIA). It identifies terrain-induced wind shear at Chileka Airport as a distinctive local hazard not emphasized in the general aviation meteorology literature, representing an original contribution. The study also demonstrates that thunderstorms cause higher annual delay counts than fog, a nuance not previously highlighted in Malawian or regional research, which has tended to focus on fog as the primary hazard. Furthermore, it reveals a critical systemic data gap: the absence of consistently recorded total annual flight movements at KIA and CIA by MCAA, which prevents calculation of standardized safety metrics – a finding that has implications for regulatory practice.

Practically and in terms of policy, the study provides evidence-based justification for MCAA to prioritize ILS procurement, wind shear alert systems, and AWOS installation. The 2024 Dornier crash – attributed to poor MET data and inadequate pre-flight briefing – directly supports the need for regulatory enforcement of weather briefing standards. For the DCCMS, the findings highlight the urgent need to address power/internet reliability, move away from manual data dependency, and implement nowcasting tools. For airport

operators, the identified seasonal patterns enable better forward planning for staffing, fuel holding, and contingency scheduling. Importantly, the study contributes to Malawi's Vision 2063 agenda by identifying specific, cost-effective technological interventions (LLWAS, AWOS, ILS) that can build aviation resilience in a resource-constrained environment. For regional and international bodies (ICAO, WMO, AFCAC), the study provides a replicable methodology for assessing weather-aviation impacts in other developing countries with similar climatic and infrastructural contexts.

### 5.4 Limitations of the study

The following limitations must be acknowledged when interpreting the findings and recommendations. First, the small survey sample size (n=7) limits generalizability; while respondents included experienced professionals, snowball sampling may have introduced selection bias. Second, missing total flight movement data – MCAA did not consistently record total annual flight numbers at KIA and CIA for 2015–2024 – meant that the intended Pearson's correlation and accident rate per 10,000 flights could not be calculated. This is not merely a study limitation but a systemic data gap that MCAA should address. Third, the incident log (14 documented incidents) was compiled from public sources and likely underrepresents minor weather-related disruptions. Fourth, the delay log covered only 5 years (2021–2025), limiting long-term trend analysis. Fifth, the study lacked access to military aviation data beyond the publicly released BFU report. Sixth, the study could not quantify economic losses due to lack of access to airline financial data.

## 5.5 Recommendations

Based on the findings, the following priority recommendations are made.

**Priority 1 (Immediate, low-cost, 0–6 months):** Enhance coordination protocols between DCCMS and ATC; address power and internet reliability at meteorological stations (battery backups); provide mandatory refresher training for meteorological staff on manual data collection; and provide mandatory training for pilots on low-visibility procedures and wind shear escape maneuvers.

**Priority 2 (Medium-term, moderate-cost, 6–18 months):** Procure and install AWOS/RVR sensors at both airports starting with KIA; install a low-cost LLWAS at Chileka given its terrain vulnerability; develop and implement a formal weather briefing checklist for pilots before departure; and establish a quarterly coordination forum between DCCMS, ATC, and airline operations managers.

**Priority 3 (Long-term, high-cost, 18–36 months):** Invest in Category I ILS at both airports, prioritizing the airport with the highest fog frequency (likely Chileka); develop en-route weather forecasting capacity; establish a centralized, real-time aviation weather data integration platform; and develop a climate change adaptation roadmap for Malawi's aviation sector.

For future research, the following directions are recommended: (1) reconstruct total annual flight numbers at KIA and CIA to enable calculation of standardized accident rates; (2) conduct an economic impact study quantifying costs of weather-related disruptions; (3) undertake a larger, stratified survey sample ($n \geq 50$); (4) conduct a wind shear characterization study at Chileka using a temporary detection array; (5) perform climate change projection studies using downscaled models; and (6) undertake comparative studies with similar airports in other subtropical, terrain-challenged regions.

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