An evaluation of flood control mechanisms to withstand and adapt to flooding in Vhembe District, Limpopo Province

By

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DECLARATION

I, **Lily Munzhedzi,** hereby declare that this dissertation submitted to the Department of Geography and Environmental Sciences for the award of Master's in Environmental Sciences at the University of Venda, has not previously been submitted for a degree at this or any other institution. This is my own work in design and execution, and all reference materials contained herein have been duly acknowledged.

Signature: Munzhedzi L.................... Date: 07 February 2024

DEDICATION

To my Mother **Tendani Munzhedzi**

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ABSTRACT

The Vhembe district is currently grappling with a rising prevalence of flooding, a phenomenon attributed to a combination of natural elements, such as heavy rainfall, and human-induced activities like deforestation and inadequate infrastructure management. The resultant damages encompass infrastructure destruction, loss of life, crop and soil damage, and environmental harm, with implications extending to human health, housing, livelihoods, government resources, and significant economic consequences. Consequences vary based on the resources and development levels of different areas, emphasising the need to understand each community's unique aspects for the development of resilient flood control strategies. The aim of this study is to evaluate the flood control mechanisms to determine if they can withstand and adapt to flooding in the selected study areas of Musina, Duthuni, and Sane in the Vhembe District. The study pursues two objectives: investigating trends in extreme rainfall and its relationship to flood occurrences, and characterising the nature, effectiveness, and adaptability of flood control mechanisms in the Vhembe district area. Employing a mixed-methods approach, the research design integrates both quantitative and qualitative methods to gain comprehensive insights. The data collection process involved the administration of in-depth questionnaires to participants, coupled with observational analyses of flood control mechanisms. This multifaceted approach allowed for a qualitative assessment of the nature, effectiveness, and adaptability of these mechanisms. Additionally, daily rainfall data sourced from the NASA POWER website was utilised. This data facilitated the computation of an average seasonal precipitation table, the generation of monthly precipitation figures, and tables displaying the count of days when precipitation exceeded the 95th percentile. The findings reveal a recurring pattern of precipitation throughout the seasons, with the highest average precipitation consistently occurring from December to February, and January emerging as a critical month for flood risk. The analysis of flood events spanning from 2000 to 2020 establishes a connection between daily rainfall exceeding 20 mm and instances of flooding, particularly evident in Duthuni, where nearly annual flooding has been observed. The study identified diverse flood control mechanisms linked to the level of development and community traditions. Natural and traditional measures, such as furrows and vegetation-based flood control mechanisms, dominate the rural village of Sane. In contrast, the urbanised Musina prefers engineered solutions like culverts and concrete channels, while Duthuni integrates both approaches. Furrows are popular at the household level across all the study areas, although their effectiveness is considered to be lower in comparison to other household flood control mechanisms. The field observational analysis emphasises the construction of flood control mechanisms using reinforced materials and underscores the importance of regular maintenance. The study underscores the importance of region-specific flood control solutions tailored to local conditions and preferences, considering climate patterns and community traditions. By adopting this approach, the Vhembe district can enhance its readiness and adaptive capacity for flooding. The study's results provide a foundation for well-informed decision-making and policy development, emphasising the necessity for initiatives to align flood management with the distinct challenges and preferences of local communities.

Keywords: Extreme rainfall, Flood occurrences, Flood control mechanisms, Mixed-methods approach, Observational analyses

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LIST OF ABBREVIATIONS AND ACRONYMS

DRR:	Disaster Risk Reduction
GDP:	Gross Domestic Product
MAE:	Mean Absolute Error
MBE:	Mean Bias Error
NASA:	National Aeronautics and Space Administration
NASA POWER:	National Aeronautics and Space Administration's Prediction of Worldwide Energy Resources
NBS:	Nature-Based Solutions
NDMC:	National Disaster Management Centre
NGO:	Non-governmental Organisation
RDMS:	Rural Disaster Mitigation Service
RMSE:	Root Mean Square Error
SAWS:	South African Weather Service
SALGA:	South African Local Government Association
SPSS:	Statistical Package for the Social Sciences
UNISDR:	The United Nations International Strategy for Disaster Reduction
WMO:	World Meteorology Organisation

CHAPTER 1: Introduction

1.1 Background

Floods are among the most common and devastating natural disasters worldwide, affecting communities and ecosystems across the globe. The prevalence of flood-related challenges has escalated in recent decades, posing significant threats to human lives, property, infrastructure, and the environment (Yang, et al., 2023). Floods are a widespread phenomenon affecting regions on every continent. With climate change and urbanisation, their prevalence has intensified in both frequency and magnitude (Svetlana, et al., 2015). Over the past few decades, the world has witnessed a sharp increase in the occurrence of extreme rainfall events, leading to flooding in many parts of the world (Yang, et al., 2023). South Africa, in particular, has experienced its fair share of flooding incidents, affecting urban and rural areas alike (Dyson & Van Heerden, 2001).

Flood trends have undergone significant shifts, primarily due to changing climate patterns, deforestation, and altered land use (Haghtalab, et al., 2020). Rising sea levels, prolonged droughts followed by heavy rainfall, and the increased severity of storms are all contributing factors to the evolving flood landscape. In addition to climatic influences, urbanisation and improper land management have exacerbated floods (Watanabe, et al., 2018). South Africa, with its unique climatic regions and socio-economic factors, offers a valuable case study for analysing these trends and their impact on local communities.

Floods exact a heavy toll on communities and ecosystems, with consequences ranging from loss of life and displacement of populations to infrastructure damage and economic losses (Yang, et al., 2023). Globally, flood-related disasters have resulted in billions of dollars in damages annually. Moreover, the social and psychological effects on affected communities are often long-lasting. In South Africa, where socio-economic disparities and limited resources can amplify the impact of floods, understanding these devastating consequences is essential for devising effective resilient strategies and flood control mechanisms.

South Africa faces a unique set of challenges in managing flood risks due to its diverse geography, ranging from arid regions to coastal areas. The country's socio-economic disparities further complicate the resilience-building process, making it imperative to tailor flood management strategies to local conditions (Munyai, 2017). South Africa's experiences with floods provide valuable insights into how communities can adapt to changing flood trends and mitigate their devastating impacts (Munyai, et al., 2021).

Extensive flooding is currently occurring in South Africa. For instance, the floods in the Vhembe district during 2010–2011 were a devastating natural disaster that caused widespread destruction and displacement (Musyoki, et al., 2016). These floods were shaped by a range of human factors, including economic, political, and social systems. While heavy rainfall was the immediate cause of the floods, the disaster's severity was amplified by social factors such as poverty, inequality, and inadequate infrastructure (Arnall, et al., 2013). These floods left hundreds of thousands homeless and prevented them from accessing essential services, food, and clean water (Makungo, et al., 2019).

The Limpopo Province is highly susceptible to extreme climate and weather events, which makes it more vulnerable to climate change impacts like flooding. When the 2000 floods hit, most of the northern regions of the Limpopo River Basin were designated disaster areas both during and after the floods (Dube & Nhamo, 2020). Emergency and relief efforts were made; however, they were insufficient because they were poorly coordinated, and the coping and adaptive strategies for flooding that were established were insufficient on their own (Fitchett, et al., 2016).

Floods have been and continue to be one of the most significant natural hazards, causing economic losses and human casualties. They have a direct and indirect influence on a variety of infrastructure components (Diakakis, et al., 2020). Their impacts include, but are not limited to: (i) damage and destruction of buildings, bridges, and roadways; (ii) the introduction of waterborne diseases; (iii) disruptions in the provision of safe drinking water, wastewater treatment, electricity, and services for transportation, communication, education, and health care; (iv) an impact on agricultural production, which may lead to a rise in community food insecurity (Musyoki, et al., 2016).

Floods are not only caused by external forces such as heavy rainfall or river overflow but also by human activities like deforestation, urbanization, and poor land management practices (Cirella & Iyalomhe, 2018). While these natural factors certainly contribute to floods, the severity of the disaster is often exacerbated by human activities. Deforestation, urbanization, and poor infrastructure planning are frequently overlooked or minimized in discussions of flood disasters, leading to ineffective or inadequate responses (Rana, et al., 2020).

Flood disasters are socially constructed phenomena because they are not simply natural occurrences that occur independently of human society (Chmutina & Von Meding, 2019). Instead, they are shaped by how societies are organised as well as the decisions made by individuals and institutions. People's understanding and responses to them are influenced by social, cultural, economic, and political factors (Ward & Shively, 2017). This means that human actions, decisions, and values influence flood impacts and how they are perceived, managed, and mitigated (Bogdan, et al., 2020).

Flood damage can be reduced and avoided through the use of structural and non-structural measures. Structural measures involve the construction of physical structures such as dams and dykes and other flood control mechanisms, which are designed to hold and divert water away from areas that are prone to flooding (Kundzewicz, et al., 2019). These measures can help reduce the impact of floods and prevent damage to infrastructure and property. Non-structural measures include early warning systems and education. Early warning systems are designed to provide people with information about impending floods, giving them enough time to prepare and evacuate if necessary (Kreibich, et al., 2015). Education can also play a critical role in flood prevention by increasing public awareness about the risks of floods and teaching people how to protect themselves and their property.

To reduce the impact of floods, serious attention is needed to adapt, prevent, mitigate, respond, and reduce flood impacts on the socio-economic and physical environment. This involves developing comprehensive flood management plans that take into account the unique characteristics of each community and the potential risks of flooding. It also requires the collaboration of various stakeholders, including government agencies, private sector organisations, and local communities (Manzoor, et al., 2022).

1.1.1 Background summary

Flooding is a multifaceted issue extensively researched across various disciplines. Previous studies highlight both natural causes, such as extreme rainfall and rising sea levels, and human activities like deforestation and urbanization as key contributors to floods (Yang, et al., 2023). The impacts are profound, including direct damage to infrastructure, introduction of waterborne diseases, disruption of essential services, and significant effects on agricultural productivity, leading to food insecurity (Musyoki, et al., 2016). Additionally, floods have long-lasting social and psychological effects on affected populations (Yang, et al., 2023).

Effective flood management requires a combination of structural measures, such as dams and dykes, and non-structural measures, like early warning systems and public education (Kundzewicz, et al., 2019). However, several gaps remain in the literature. There is a need for more localized studies, particularly in regions with unique climatic and socio-economic conditions like South Africa. Furthermore, research often fails to integrate structural and non-structural measures or address the social and psychological dimensions of floods. Most studies also focus on short-term solutions, neglecting sustainable, long-term strategies.

This study aims to address these gaps by developing effective flood management strategies tailored to South Africa. It will enhance community resilience, reduce poverty, and ensure food security by stabilizing agricultural production. Additionally, the study's findings will inform policymakers, guiding the development of comprehensive flood management policies that consider both immediate and long-term solutions. By adopting an integrated approach and focusing on the Vhembe district context, this research will contribute valuable insights applicable to similar regions globally, aiding in the overall effort to manage flood risks and build resilient communities.

The study was conducted in the Vhembe District of Limpopo Province, South Africa, focusing on Sane, Musina, and Duthuni villages, chosen for their varying flood susceptibility and socioeconomic development. The district features diverse topography, including floodplains and mountains, with numerous perennial river (Ramaano, 2022). It covers 2,771 square kilometers at an average altitude of 400 meters, with varied soil and vegetation.

The subtropical climate brings wet summers and dry winters, averaging 24.6°C annually and about 500mm of rainfall. Home to over 1.2 million predominantly rural residents reliant on subsistence farming, the district faces poverty and infrastructure challenges, exacerbating flood impacts (Ofoegbu, et al., 2015). The study sites range from the rural and underdeveloped Sane to the more developed Musina and semi-urban Duthuni, providing a comprehensive understanding of flood impacts on different communities (Sinthumule & Mudau, 2019).

1.2 Problem statement

Climate change has resulted in an increased frequency and severity of floods in South Africa, causing damage to the environment, infrastructure, and property. The Vhembe District is a matter of concern due to its susceptibility and vulnerability to flooding, which has detrimental effects on local communities (Musyoki, et al., 2016). As often occurs during many rainy seasons, significant damage to infrastructure and property occurred during the rainy season of December 2010 and January 2011 due to flooding. The Limpopo Province, in particular, suffered extensive losses, with the provincial government reporting damage to 1,540 houses, private properties, and schools. The Vhembe District Municipality documented 632 houses damaged in 2011 (Vhembe District Disaster Management Centre, 2011). The Vhembe District Municipality lacked a clear understanding of the community's perceptions, experiences, responses to the floods, and the effective and preferred flood control mechanisms in their areas.

Flood control mechanisms are constructed in flood-prone areas to reduce the risk and impact of floods on the surrounding environment and communities. Different mechanisms are employed depending on local conditions and the severity of the flood risk. Despite proactive measures taken by some communities in the Vhembe District to construct and implement flood control mechanisms, there is still a lack of information on the nature and effectiveness of these mechanisms in the study areas. As a result, this research aims to evaluate the flood control mechanisms to determine if they can withstand and adapt to flooding in the selected study areas in the Vhembe District. The ultimate goal is to recommend strategies that can reduce the negative effects of flooding in the Vhembe district municipality.

1.3 Aim, Objectives and Research questions

1.3.1 Research Aim

The aim of this study is to evaluate the flood control mechanisms to determine if they are able to withstand and adapt to flooding in the selected study areas in the Vhembe District.

1.3.2 Specific Objectives

The specific objectives of this study are to:

a. To investigate trends in extreme rainfall and their relationship to flood occurrences.

b. To characterise the nature, effectiveness, and adaptability of flood control mechanisms in the Vhembe district area.

1.3.3 Research Questions

a. Is there a relationship between extreme rainfall events and flood occurrences in Vhembe district?

b. i. Which flood control mechanisms are effective in reducing flooding in Vhembe district?

ii. How effective are the current flood control mechanisms in Vhembe district?

iii. How adaptable are current flood control mechanisms to increased flooding, and what factors influence their adaptability?

1.4 Justification of the study

This study on the nature and effectiveness of flood control mechanisms in the Vhembe district is important not only because floods pose significant risks to human lives, animal habitats, and property, but also because floods are social constructs that require a nuanced understanding of the local context. While flood control mechanisms can help mitigate the effects of floods, they can also create a false sense of security, which may lead to complacency and inadequate preparation for future floods. Additionally, certain flood control mechanisms may disproportionately affect vulnerable communities, further exacerbating existing social inequalities.

Given these complexities, this study evaluated the existing flood control mechanisms in the Vhembe district through a social lens, considering how these mechanisms are viewed by the residents. By engaging with the residents, the study provided valuable insights into the social construction of floods and the effectiveness of current flood control mechanisms and strategies that are more responsive to the needs of the people. The gaps identified in the current mechanisms can help provide opportunities for improving the district's resilience to floods. In addition, the findings of the study can foster evidence-based policies and strategies for flood control and management in the Vhembe district, taking into account the social and economic context as well as the potential impacts on different social groups. By doing so, the study will help to reduce the social and economic costs of flooding in the district, promote sustainable development, and improve the overall well-being of residents.

1.5 Organization of the dissertation

Chapter 1 serves as the introduction, providing essential background information for the thesis. It discusses the concept of flooding, with a specific focus on the Limpopo province. Furthermore, it explores the societal perspective on flood disasters and investigates strategies for mitigating and preventing flood damage. In addition to this, Chapter 1 presents the problem statement and outlines the specific aims and objectives of the research.

Chapter 2 comprises an in-depth literature review, delving into the conceptual framework applied in the study. It serves as a comprehensive exploration of existing research and theories related to the topic.

Chapter 3 focuses on the methodology and provides a detailed description of the study area, including the methods used to collect and analyze the data. This chapter lays the foundation for the empirical work conducted in the subsequent chapters.

Chapters 4 and 5 are the analytical chapters that present and discuss the findings related to the specific objectives. These chapters provide a thorough analysis of the research data, helping to address the research questions and objectives established in Chapter 1.

Chapter 6 offers comprehensive conclusions, discusses limitations encountered during the research process, and provides valuable recommendations for the dissertation. Additionally, Chapter 6 suggests areas warranting further study.

CHAPTER 2: Literature review

2.1 Introduction

Floods, as devastating natural disasters, continue to pose significant challenges worldwide, causing widespread damage to infrastructure, loss of life, and economic disruption. In response, countries around the globe have implemented various flood control mechanisms to mitigate the impact of these events and protect vulnerable communities. This literature review aims to provide a comprehensive analysis of flood control mechanisms implemented in different countries, focusing on Europe, Asia, North America, and Africa. By examining the strategies, approaches, and lessons learned from diverse regions, this review seeks to contribute to our understanding of effective flood management practices in different areas.

2.2 Approaches to the evaluation of flood control mechanisms

There are various ways to approach natural disasters. The primary themes involve acknowledging that hazards can stem from natural causes as well as other factors such as human behaviour and how individuals manage their lives in relation to their geographic surroundings (Chisola, 2012). While floods are a natural occurrence, humans have worsened their frequency. In the past, floods were analysed through the causality approach, which relied on previous impacts to understand them rather than a predictive approach. However, the contemporary approach combines both historical and predictive methods to mitigate and prevent the effects of hazards.

In the field of social sciences, Wisner, et al. (2004) and Chisola (2012) identified three primary approaches to natural hazard theory: the dominant approach, the behavioural approach, and the structural approach. The dominant approach views floods as a natural phenomenon caused by the environment, and thus solutions to hazards require controlling, monitoring, and predicting natural events (Wisner et al., 2004). According to this approach, the natural environment is uncontrollable and constantly changing. However, modern research has criticised this view as new information has been discovered about the nature of floods (Manfreda, et al., 2021). Wisner et al. (2004) suggested that vulnerability is socially constructed, meaning that natural hazards are not solely caused by the environment but also by social factors; therefore, it is essential to consider both the natural and social aspects of natural hazards.

The behavioural approach explains how people respond to natural hazards, focusing more on adaptation than causality. It examines the relationship between humans and their environment and how they react to natural hazards, including their vulnerability, livelihood, use of natural resources, and coping mechanisms (Montz, et al., 2017). The behavioural approach considers the interconnection between humans and their environment, and the resilience produced by their efforts. The socio-economic status of people is also crucial in determining their response to natural hazards (Munyai, 2017).

On the other hand, the structural approach focuses on the institutional structures available to aid vulnerable people in coping with natural hazards. It considers political and economic structures that determine individual adjustment to the environment. The structural approach looks at the interaction between human and environmental systems (Munyai, 2017).

These approaches are relevant in developing flood adaptation measures as well as flood control mechanisms, which require a comprehensive understanding of the vulnerability of the affected population and the socio-economic factors that contribute to their resilience. A combination of all three approaches is crucial in developing flood control mechanisms that are effective in mitigating the impacts of natural hazards. By implementing these approaches, communities can enhance disaster risk reduction efforts and work towards building a more resilient future in the face of natural hazards.

2.3 Disaster Risk Reduction (DRR)

The United Nations International Strategy for Disaster Reduction (UNISDR) defines DRR as ‘the concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events (UNISDR, 2015). The goal of DRR is to build resilience and reduce the impact of disasters by increasing the capacity of individuals, communities, and systems to withstand, adapt to, and recover from the effects of disasters. It is an essential part of sustainable development and is critical to achieving the United Nations' Sustainable Development Goals (Etinay, et al., 2018).

Disaster Risk Reduction (DRR) is an important aspect of managing floods. It involves taking proactive measures to reduce the risk of floods and minimise their impact on people and communities. This includes measures to prevent or mitigate floods, as well as measures to prepare for and respond to floods when they do occur (Ward, et al., 2020). In recent years, there has been an increasing emphasis on the importance of DRR and flood adaptation strategies to reduce the negative impacts of floods (Zimmermann, et al., 2023).

2.3.1 DRR in flood adaptation

One of the central findings of research on DRR in flood adaptation is the importance of a comprehensive and integrated approach to reducing flood risk. For example, a study by (Ciullo, et al., 2017) found that a combination of structural measures, such as dams and levees, and non-structural measures, such as early warning systems and floodplain zoning, can reduce flood risk and increase community resilience. The study also emphasised the importance of involving the community in the development and implementation of DRR strategies.
Another key finding is the need for effective risk communication and awareness-raising among the population. A study by (Gomez-Cunya, et al., 2022) found that flood preparedness and response is strongly influenced by the perceived risk and level of awareness among the population. Effective risk communication and education programmes can improve public preparedness, reduce damage, and increase the effectiveness of DRR measures.

Research also highlights the importance of disaster response planning and preparedness in DRR and flood adaptation. For example, a study by (Monteil, et al., 2022) found that flood preparedness measures, such as the availability of emergency services and evacuation plans, are critical to reducing flood damage and increasing community resilience. The study also found that preparedness measures are more effective when combined with other DRR measures, such as structural and non-structural measures.

In addition, research has emphasised the importance of a long-term perspective in DRR and flood adaptation efforts. A study by (Hemmati, et al., 2020) found that long-term planning and investment in flood protection measures can significantly reduce flood damage and increase resilience. The study also emphasised the importance of adapting to changing flood risks due to factors such as climate change and population growth.

Overall, the literature suggests that DRR is an essential component of effective flood adaptation strategies. An integrated approach, community involvement, effective risk communication, and long-term planning are key to reducing flood risk and increasing resilience to floods. Further research is needed to develop and test effective DRR strategies in different contexts and regions. Moreover, it is important to recognise that investing in DRR not only enhances flood resilience but also contributes to sustainable economic development by reducing the potential for damage and losses caused by floods.

2.3.2 DRR and economic development

Economic development has a significant influence on Disaster Risk Reduction (DRR) as it affects a community's ability to prepare for, respond to, and recover from disasters. It can increase a community's resilience to disasters by providing the necessary resources to fund DRR initiatives (Kusumastuti, et al., 2014). Economic development can lead to the development of sophisticated DRR strategies that can better protect communities from disasters. This can include the development of advanced warning systems, the creation of disaster-resistant infrastructure, and the implementation of effective evacuation plans (Palliyaguru, et al., 2013).

Economic development can also influence the recovery process after a disaster. According to (Tierney & Oliver-Smith, 2012), communities with higher levels of economic development are better able to recover from disasters due to their ability to access resources and their capacity to rebuild infrastructure. Economic development can also provide the necessary resources to fund social safety nets and other recovery programmes that can support affected communities in the aftermath of a disaster (Chhibber & Laajaj, 2013).

DRR strategies have the potential to contribute to long-term development by fostering adaptive capacities and promoting sustainable practices in both developing and developed countries (Ishiwatari, 2022). By engaging local communities in the design and implementation of DRR initiatives, these strategies empower individuals and organisations to actively participate in shaping their own development trajectory (Baudoin, et al., 2016). Participatory approaches, combined with knowledge-sharing and capacity-building activities, enhance community resilience and encourage the adoption of sustainable livelihood practices (Baudoin, et al., 2016).

Furthermore, integrating DRR measures into existing development programmes, such as education, health, and infrastructure, not only strengthens their effectiveness but also minimises the risk of future disaster-induced setbacks. Consequently, DRR strategies that prioritise vulnerability reduction can result in more sustainable development outcomes, promoting economic growth, social well-being, and environmental sustainability (Palliyaguru, et al., 2013). Flood control mechanisms are an essential part of disaster risk reduction (DRR) efforts (Ishiwatari, 2022). They contribute to proactive measures by constructing and maintaining infrastructure like levees and floodwalls and redirecting floodwaters away from vulnerable areas. By integrating flood control mechanisms into DRR, communities enhance resilience, protect lives and property, and promote sustainable development in flood-prone regions (Ishiwatari,2022)

2.4 Mechanisms to control floods

Flood control mechanisms refer to a variety of measures and techniques designed to prevent or reduce the impact of floods on human settlements and infrastructure. These mechanisms can be divided into two categories: structural and non-structural mechanisms (Li, et al., 2016). The implementation of these flood control mechanisms is commonly carried out by local municipalities, non-governmental organisations (NGOs), or the affected individuals themselves (Gautam & Phaiju, 2013).

Structural flood control mechanisms involve the construction of physical infrastructure to reduce the risk of floods (Chan, et al., 2020). Dams, levees, flood walls, and stormwater drainage systems are all examples of structural methods. These engineering interventions are typically designed to increase water storage capacity, enhance floodplain management, prevent overflow and redirecting and containing floodwaters (Matsui, 2022).

Non-structural flood control mechanisms, on the other hand, involve measures that do not rely on physical structures (Chan, et al., 2020). These methods aim to reduce the vulnerability of people and property to flood hazards through land use planning, zoning regulations, and public awareness campaigns. Non-structural methods also include the establishment of early warning systems, emergency response plans, and flood insurance programmes (Sun, et al., 2012).

Other flood control mechanisms include natural or nature-based solutions such as wetlands restoration, shoreline stabilisation, and floodplain management. These solutions rely on restoring or improving natural systems to mitigate the effects of floods, ensuring long-term sustainability and resilience for communities at risk. (Turkelboom, et al., 2021). In addition, these natural or nature-based flood control mechanisms often provide added benefits such as enhanced biodiversity, improved water quality, and recreational opportunities for local communities (Turkelboom, et al., 2021).

2.5 Global overview of flood risk and flood control mechanisms

Floods have had a significant impact worldwide, resulting in severe damages in both developed and developing nations (Tanoue, et al., 2016). When compared to other hazards, floods incur the highest economic losses globally. The World Bank (2007) has also highlighted floods as a major risk that affects the Gross Domestic Product (GDP) of countries worldwide. Floods are highly contextual, which means that their impacts and vulnerability vary depending on the context (Koop, et al., 2018).

Efforts to mitigate and control floods have become a global priority in recent years (Dano, 2020).

Recognising the devastating consequences of floods, nations have implemented various flood control mechanisms to minimise the impacts on human lives, infrastructure, and economies. These mechanisms encompass a range of strategies, including structural and non-structural measures. They also involve ecosystem-based approaches, such as the restoration and preservation of wetlands and floodplains, which have gained attention due to their ability to provide natural flood control by absorbing and storing excess water (Van Wesenbeeck, et al., 2014; Karrasch, et al., 2021).

The specific flood control mechanisms employed differ across regions, adapting to contextual differences, but the shared objective is to establish a comprehensive and integrated approach to flood management (Ishiwatari, 2019). This approach encompasses engineering solutions, community involvement, and environmental considerations as key components to effectively address and mitigate the devastating impacts of floods. This approach, in turn, helps nations protect their communities from future flood events and minimise the destructive consequences associated with flooding.

2.5.1 Flood control mechanisms in Europe

Flood control mechanisms in Europe have a long and evolving history. One of the earliest recorded examples dates back to the devastating storm of 1953 in the Netherlands (Mishra & Rani, 2018). Since then, flood protection infrastructure has been strengthened nationally, and regulations have improved with every flood encounter. The safety of the flood protection mechanisms is routinely evaluated to build on this past experience (Mishra & Rani, 2018).

In the Netherlands, flood control is a matter of utmost importance. Approximately 25% of the country's land lies below sea level, and a vast network of primary flood protection structures has been put in place to protect against storm surges and river discharges (Duan & Gao, 2019). The nation's continued development depends on the creation, management, and upkeep of flood protection infrastructure. Over the years, flood protection mechanisms have been continually improved, with each flood disaster leading to modifications, including increasing river capacity, elevating dikes, and strengthening regulations (Nillesen & Kok, 2015).

Belgium, on the other hand, has adopted two primary flood control mechanisms: the technical solution and the nature-based solution (NBS) (Turkelboom, et al., 2021). The technical approach involves the collection of excess floodwater at peak discharges and its storage in storm basins before gradually releasing it back into the river to prevent downstream flooding. This approach is complemented by a range of infrastructure, including dikes and concrete structures (Turkelboom, et al., 2021). The NBS approach, on the other hand, focuses on the restoration of alluvial floodplain ecology and a more natural flooding regime. This approach is designed to allow the river to overflow its banks and flood the depressions in the floodplain, which serves to restore the natural ecology of the region (Nesshöver, et al., 2017).

In recent years, there has been a growing trend towards nature-based solutions in flood control measures in Europe. The NBS approach provides flood security at a lower cost than technical solutions, with added benefits to ecosystem services and biodiversity (Albert, et al., 2021). However, it is essential to take into account the impacts on the environment and the cost of maintenance and investment when evaluating different flood control options.

Overall, flood control mechanisms in Europe have come a long way, from early attempts to combat flooding to sophisticated systems that incorporate nature-based solutions (Nesshöver, et al., 2017). It is clear that there is no one-size-fits-all solution, and the most effective approach depends on the specific circumstances of each region. However, the adoption of innovative solutions is critical to ensuring the safety and progress of nations in the face of climate change and the increasing threat of flooding.

2.5.2 Flood control mechanisms in Asia

Asia is a region that has long been plagued by devastating floods, causing significant loss of life and property damage (Mirza, 2011). Flood control mechanisms have been developed and implemented to mitigate the negative impact of floods. Throughout history, many civilizations in Asia have developed innovative flood control mechanisms (Kron & Cheng, 2019).

China has a long history of constructing various types and sizes of dikes and dams to prevent flooding. These structures continue to play a vital role in flood prevention today. By the end of 2006, about 280,000 km of dykes had been constructed, providing protection for over 550 million people (Kron & Cheng, 2019). China has also realised the growing importance of non-structural measures alongside conventional structural measures. Significant progress has been achieved in enhancing flood forecasting systems through the integration of mathematical modelling, advanced information technology, telecommunication, and remote sensing (Kundzewicz, et al., 2019).

In the Yangtze River basin in China, dams and other mountainous reservoirs have been used as the primary means to contain flood peaks in less populated mountainous areas, reducing the pressure of flood control in the middle and lower plain areas (Wang, et al., 2020). Currently, in the Yangtze River basin, a combination of engineering and non-engineering approaches is employed for flood management (Kundzewicz, et al., 2019). These include approaches and measures with engineering defence capabilities, environmental recovery capabilities, forecasting and early-warning capabilities, and emergency response capabilities. China's effective implementation of these measures to reduce disaster risks has led to a substantial decline in losses caused by disasters in the Yangtze River (Jia, et al., 2022).

In Bangladesh, since the mid-1960s, there has been a steady increase in flood control and drainage projects, involving the construction of embankments, drainage channels, sluices, and regulators, covering a total area of 5.37 million hectares. However, these structural solutions have been shown to have adverse environmental, hydrological, and economic consequences (Rahman & Salehin, 2013). Therefore, the focus has shifted, and currently, the emphasis is on adopting best management practices at the watershed level. These practices include floodplain zoning, planned urbanisation, the restoration of numerous channels and lakes, river and stream dredging, and the establishment of buffer zones along rivers. These measures are considered effective (Islam, et al., 2016).

Disaster management is a crucial aspect of development for every country. Each country has its own methods to deal with disasters, which have evolved over time in response to historical trends and current challenges (Sylves, 2019). In Malaysia, for example, their methods for dealing with flooding have evolved from canalization of rivers, raising river embankments and multi-purpose dams to include a holistic approach to giving information and assistance before, during, and after disasters (Islam, et al., 2016). These comprehensive strategies demonstrate the importance of continuous adaptation and collaboration to effectively mitigate the impact of disasters and ensure the safety and well-being of communities worldwide.

Lastly, Japan has developed a sophisticated and all-embracing disaster management system in response to being one of the most disaster-prone countries in the world (Islam, et al., 2016). The current emergency response system in Japan has undergone extensive development over an extended duration. This system empowers the nation to swiftly mobilise its forces and resources, effectively addressing major disasters and significantly reducing the extent of damage and loss (Islam, et al., 2016).

After each disaster, new approaches, methods, and design standards were implemented, including improvements to flood frequency analysis methods, changes in economic assessment procedures, and various structural measures such as dams, embankments, erosion and sediment control, sewage systems, as well as high-level embankment and comprehensive flood control (Koike, 2021). As a result, the number of victims and flooded areas decreased dramatically during the period of rapid economic growth in the 1950s and 1960s (Koike, 2021). In the future, Japan will likely continue to prioritise disaster management as an integral aspect of its national economic and social development.

2.5.3 Flood control mechanisms in North America

In North America, floods have caused significant destruction, leading to the loss of lives and property (Hodgkins, et al., 2017). North America has experienced several devastating floods, resulting in the development of various flood control measures. One of the notable floods was the one in Manitoba, Canada which resulted in the construction of diversions, dikes, and floodways (Rannie, 2016).

The government of Canada constructed a massive system of diversions, dikes, and floodways, including the Red River Floodway and the Portage Diversion, to protect the city of Winnipeg from future floods (Blais, et al., 2016). The system kept Winnipeg safe during the 1997 flood, which devastated many communities upriver from Winnipeg, including Grand Forks, North Dakota, and Ste. Agathe, Manitoba (Rannie, 2016). With ongoing improvements and maintenance, this resilient infrastructure continues to safeguard the city and its residents from the threat of flooding, demonstrating Canada's commitment to disaster prevention and preparedness (Rannie, 2016) (Blais, et al., 2016).

In the United States of America, the U.S. Army Corps of Engineers has been the lead flood control agency, with various flood control mechanisms across the country (Rogers, et al., 2015). In 2005, Hurricanes Katrina and Rita exposed flaws in the United States Gulf Coast's severe storm and flood protection plans. Initial criticism focused on the engineering design and management issues (e.g., impact and loss projections, flood protection infrastructure) and the degradation of the region's wetland defences over time by various industries (e.g., energy, transportation) (Gall & Cutter, 2019). Several studies have emphasised the significance of considering human and social factors alongside physical measures when evaluating flood risk (Gheytanchi, et al., 2007) (Wood, et al., 2012). The recommendations included adapting to river expansion caused by rainfall and giving more importance to the human aspect of flood management in the areas. The implementation of these suggestions, which took into account human and social aspects in addition to physical measures, has led to their current effectiveness (Wood, et al., 2012).

Flood modelling and forecasting also play a pivotal role in managing and preparing for extreme flood events in North America (Wu, et al., 2020). With the increasing frequency and intensity of floods, it has become crucial to employ advanced techniques to assess potential risks and develop effective mitigation strategies (Wasko, et al., 2021). By accurately representing the complex dynamics of flood events, these models enable scientists and emergency management authorities to identify vulnerable areas, estimate flood depths and velocities, and anticipate the extent of damage (Wu, et al., 2020).

Furthermore, flood forecasting makes use of real-time data from weather radar, river gauges, and precipitation sensors, as well as historical data and predictive models, to provide timely and accurate warnings of impending floods. This proactive approach allows authorities to issue evacuation orders, deploy resources, and implement emergency response plans, ultimately minimising the loss of life and property (Munawar, et al., 2022). The Federal Emergency Management Agency (FEMA) has also successfully prevented flood impacts by buying out flood-prone properties and converting them into wetlands, which act as a natural defence during storms and save resources during subsequent flooding events (Mach, et al., 2019).

In North America, devastating floods have led to significant damage and loss of life. However, both Canada and the United States have implemented proactive measures to improve flood control. Canada has constructed diversions, dikes, and floodways, protecting cities like Winnipeg, while the United States has learned from past events and emphasised engineering design and wetland defences. Overall, these efforts demonstrate a commitment to comprehensive flood control strategies prioritising community safety and resilience.

2.5.4 Flood control mechanisms in Africa

Historically, flood control in Africa has been characterised by traditional methods that involve the use of indigenous knowledge systems. For example, for decades, Nigeria's coastal communities developed and applied indigenous knowledge in flood control and management (Obi, et al., 2021). The coastal communities' coping strategies include planting early maturing crops, harvesting crops before floods, relocating to higher ground, and building water channels. Others include building local bridges, concrete embankments, and rock embankments to protect shorelines and villages (Fabiyi & Oloukoi, 2013). Looking forward, Obi et al. (2021) suggest that incorporating indigenous knowledge into flood risk reduction efforts in more flood-prone areas of Nigeria could lead to more sustainable and effective solutions.

Kenya experienced severe floods in 1997-1998 that led to severe losses of life (human and livestock) and property, destruction of infrastructure, disruption of communication networks, and large losses to the economy (Huho, et al., 2016). These floods were reported to have caused economic losses of over $151.4 million in public and private property damage (Opere, 2013). In response, Kenya implemented several flood control mechanisms, including the construction of drainage systems, the establishment of flood early warning systems, and the development of flood risk maps. As a result of these measures, Kenya has significantly improved its ability to mitigate the devastating impacts of floods and protect its citizens and infrastructure from future disasters (Ochieng & Otuya, 2018).

In the past, Africa has experienced devastating floods that have caused loss of life and property damage. For instance, in 2000, Mozambique, South Africa, and Zimbabwe experienced severe floods that affected over 1.4 million people; over 600 people were killed, and 200 bridges and 1000 kilometres of road were destroyed (Fauchereau, et al., 2003). In response to these floods, these countries implemented several flood control mechanisms, including the construction of dams, dykes, and levees to protect communities from future floods (Twumasi, et al., 2017).

In the Limpopo Province of South Africa, community adaptation strategies play a crucial role. The implementation of flood disaster response mechanisms varies depending on the severity of the events and the vulnerability of the community and households affected (Musyoki, et al., 2016). To control floods in the Limpopo Province, various methods are employed, including furrows, roadside culverts, and the widely used "Le-guba" approach in the Mopani District municipality (Munyai, 2017). Structural flood control mechanisms are very prevalent in these areas; therefore, looking forward, Musyoki et al. (2016) recommend that non-structural measures be integrated into flood risk management plans to improve their effectiveness. The use of technology such as remote sensing and geographical information systems (GIS) could also enhance flood forecasting and readiness in South Africa (Mawasha & Britz, 2020).

In South Africa, flood control management depends on a range of stakeholders working together. Effective flood management in the region depends on the collaboration of various stakeholders, including government agencies, local communities, NGOs, and research institutions. By fostering multi-stakeholder collaboration, South Africa can strengthen its resilience and response to flood disasters while protecting its communities.

2.6 Environmental impacts of flood control mechanisms

Flood control mechanisms are essential for safeguarding human communities from the destructive consequences of flooding, which can lead to loss of life, property damage, and economic disruption. However, it is crucial to recognise that these mechanisms exert substantial environmental impacts, which can affect ecosystems in complex and interconnected ways. We will explore the intricate relationship between flood control strategies and their impact on natural environments.

One of the primary ways flood control measures affect ecosystems is through the alteration of hydrological systems. Structures like dams, levees, and reservoirs are often deployed to manage and control water flow. Levees, for instance, have been known to restrict the natural course of rivers and canals, thereby disrupting their regular flow patterns (Knox, et al., 2022). Dams and reservoirs are designed to store water, preventing downstream flooding but also altering the natural flow of rivers. These modifications can have profound effects on aquatic and riparian ecosystems, potentially leading to habitat loss and a decrease in biodiversity (Miguez, et al., 2015).

Another notable consequence of flood control mechanisms is the accumulation of sediment.

Dams and reservoirs are effective at trapping sediments that are carried by rivers, preventing them from reaching downstream areas. This sediment capture can result in downstream erosion, negatively impacting riverbeds and estuarine ecosystems (Ran, et al., 2013). Furthermore, the accumulation of sediments can reduce the lifespan and storage capacity of reservoirs, which has implications for water supply and management (Kondolf, et al., 2014).

Flood control measures can also influence water quality. By disrupting the natural flow of nutrients, contaminants, and organic matter, these measures can lead to stagnant water conditions, decreased oxygen levels, and adverse effects on aquatic life (Li, et al., 2019). Additionally, the accumulation of pollutants and nutrients in reservoirs can result in water quality issues that affect both aquatic and terrestrial ecosystems (Bashir, et al., 2020).
Migration patterns of migratory fish and wildlife species can be disrupted by flood control mechanisms, particularly dams. These structures can obstruct the movement of species and disrupt their life cycles, potentially affecting the entire aquatic food web and, by extension, terrestrial ecosystems (Harris, et al., 2016).

Furthermore, flood control mechanisms can disrupt ecosystem services provided by floodplains and wetlands. These services include floodwater storage, which helps reduce the risk of flooding in downstream communities, as well as water purification and support for recreational activities (Hornung, et al., 2019). The alteration or removal of these habitats due to flood control measures can have detrimental effects on these services, impacting both the environment and human communities.

In conclusion, the relationship between flood control strategies and their impacts on ecosystems is intricate and multifaceted. While flood control mechanisms are essential for human safety and infrastructure protection, they must be carefully designed and managed to minimise their adverse effects on the environment. Balancing the need for flood control with the preservation of natural ecosystems is a critical challenge for policymakers and environmental experts.

2.7 Multi-stakeholder collaboration in disaster management in South Africa

In South Africa, disaster management is mostly handled by the National Disaster Management Centre (NDMC). The establishment of the National Disaster Management Centre (NDMC) was authorised by Section 8 of the Disaster Management Act, 2002 (Act No. 57 of 2002) (DMA) (Republic of South Africa, 2005; Munyai, 2017). It was created under the Department of Cooperative Governance and Traditional Affairs. The primary aim of the National Centre is to facilitate an integrated and coordinated disaster management system, with a particular focus on prevention and mitigation, involving national, provincial, and municipal government bodies, statutory authorities, other stakeholders involved in disaster management, and communities

(Republic of South Africa, 2005).

Disaster risk management is recognised in South Africa as a responsibility of the public sector at each level of government (Van Niekerk, 2006). However, it is important to note that in some communities, they take matters into their own hands by constructing their own flood control mechanisms. These resourceful individuals have firsthand experience with the devastating effects of flooding, and their proactive approach reflects their determination to safeguard their homes and communities (Munyai, 2017).

Effective disaster management relies on partnerships among stakeholders and collaborative relationships between different levels of government, the private sector, and civil society. All stakeholders have a role to play in disaster reduction, which goes beyond being solely a line function responsibility (Van Niekerk, 2006). By working together, sharing knowledge, and coordinating resources, these partnerships can enhance preparedness, response, and recovery efforts, leading to more resilient communities in the face of adversity (Botha, et al., 2011).

Several disaster management organisations and programmes have been established in South Africa. The Rural Development and Land Reform Department established a sub-programme called the Rural Disaster Mitigation Service (RDMS) within the Geospatial Services, Technology Development, and Disaster Management Branch. Its primary objective is to decrease disasters in rural areas by ensuring a continuous and integrated system of disaster management (Department of Rural Development and Land Reform, 2013). The RDMS places significant emphasis on disaster prevention, preparedness, and mitigation within rural development and land reform initiatives (Department of Rural Development and Land Reform, 2013; Munyai, 2017). The South African Local Government Association (SALGA) also has a vested interest in the successful implementation of the Disaster Management Act and Policy Framework in South Africa. SALGA's main goal is to provide effective support to local government and assist in ensuring the successful implementation of disaster management measures (Mamabolo & Sebola, 2021).

In conclusion, South Africa has established the National Disaster Management Centre (NDMC) to coordinate and integrate disaster management efforts. The responsibility for disaster risk management is recognised at all levels of government, with a focus on partnerships and collaboration among stakeholders (Republic of South Africa, 2005; Munyai, 2017). While the public sector plays a crucial role, communities have also taken proactive measures to protect themselves. Effective disaster management relies on the collective efforts of the government, private sector, civil society, and communities (Munyai, 2017). Various organisations and programmes, such as the Rural Disaster Mitigation Service (RDMS) and the South African Local Government Association (SALGA), support the implementation of disaster management measures. South Africa's approach emphasises prevention, preparedness, and mitigation to create a safer and more resilient nation (Mamabolo & Sebola, 2021).

2.8 Conceptual Framework

The resilience conceptual framework (Figure 1) is an approach used to understand and address the vulnerability of communities and systems facing various shocks and stressors (Béné, et al., 2015). It provides a lens through which researchers, policymakers, and practitioners can analyse and enhance the ability of individuals, communities, and larger systems to withstand and recover from adverse events (Teo, et al., 2015). At its core, the resilience framework recognises that shocks and stressors, such as natural disasters, are inevitable and can have significant consequences for individuals and communities (Harrison & Williams, 2016). Rather than focusing solely on prevention, the framework emphasises the importance of developing capacities to effectively respond, adapt, and recover when these events do occur (Béné, et al., 2015).

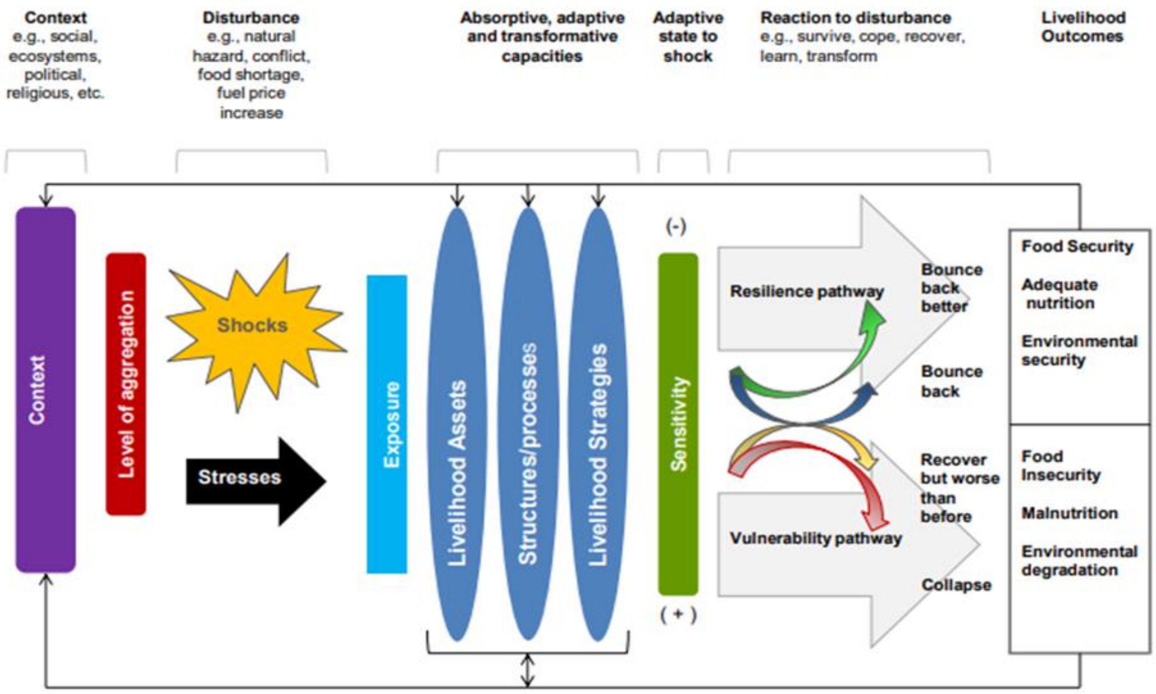


Figure 1: Resilience conceptual framework *(Béné, et al., 2015)*

The framework considers multiple dimensions of resilience, including social, economic, ecological, and institutional aspects (Béné, et al., 2015). It recognises that resilience is a dynamic process that evolves over time rather than a fixed attribute (Berkes & Ross, 2013). Resilience is more than just the ability to return to a pre-event state; it is also the ability to transform and learn from experiences in order to build stronger systems (Béné, et al., 2015). In the context of this study, the resilience conceptual framework focuses on understanding and addressing the vulnerability of communities and systems to floods as a shock and stressor. It is a framework for analysing and enhancing the adaptive capacity of individuals, communities, and larger systems through the construction of flood control mechanisms (Béné, et al., 2014). Recognising that floods are recurring events with significant impacts on individuals and communities is central to this framework. Instead of solely focusing on preventing floods, the framework emphasises the importance of developing capacities to effectively respond, adapt, and recover from floods (Béné, et al., 2015).

Learning from previous flood events is an important part of building resilience (Saravi, et al., 2019). This includes assessing the effectiveness of flood control mechanisms and identifying areas for improvement. Feedback loops enable continuous learning and adaptation, resulting in the development of more effective flood control strategies and measures. If flood control strategies and measures are in place, the affected area will recover better than it did before (Béné, et al., 2015).

Adopting the resilience conceptual framework in the context of floods and flood control mechanisms allows stakeholders to better understand the vulnerabilities and risks associated with floods and develop strategies to improve the adaptive capacity of communities and systems. This includes implementing effective and adaptable flood control measures, improving preparedness and response mechanisms, and cultivating a resilient culture to reduce flood impacts and ensure the long-term well-being of affected communities (Dewa, et al., 2023).

2.9 Insights from literature

This literature review has provided a comprehensive analysis of flood control mechanisms implemented in different countries, shedding light on the diverse strategies, approaches, and lessons learned across the globe. The findings highlight the importance of context-specific solutions and adaptive measures in effectively managing and mitigating the impact of floods.

Throughout the review, it became evident that successful flood control mechanisms require a combination of structural, non-structural, and ecosystem-based measures. The integration of these approaches, tailored to local conditions and needs, is crucial for achieving comprehensive flood management. The review also emphasised the significance of multi-stakeholder collaboration, involving governments, communities, and relevant organisations. Effective flood control requires cooperation between different sectors. For example, in South Africa, the government, the private sector, and civil society come together to tackle these issues collectively. By fostering partnerships and knowledge exchange, countries can benefit from shared experiences and best practices, leading to improved flood resilience.

The primary gaps identified revolve around the limited knowledge regarding the nature and effectiveness of flood control mechanisms in Limpopo province, particularly in the Vhembe District area. The study aims to bridge this knowledge gap by employing a resilience conceptual framework, which will provide valuable insights into the intricacies of flood control. Incorporating the resilience conceptual framework into the study of flood control mechanisms in the Vhembe

District can significantly enhance our understanding of these mechanisms and address the identified gaps in the literature. This research will not only benefit the Vhembe District but also serve as a valuable case study for other regions facing similar challenges in flood control and resilience-building.

CHAPTER 3: Research methodology

3.1 Introduction

This chapter starts with a description of the study and serves as a comprehensive guide to our research approach, encompassing the research design, sampling methods, data collection techniques, and data analysis processes. It outlines the rationale behind each step, from the overarching design choices to the specific methods employed. By the end of this chapter, readers will have a clear understanding of how our research was conducted, laying the groundwork for the subsequent exploration of our findings and their implications.

3.2 Description of the study area

This study was conducted in the Vhembe district, located in the northern part of the Limpopo Province of South Africa. Within this district, three specific study sites were selected based on their susceptibility to persistent floods over the years and variations in socioeconomic development. These sites include Sane village (22.7731° S, 30.1792° E) in the Makhado Municipality, Musina village (22.3813° S, 30.0319° E) in the Musina Municipality, and Duthuni village (22.9722° S, 30.3810° E) in the Thulamela Municipality, as depicted in Figure 2.

The Vhembe District is located in the northeastern corner of South Africa, sharing its borders with Zimbabwe to the north and Mozambique to the east. To the south and west, it adjoins other districts within Limpopo Province (Ramaano, 2022). The district boasts a diverse topography, characterised by low-lying floodplains, hills, and mountainous areas. One of its prominent features is the Soutpansberg Mountains, which run along the southern edge of the district (Stuart, 2018).

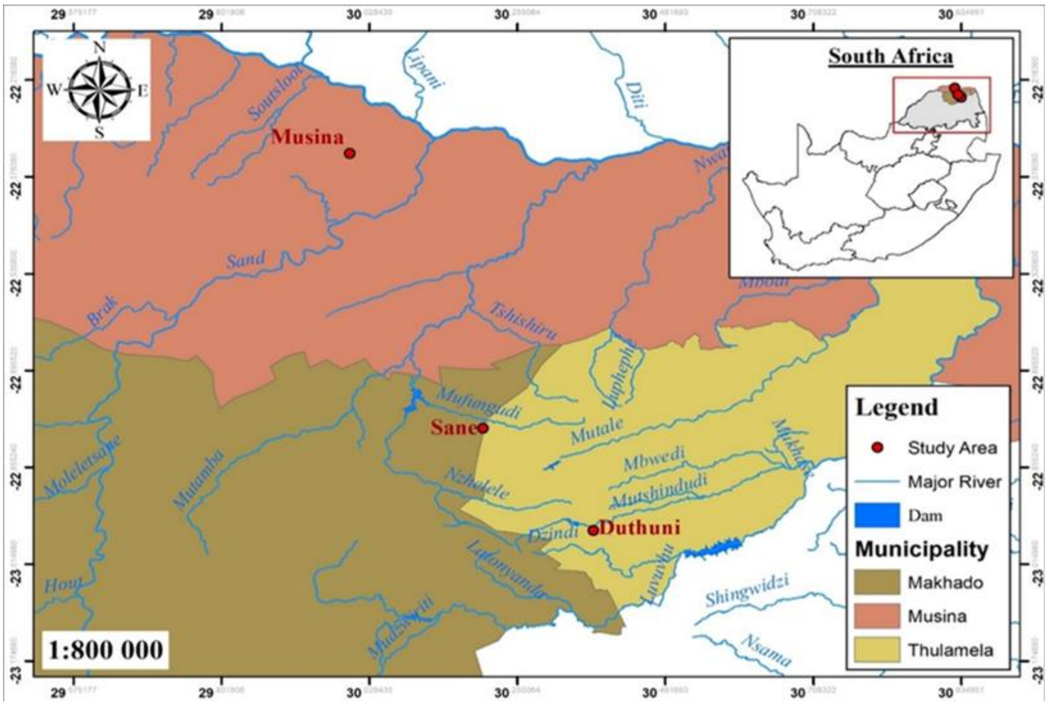


Figure 2: Map showing the 3 study sites in the Vhembe District Municipality

Crisscrossing this terrain are numerous rivers; the rivers in Vhembe District are perennial. Major river catchments in the area include the Limpopo and Luvuvhu rivers. Additionally, there are smaller rivers, such as Sand, Tshishuru, Mufungudi, Luphephe, Mutamba, Dzindi, Nzhelele, Mbwedi, Mudzwiriti, Latonyanda, Shingwidzi, Brak, Mbodi, Soutsloot, Moletsane, Hout, Tshinane, and Mutshindudi. Near the border of Kruger National Park, specifically in the Steep Lanner Gorge, the Mutale River merges with the Luvuvhu River. Subsequently, the Luvuvhu River converges with the Limpopo River near Pafuri, located at Crook's Corner on the border with Mozambique (Traoré, et al., 2016).

The Vhembe District encompasses an area of approximately 2,771 square kilometres and is situated at an average altitude of 400 metres above sea level (Maluta, et al., 2014). The soils in this district exhibit significant variability, with a tendency towards sandy soils in the western areas and a higher proportion of loam and clay content in the eastern parts. These soils primarily originate from basalt and sandstone (Materechera & Scholes, 2021).

The Vhembe District comprises dense deciduous woodlands and evergreen montane forests, characterised by a limited presence of grassy vegetation. Additionally, in other areas, there is a relatively open savannah-type ecosystem (Nenwiini, 2017). The Vhembe District's diverse landscape also includes picturesque wetlands and pristine riverine habitats, creating a haven for a wide range of unique flora and fauna.

This region experiences a subtropical climate with distinct wet and dry seasons. The summer months (November to March) bring heavy rainfall, increasing the likelihood of flooding, especially in low-lying areas and river floodplains. The district receives an annual rainfall of around 500mm, with the majority (87.1%) occurring between October and April (Mufungizi, et al., 2020). Throughout the year, the Vhembe District typically sees an average temperature of approximately 24.6°C, with the lowest monthly average of around 18.9°C in June and the highest monthly average reaching 28.2°C in January (Coetzer & Adeola, 2020).

The Vhembe district is home to more than 1.2 million residents, and approximately 90% of its population resides in rural areas (Ofoegbu, et al., 2015). Many of these communities depend on subsistence farming as their primary source of income. In addition to its substantial rural population, the Vhembe district is known for its rich cultural heritage and diverse landscapes (Makgopa & Frangton, 2016). The Vhembe District Municipality features numerous low-lying areas, including floodplains (Musyoki, et al., 2016). The abundance of these low-lying areas, including floodplains, renders the district susceptible to riverine and flash flooding during periods of heavy rain (Kamal, et al., 2018). This poses a significant risk to communities and infrastructure.

In some parts of the district, inadequate drainage infrastructure exacerbates flood risk. Drainage systems may become overwhelmed during heavy rains, leading to local flooding. Many communities in Vhembe District are economically disadvantaged, and their vulnerability to flood risk is compounded by limited resources and infrastructure (Sinthumule & Mudau, 2019).
Flooding can lead to the loss of homes, crops, and livelihoods. Flooding can also impact the district's rich biodiversity, damaging ecosystems and potentially threatening the survival of certain species (Merz, et al., 2021). Access to basic services such as healthcare, education, and clean water remains a challenge for many communities in the district (Murei, et al., 2022). The impacts of weather and climate-related risks such as floods and droughts often exacerbate poverty and inequality, leading to further socio-economic challenges.

The three study areas exhibit significant variations in their socioeconomic development, with distinct disparities observed in income levels, educational opportunities, and infrastructure development. Sane is a rural village characterized by basic infrastructure, low incomes, and limited access to services. In contrast, Duthuni represents a slightly more developed area with better infrastructure, increased economic activities, and improved access to education and healthcare. Musina, on the other hand, is a town boasting well-developed infrastructure, a plethora of economic opportunities, and higher incomes, thus providing its residents with a higher standard of living (Statistics South Africa, 2022).

These sites were purposively selected to provide a comprehensive understanding of the flood dynamics and their impacts on different communities within the district. Musina is a larger town with a population of approximately 42, 678 people (Statistics South Africa, 2011). It is a major commercial and transportation hub located near the Zimbabwean border. The town's economy is driven by mining and agriculture, and there are also some manufacturing and retail businesses (Ramaano, 2021). Duthuni is a village in the Vhembe district's eastern region. It has a population of approximately 6,345 people (Statistics South Africa, 2011). Although the village has semi-urban areas and events, the vast majority of its residents are involved in subsistence farming and livestock raising (Mhlongo, 2021). Sane is a small village located in the western part of the Vhembe district. It is a rural village characterised by basic infrastructure, low incomes, and limited access to services. It has a population of approximately 447 people (Statistics South Africa, 2011). Sane is largely rural, with most residents engaged in subsistence and livestock farming. Poverty, limited access to basic services, and high unemployment are among the challenges confronting the village.

3.3 Research Design

The study employed a mixed-methods approach, incorporating both quantitative and qualitative methods for data collection and analysis. Both primary and secondary data sources were utilised in this research. Primary data was gathered through a questionnaire survey, while secondary data consisted of rainfall data obtained from NASA POWER (National Aeronautics and Space Administration's Prediction of Worldwide Energy Resources). Using a mixed-methods approach, which combines both quantitative and qualitative research methods, can provide a more comprehensive and robust understanding of complex phenomena like flooding and flood control mechanisms (Haq, 2015). Flooding is a multifaceted issue influenced by a variety of factors, including environmental, social, and infrastructural elements (Jamshed, et al., 2020).

Qualitative data, such as surveys and interviews, can offer significant contextual insights when combined with quantitative data. For example, individuals participating in a survey can expand upon their encounters with flooding and methods for flood control, revealing their unique experiences and viewpoints (Louw, et al., 2019). Using both quantitative and qualitative methods allows researchers to gain a holistic understanding of the problem by examining not only the numerical data but also the underlying context and human experiences (Yilmaz, 2013).
Table 1 provides a summary of the approaches utilised to achieve the specific objectives of the study.

Table 1: Summary of objectives, the data required, data collection and analysis

Objectives	Data collected	Data collection tools	Data analysis and software used
To investigate trends in extreme rainfall and their relationship to flood occurrences	Daily rainfall Flood days	Online Database (NASA POWER database) In-depth questionnaire	Seasonal analysis using Excel. Extreme rainfall analysis using R software. Content analysis using Excel software.
To characterise the nature and effectiveness and adaptability of flood control mechanisms in the Vhembe district area.	Current flood control mechanisms data	In-depth questionnaire Field Observations Digital Camera Document Reviews	Frequency analysis using the IBM SPSS Data integration and visualization tools (Microsoft excel and word) Map construction using ArcGIS software

3.4 Sampling

The research employed purposive sampling, which is a strategic and deliberate approach to selecting research participants that is particularly effective when studying a specific, targeted population (Suri, 2011). This approach was used to select households that had been directly affected by or had previous experience with flood events. Purposive sampling was chosen to ensure that the participants selected possessed firsthand experience and the knowledge necessary to provide valuable insights into the impact of floods and the flood control mechanisms found in the area.

After conducting a reconnaissance survey in the Vhembe district, three areas - Duthuni, Sane, and Musina - were chosen due to their vulnerability to flooding and the recurrent nature of floods in those regions. A total of 90 households, with 30 households in each village, were purposely selected for in-depth interviews. More precisely, adult members of each household were the focus of these interviews.

3.5 Data collection

To achieve the research objectives, a combination of primary and secondary data sources was employed in this study. Primary data was acquired through qualitative, in-depth interviews and thorough field observations. Alongside the collection of primary data, secondary data, specifically rainfall information, was also gathered. The daily rainfall data was sourced from NASA POWER website (Power, 2020). Combining these two sets of data aids in achieving a comprehensive understanding of the research objectives.

3.5.1 Daily rainfall data

Daily rainfall data for the period 1991-2020 was downloaded from NASA's POWER website (National Aeronautics and Space Administration's Prediction of Worldwide Energy Resources) (Power, 2020). NASA POWER offers free access to long-term rainfall and other climate data through a web interface. The precipitation information is provided on a global 0.1° x 0.1° latitude/longitude grid, which translates to approximately a 10km resolution (Huffman, et al., 2014).

The dataset obtained from NASA's POWER website comprises long-term climatologically averaged estimates of precipitation data. These estimates represent the mean daily values and are presented in a time series format (Huffman, et al., 2014). The data consists of satellite and model-based products that have undergone extensive validation and have been demonstrated to provide accurate meteorological resource information (Sparks, 2018).

In many remote or sparsely populated regions, there is a shortage of rain gauge stations. This deficiency in coverage poses challenges when attempting to collect precise rainfall data using traditional rain gauges. This situation was indeed the case in the Duthuni and Sane study areas. Furthermore, even when rain gauges are present nearby, an issue arises regarding their distance from the specific study area. Rainfall can exhibit significant variations over short distances, rendering data from distant rain gauges unreliable for accurately representing the conditions within the study area. Furthermore, there was the issue of discontinuing rain gauge stations in Musina. While new stations were introduced, they were placed in different locations. These alterations lead to data inconsistencies and gaps, posing challenges to maintaining a continuous and dependable dataset for long-term studies. Consequently, satellite data was selected as the solution.

3.5.2 Qualitative in-depth Interviews

A survey questionnaire with a combination of open-ended and closed-ended questions was used to gather insights on flooding and the effectiveness of the flood control measures employed. Prior to conducting the in-depth survey, a preliminary survey was carried out to ensure the relevance and appropriateness of the questions. The questionnaire covered various aspects, including the frequency of flood occurrences, the flood control mechanisms implemented in both the community and households, the effectiveness and adaptability of these flood control mechanisms (as perceived by the respondents), the preparedness of the community and households for flood events, and the coping measures recommended by the respondents. The data collected aligned with the study's stated objectives, which were twofold: first, to investigate trends in extreme rainfall and its relationship with flood occurrences; and second, to characterise the nature, effectiveness, and adaptability of flood control mechanisms in the Vhembe district area.

Prior to proceeding with the survey, participant consent was obtained after a brief introduction to the study. The in-depth questionnaire proved highly effective in data collection due to its capacity to comprehensively gather information regarding attitudes, behaviours, and perceptions related to flooding and flood control mechanisms. This thorough survey instrument enabled a comprehensive exploration of participants' viewpoints, shedding light on critical insights that could inform flood management strategies and policies.

3.5.3 Field Observation

The study primarily focused on structural mechanisms for dealing with floods. These mechanisms were physical constructions designed to control, divert, or manage floodwaters. Structural mechanisms provided immediate and tangible solutions to flood risks, offering protection to vulnerable areas and minimizing the impact of flooding on human settlements and infrastructure. However, the specific flood control mechanisms available in the study area were not yet known. As part of our research, we identified and documented these mechanisms through comprehensive field observations. By examining the existing flood control infrastructure on-site, we aimed to gain a detailed understanding of the types and characteristics of these mechanisms, assess their effectiveness, and determine their suitability for managing local flood risks. This approach ensured that our study was grounded in empirical evidence and tailored to the actual conditions present in the field.

Field observations proved highly advantageous in this study as they provided valuable insights into flood control mechanisms. The study encompassed an examination of the following elements within these mechanisms: composition, structural integrity, erosion and wear, maintenance and repairs, and environmental considerations. Prior to these observations, we comprehensively reviewed pertinent documents. We used a digital camera to capture images of flood control mechanisms. Through direct observation, we examined the intricate workings of flood control mechanisms and assessed their effectiveness. By incorporating field observations, this study not only complemented existing data but also served as a means of cross-verification.

Here's an explanation of each of the components that were examined:

a. Composition:

• Composition Analysis: This involves examining the materials and elements that make up the flood control structure. It assesses the quality, durability, and suitability of the materials used in construction. This analysis helps identify potential weaknesses or vulnerabilities related to the composition of the structure.

b. Structural Integrity:

• Overall Infrastructure Condition: This part of the observation assesses the overall condition and stability of the flood control structure. It examines whether the structure is free from any signs of damage, deterioration, or structural weaknesses that could compromise its effectiveness during flood events.

• Reinforcing Materials: Observing the presence or absence of reinforcing materials is crucial to ensure that the structure has been built to withstand the forces exerted by floodwaters. A lack of reinforcing materials can be a sign of potential structural weaknesses.

c. Erosion and Wear:

• Erosion Levels: This component focuses on monitoring the erosion that may occur due to water flow or environmental factors. Observers check for any signs of erosion, such as the removal of soil or material from the structure's surface, which can weaken the structure over time.

• Wear and Tear: Wear and tear assessment involves identifying physical damage or signs of deterioration that occur over time. This could include cracks, corrosion, or other forms of damage caused by weather conditions, water exposure, or age. Regular inspection helps identify areas that may require maintenance or repairs.

d. Maintenance and Repairs:

• Maintenance: Observational flood control mechanisms involve inspecting the structure for any required maintenance tasks. Routine maintenance activities include cleaning, lubricating moving parts, and addressing minor issues to ensure the structure remains in good working condition.

• Repair Recommendations: If any damage or structural issues are identified during observation, repair recommendations are made. These recommendations provide guidance on how to address and rectify the identified problems to maintain the structural integrity of the flood control mechanism.

e. Environmental Considerations:

• Impact on Local Ecosystems: Observational flood control mechanisms take into account the potential impact of the structure on the local environment and ecosystems. This assessment considers whether the flood control structure has unintended consequences for nearby ecosystems, such as disrupting natural water flow patterns or harming aquatic habitats. It aims to balance flood control needs with environmental preservation.

In contrast to relying solely on data derived from social surveys, field observation provided an alternative method to authenticate the phenomena under investigation (Phillippi & Lauderdale, 2018). The comprehensive nature of field observation allowed for firsthand witnessing of the tangible consequences of flooding, lending credibility to the conclusions. Through direct observation, the intricate workings of flood control mechanisms could be examined, and their effectiveness assessed. By incorporating field observations, this study not only complemented existing data but also served as a means of cross-verification. Through the utilisation of multiple avenues of investigation, a robust foundation for drawing conclusions was established.

3.6 Data Analysis

3.6.1 Rainfall data analysis

Daily rainfall data were collected from NASA's POWER website and subsequently meticulously processed and organised within Microsoft Excel. The analysis was conducted using a multifaceted approach, which included generating various graphical representations. Variations in monthly precipitation figures were created to visualize fluctuations in rainfall patterns over the course of a year. This allows for the identification of any seasonal trends or anomalies. A seasonal rainfall variability table was constructed to provide a broader perspective, highlighting changes in precipitation across different quarters of the year or specific seasons. These representations served as powerful visual tools, aiding in the comprehension of complex rainfall data. Subsequently, the data was subjected to an analysis in R Studio using the R95p extreme rainfall index, which specifically characterises exceptionally wet days (Table 2). This index facilitates the investigation of days with heavy rainfall and rainfall quantities surpassing the 95th percentile.

Table 2: Extreme Rainfall Index

Indices	Name	Indices Calculation	Definition	Unit
R95p	Very wet day	$R95P_j = \sum_{w=1}^{W} RR_{wj}$	Annual total rainfall when RR>95 percentile	mm

3.6.2 Questionnaire data analysis

Descriptive statistics played a pivotal role in the analysis of the questionnaire data. In this particular context, frequencies and percentages were employed. Frequencies assist in identifying the frequency of specific events or values within the dataset, while percentages offer a means to express these frequencies relative to the total sample size. Microsoft Excel 2010 and the Statistical Package for the Social Sciences (SPSS) version 23 were used to facilitate the analyses. Microsoft Excel served as one of the primary tools for data management and basic statistical computations. It is well-suited for tasks involving data organisation and fundamental statistical calculations. Before inputting the data into the SPSS software, it was imperative to code and organise it meticulously. This step ensured that the data was structured in a manner conducive to meaningful analysis.

SPSS was used to generate the frequencies and percentages necessary for a thorough understanding of flood control mechanisms. To effectively convey the findings, a diverse range of visual aids was employed. Tables were used to systematically organise and present the data, facilitating readers' comprehension of key insights. Tables and Figures were employed to visually represent the proportional distribution of various factors related to flood control mechanisms. These representations often convey information more intuitively than raw data alone.

3.6.3 Field Observation analysis

The study conducted a comprehensive analysis of field observation data to gain valuable insights into flood control mechanisms. The examination encompassed various elements, including composition, structural integrity, erosion and wear, maintenance and repairs, and environmental considerations. In the composition analysis, the study scrutinised the materials and elements constituting the flood control structure, assessing their quality, durability, and suitability for construction. Structural integrity observations focused on evaluating the overall condition and stability of the structure, checking for signs of damage, deterioration, or structural weaknesses. Erosion and wear components monitored potential erosion due to water flow or environmental factors, as well as wear and tear, identifying areas requiring maintenance or repairs.

The maintenance and repair aspect involved routine inspections for necessary tasks and provided repair recommendations for any identified issues. Environmental considerations assessed the impact of the structure on local ecosystems, aiming to balance flood control needs with environmental preservation. The study emphasised the authenticity of field observations in validating the phenomena under investigation, offering firsthand insights into the consequences of flooding, and contributing to a robust foundation for drawing conclusions. The incorporation of field observations not only complemented existing data but also served as a means of cross-verification, enhancing the study's credibility.

3.7 Chapter Summary

This chapter provides a comprehensive overview of the research approach adopted for the study on flooding and flood control mechanisms in the Vhembe district area. The chapter begins with an introduction outlining the significance of understanding the research methodology and its role in laying the groundwork for the subsequent exploration of findings and implications. The research design is discussed, emphasising the adoption of a mixed-methods approach that combines both quantitative and qualitative methods. This approach is deemed essential for gaining a holistic understanding of the multifaceted issue of flooding, influenced by environmental, social, and infrastructural elements. The chapter details the specific methods used for data collection, including in-depth questionnaires, field observations, and the use of NASA POWER database for rainfall data.

Purposive sampling is justified as the chosen method for participant selection, with three vulnerable areas identified for in-depth interviews. The chapter delves into the rationale behind using both primary and secondary data sources, explaining the importance of combining qualitative insights with quantitative data to achieve a comprehensive understanding. The methodology for collecting daily rainfall data from NASA POWER website is explained, addressing the challenges faced in the need to use traditional rain gauge station data and the reliability of satellite data for the study areas. The in-depth interviews and field observations are detailed, providing insights into the qualitative aspects of the research.

The subsequent section covers data analysis, outlining the multifaceted approach used for rainfall data analysis, questionnaire data analysis, and field observation analysis. Graphical representations and statistical tools, including R software and SPSS, are employed to analyse and interpret the data, ensuring a thorough exploration of trends and patterns related to extreme rainfall and flood control mechanisms.

Incorporating various elements of field observation, including composition, structural integrity, erosion and wear, maintenance and repairs, and environmental considerations, enhances the credibility of the study. The chapter emphasises the authenticity of field observations in validating the phenomena under investigation and contributing to a robust foundation for drawing conclusions. Overall, this chapter serves as a detailed guide to the research methodology, providing a clear understanding of the chosen approaches and methods. The meticulous planning and execution of the research design and data collection methods lay the groundwork for a comprehensive exploration of the research objectives in the subsequent chapters.

CHAPTER 4: Trends in extreme rainfall and their relationship to flood occurrences in Vhembe District

4.1 Introduction

Understanding the patterns and trends of rainfall is crucial for various reasons. It helps in assessing the frequency and quantity of precipitation in a specific region and examining the correlation between heavy rainfall events and potential flooding. By conducting rainfall trend studies, vulnerabilities can be identified, and people living in these areas can become aware of the evolving rainfall patterns they might face (Munyai, et al., 2021). This chapter presents a comprehensive analysis and interpretation of the rainfall indices as well as part of the survey findings.

4.2 Rainfall variability in Vhembe district

This section presents the findings related to rainfall variability in the study areas within the Vhembe District. The results of seasonal variability are meticulously presented in tabular form, offering a comprehensive analysis of the changes in rainfall throughout the seasons. Monthly variability is visually depicted in figures, providing a clear representation of the fluctuations. These figures encapsulate information spanning a 30-year period, from January 1991 to December 2020.

4.2.1 Seasonal rainfall variability.

Table 3: Average seasonal precipitation for Duthuni, Musina and Sane (1991-2020).

Location	DJF	MAM	JJA	SON
Duthuni	336.35	114.85	25.03	131.43
Musina	281.25	87.16	33.54	114.41
Sane	332.03	119.44	24.30	137.16

Table 3 displays average seasonal precipitation data for the regions of Duthuni, Musina, and Sane from 1991 to 2020. The focus of this analysis is on the three-month seasons: December, January, and February (DJF); March, April, and May (MAM); June, July, and August (JJA); and September, October, and December (SON).

The months of December, January, and February (DJF) consistently exhibit the highest average seasonal precipitation across all three areas. In DJF, Duthuni experiences the highest average seasonal precipitation at 336.35 mm, followed by Sane with 332.03 mm and Musina with 281.25 mm. These values indicate that DJF is the wettest season in all three regions during this period.
The high levels of precipitation in DJF are significant in the context of flooding. The consistent pattern of heavy rainfall during DJF suggests that these months are prone to an increased risk of flooding in these regions. With Duthuni, in particular, experiencing the highest average precipitation

during this season, it is likely to be the most vulnerable to flooding during DJF.

4.2.2 Monthly rainfall variability

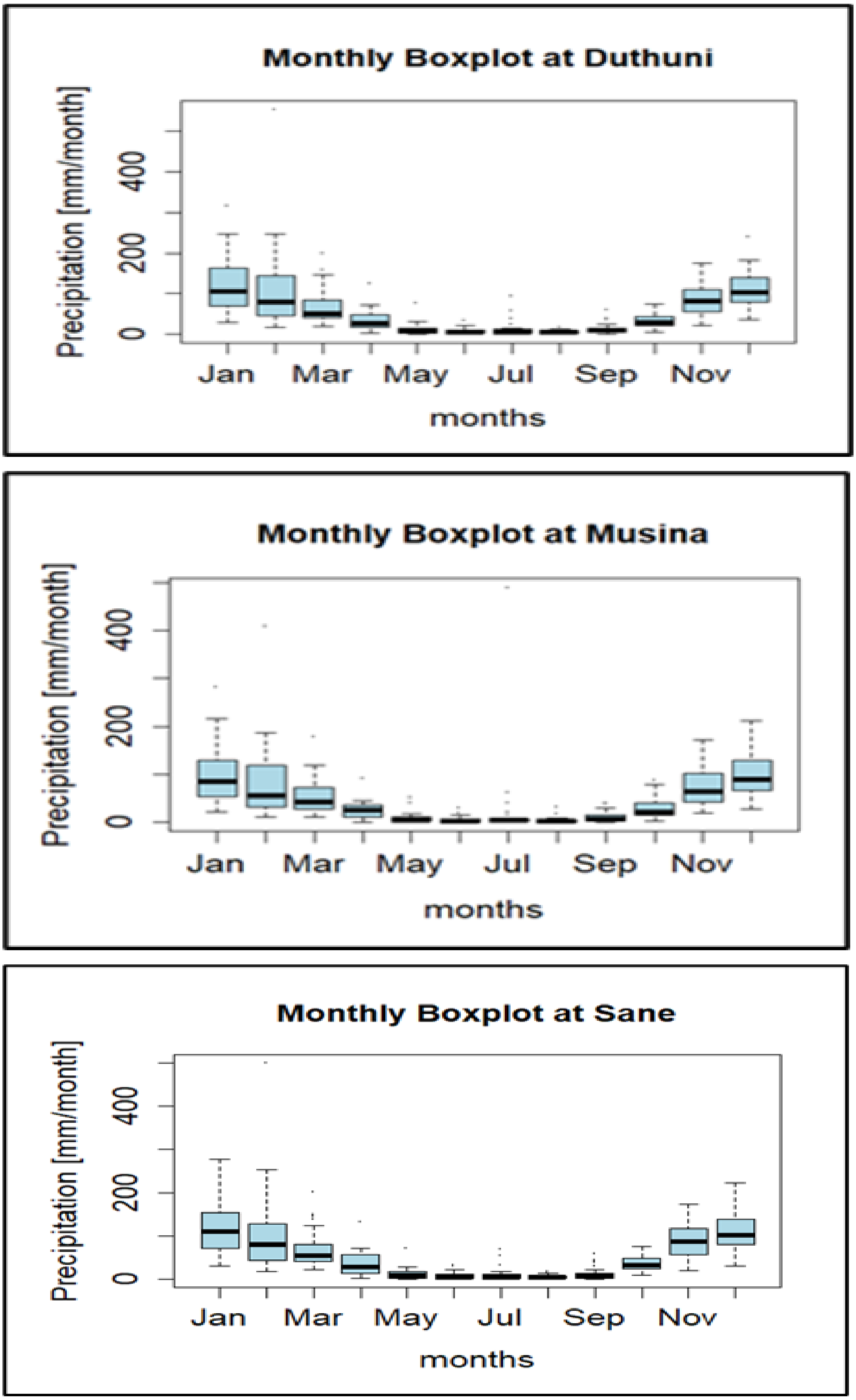


Figure 3: Variation in monthly precipitation for Duthuni (top panel), Musina (middle panel), and Sane

(bottom panel) for the period 1-Jan-1991 – 31-Dec-2020

The figures provide an overview of monthly rainfall patterns over a 30-year period, from January 1991 to December 2020. Each boxplot in the figure represents all the rainfall data for the months during these years. The height of each boxplot indicates the degree of variability in rainfall for that particular month.

The figures clearly demonstrate that significant rainfall occurs across all three study areas during the months of November through February. These months are characterised by higher median values. For November, the median rainfall in Duthuni, Musina, and Sane respectively, was 86.88, 64.69, and 86.90. In December, the corresponding values were 101.46, 89.28, and 101.52. January saw median rainfall amounts of 110.255, 84.09, and 110.26 for these areas, while February recorded values of 80.94, 56.15, and 80.98. These higher medians indicate a substantial amount of rainfall during these periods, as reflected in the wider interquartile ranges in their respective boxplots.

When focusing on rainfall variability, it becomes evident that January stands out as the most variable month in all the study areas. This is indicated by the height of the January boxplot, which extends over a wide range, suggesting significant year-to-year variation in January rainfall. This variability in January rainfall could have implications for flooding. The wettest months across all three study areas, where flooding is most likely to occur due to high rainfall, are January and December. These months consistently show the highest median rainfall values and the widest interquartile ranges in their respective boxplots. February and November also exhibit significant rainfall, although they are slightly less variable compared to January and December.

4.2.3 Significantly wet days (R95p)

Table 4: Significantly Wet Days and 95th Percentile Precipitation at Duthuni, Musina, and Sane (1991-2020)

Location	**Significantly Wet Days (R95p) [days] 1991-2020**	**95th Percentile Precipitation [mm] (1991-2020)**
Duthuni	**170**	**19.04**
Musina	**128**	**17.56**
Sane	**156**	**17.58**

Table 4 presents data on significantly wet days and 95th percentile precipitation levels at Duthuni, Musina, and Sane from 1991 to 2020. During this period, Duthuni experienced 170 days with precipitation levels exceeding the 95th percentile. In other words, Duthuni recorded 170 days of rainfall that surpassed 95% of all storm events during the 30-year span. Similarly, Musina had 128 days where the precipitation surpassed the 95th percentile. This indicates that Musina received a greater amount of rainfall compared to 95% of all storms that were recorded between 1991 and 2022. Likewise, Sane had 156 days during the same period, with precipitation levels surpassing the 95th percentile. These 156 days signify occasions when Sane received more rainfall than what was observed in 95% of all storm events between 1991 and 2022.

4.3 Flood days variability

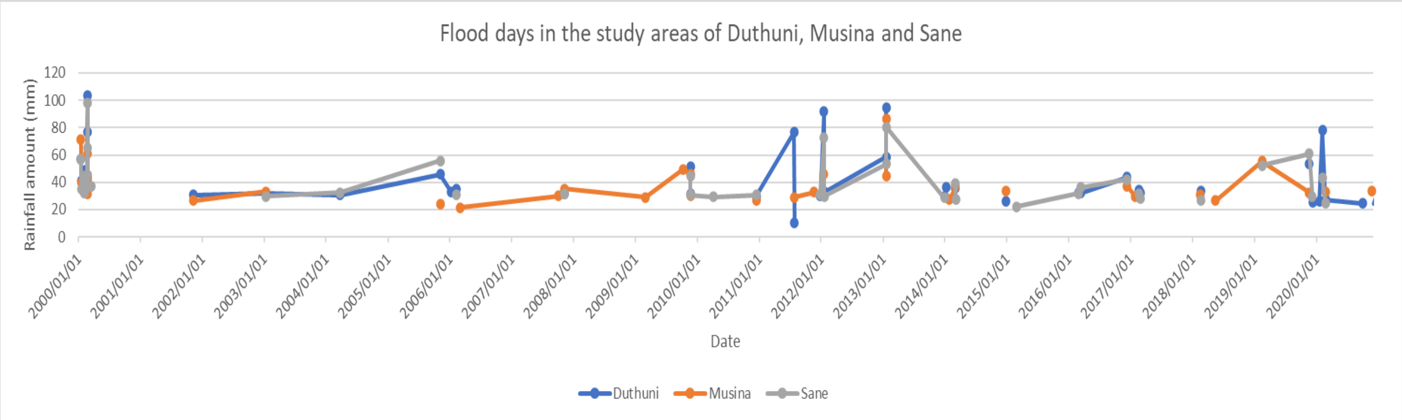


Figure 4: Variability in Annual Flood Days and Corresponding Rainfall Amounts in Duthuni, Musina, and Sane (2000-2020)

Figure 4 shows the variability in annual flood days and the corresponding rainfall amounts in Duthuni, Musina, and Sane from 2000 to 2020. In Duthuni, annual flooding was a common occurrence, happening nearly every year except for 2002, 2008, and 2015. Conversely, Musina experienced flooding only in the years 2002, 2004, 2008, and 2015. On the other hand, Sane remained flood-free in 2001, 2002, and 2008. All three areas witnessed flooding every other year from 2000 to 2020.

Between 2000 and 2010, there were 19 instances of flooding in Duthuni, 19 flood events in Musina, and 19 occurrences of floods in Sane. In the subsequent decade, from 2011 to 2020, Duthuni experienced 25 floods, Musina had 17, and Sane had 21. Consequently, the period from 2011 to 2020 saw the highest number of flood events. Most of the reported floods corresponded to rainfall amounts exceeding 20 mm per day. This implies that flooding occurs when daily rainfall amounts surpass 20 mm.

4.4 Discussion

Table 3 showcases the average seasonal precipitation data for the regions of Duthuni, Musina, and Sane from 1991 to 2020, and draws attention to several noteworthy patterns and implications. Notably, the analysis focuses on the three-month seasons: December, January, and February

(DJF); March, April, and May (MAM); June, July, and August (JJA); and September, October, and December (SON). First and foremost, the data underscores the presence of distinct seasonal precipitation patterns in these regions. Consistently, the months of DJF stand out as the period with the highest average seasonal precipitation across all three areas. In this regard, Duthuni, Sane, and Musina all experience the most substantial rainfall during DJF, marking it as the wettest season in these locales. This seasonality is a pivotal aspect of the local climate and holds significant implications for various aspects of life in these areas (Feng, et al., 2013).

The data also sheds light on a potential concern, which is the heightened risk of flooding during the DJF season. The recurrent pattern of heavy rainfall during this season indicates that these months are particularly susceptible to flooding in these regions. This vulnerability arises from a combination of factors, including topographical features, soil composition, land usage, and the state of existing infrastructure in these study areas (Mohamed & El-Raey, 2020). As such, it becomes imperative for local authorities and communities to acknowledge this vulnerability and take appropriate measures to prepare for and mitigate the risks associated with flooding.

The insights provided by Figure 3, the Monthly Rainfall Variability figures, are invaluable for understanding the rainfall patterns in the three research regions: Duthuni, Musina, and Sane. These figures offers a detailed analysis of which months yield specific amounts of rainfall, giving us a comprehensive view of the data for all months. These findings have implications not only for understanding local weather but also for various aspects of community planning, agriculture, and flood risk management (Islam & Ghosh, 2022).

The data demonstrates a clear pattern, with the months of November through February characterised by significant rainfall across all three study areas. During this period, the maximum and median values for rainfall notably surpass those of other months, indicating a substantial amount of precipitation received. This observation is reinforced by the wider interquartile ranges and the maximum rainfall seen in the boxplots, signifying greater variability and a broader distribution of data points. One key takeaway from this data is the pronounced variability in January's rainfall, which stands out as the most variable month in all the study areas. Such variability in January rainfall has noteworthy implications, particularly in terms of flood risk assessment and preparedness (Kilavi, et al., 2018).

Given the high variability observed in January, it's plausible to suggest that this month can potentially trigger flooding events. Flooding risks are a significant concern for these regions, and understanding the most variable months is pivotal for disaster preparedness and response (Leonard, et al., 2014). Furthermore, the consistent high rainfall values in January and December underscore the necessity for flood risk management measures during these months. While January and December are the wettest and most variable months, it's crucial to recognise that February and

November also experience substantial rainfall. However, they exhibit slightly less variability when compared to January and December. This suggests that, although they may not be as variable as January, they still warrant attention in terms of flood risk mitigation.

This study also examined the significantly wet days, which are the number of days with precipitation exceeding the 95th percentile and the 95th percentile of precipitation for all the wet days. During the period from 1991 to 2020, the three study areas - Duthuni, Musina, and Sane - experienced varying levels of extreme precipitation. Duthuni had 170 days with precipitation levels surpassing the 95th percentile, signifying an exceptionally high frequency of intense rainfall. Similarly, Musina recorded 128 such days, indicating a substantial occurrence of extreme precipitation events. Sane, with 156 days exceeding the 95th percentile, falls within this range as well.

The 95th percentile is a critical threshold, serving as a marker for extreme weather events in this context. It represents a point at which observed precipitation surpasses what was typically seen in 95% of all storm events recorded between 1991 and 2020. Understanding the significance of this metric is essential for assessing the impact and implications of these extreme precipitation occurrences. The data raises questions about the potential causes of these extreme events. Climate change, with its potential to increase atmospheric moisture content and result in more intense rainfall, is a likely contributing factor (Saidi, et al., 2015). Investigating local climate change trends and their connection to the increased frequency of extreme precipitation events in these regions is beneficial.

The data pertaining to the occurrences of flooding in the study areas of Duthuni, Musina, and Sane were also investigated for the period spanning from 2000 to 2020. Duthuni had nearly annual flooding, except for the years 2002, 2008, and 2015. In the initial decade, from 2000 to 2010, 19 instances of flooding were experienced, and this number rose to 25 in the subsequent decade (2011-2020). In summary, Duthuni encountered a total of 44 flood events throughout the 2000-2020 period.

Conversely, Musina had flooding every year except for 2002, 2004, 2008, and 2015. Both Duthuni and Musina had 19 flood events from 2000 to 2010, but Musina saw a decrease to 17 flood events in the following decade. As a result, the overall number of floods experienced in Musina was 36. Sane's flooding pattern differed, as it remained without floods in 2001, 2002, and 2008 but experienced flooding in all other years within the two-decade timeframe. Like Duthuni and Musina, Sane had 19 flood events in the 2000-2010 period, and this increased to 21 in the subsequent decade. Consequently, the total number of flooding events in Sane amounted to 40.

The data also suggests a connection between daily rainfall amounts and flooding events, with most floods occurring when daily rainfall exceeded 20 mm per day. This finding implies that a daily rainfall threshold of 20 mm can serve as an indicator for potential flooding. However, it's important to acknowledge that other factors, such as topography, drainage systems, and land use, can also influence the relationship between rainfall and flooding. Understanding the relationship between heavy rainfall and flooding is crucial for both disaster preparedness and long-term climate resilience. This knowledge not only helps us anticipate and respond to immediate flood risks but also informs our efforts to mitigate the impact of climate change, as extreme rainfall events are expected to become more frequent in the future (Oubennaceur, et al., 2022).

Comprehending the seasons of frequent heavy rain, the months with high rainfall rates, the days marked by extreme precipitation, as well as those when floods have occurred, along with understanding the interplay between heavy rainfall, flooding, and various local factors, is vital for disaster preparedness, community planning, and long-term climate resilience. This knowledge not only enables better anticipation and response to immediate flood risks but also informs strategies for mitigating the impact of climate change, projected to result in more frequent extreme rainfall events. This will also support effective adaptation and mitigation measures.

4.5 Chapter Summary

In conclusion, Chapter 4 delves into a comprehensive analysis of trends in extreme rainfall and their correlation with flood occurrences in the Vhembe District. The chapter begins by emphasising the importance of understanding rainfall patterns for assessing precipitation frequency, identifying vulnerabilities, and raising awareness among the local population. The focus is on the 30-year period from 1991 to 2020.

The examination of rainfall variability in the Vhembe District reveals distinct seasonal patterns, with December, January, and February consistently exhibiting the highest average precipitation across all areas. The data highlights DJF as the wettest season, emphasising the vulnerability of these regions to flooding during this period. This vulnerability is particularly pronounced in Duthuni, which consistently experiences the highest average precipitation during DJF.

The monthly rainfall variability analysis underscores the significance of the months from November to February, characterised by higher median values and substantial precipitation. January stands out as the most variable month, with implications for flood risk assessment and preparedness. The study also explores significantly wet days, indicating the frequency of extreme precipitation events exceeding the 95th percentile and providing insights into the potential impact of climate change on rainfall patterns.

The investigation into flood occurrences in Duthuni, Musina, and Sane between 2000 and 2020 reveals annual flooding, with fluctuations in the number of events over the two decades. The data suggests a connection between daily rainfall amounts exceeding 20 mm and flooding events, emphasising the importance of understanding this relationship for disaster preparedness and long-term climate resilience.

The conclusion highlights the need for local authorities and communities to acknowledge and address the heightened flood risk during the DJF season. The study's findings provide valuable insights for disaster preparedness, community planning, and climate resilience. Understanding the interplay between heavy rainfall, flooding, and local factors is crucial for effective adaptation and mitigation measures, particularly in the context of anticipated increases in extreme rainfall events due to climate change.

CHAPTER 5: Nature, effectiveness, and adaptability of flood control mechanisms in Vhembe district

5.1 Introduction

Floods are natural disasters that can cause extensive damage to both human life and property (Taib, et al., 2016). In response to the frequent occurrence of floods in Duthuni, Musina, and Sane, various flood control mechanisms have been implemented at both the community and household levels. This chapter presents and discusses the findings pertaining to the nature and effectiveness of these flood control measures, drawing from both study observations and the perspectives of the residents in these areas. The primary focus of this chapter is to analyse the effectiveness of currently implemented flood control mechanisms. The analyses of flood control mechanisms were divided into two categories: community-level and household-level.

The chapter is organised as follows: first, an assessment of the variation in socioeconomic development among the three study areas by presenting various development indicators. Thereafter, an overview of the flood control mechanisms in Duthuni, Musina, and Sane is provided. Then, an analysis of the effectiveness of flood control mechanisms based on the perceptions of the people living in these areas follows. Afterwards, an analysis of the adaptability of these mechanisms based on the perceptions of the respondents is presented. Preferred flood control measures that the respondents feel could be useful in their areas are also discussed. Finally, the chapter concludes by discussing the implications of the findings and offering recommendations for future flood control efforts.

5.2 Community and household level flood control mechanisms

5.2.1 Nature of flood control mechanisms

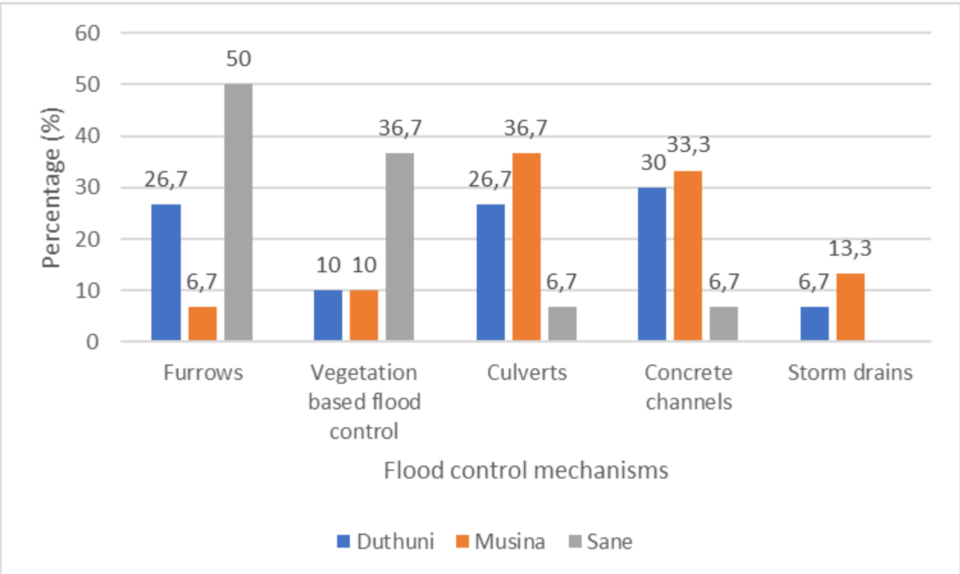


Figure 5:Flood control mechanisms at community level in Duthuni, Musina and Sane.

Figure 5 presents the flood control mechanisms in Sane, Musina, and Duthuni. Five types of flood control mechanisms were reported and observed at the three study sites. These were furrows, vegetation on flood paths, culverts, concrete channels, and storm drains. In Sane, furrows (50%) and vegetation on flood paths (36,7%) were the most commonly used flood control mechanisms, while culverts (6,7%) and concrete channels (6,7%) were used less frequently. In Musina, culverts (36,7%) were the most commonly used mechanism for flood control, followed by concrete channels (33,3%), storm drains (13,3%), and vegetation on flood paths (10%). Furrows (6,7%) were the least used mechanism in this area. In Duthuni, concrete channels (30%) were the most used flood control mechanism, followed by culverts (26,7%) and furrows (26,7%). Vegetation on flood paths (10%) and storm drains (6,7%) were the least used mechanisms in this study area.

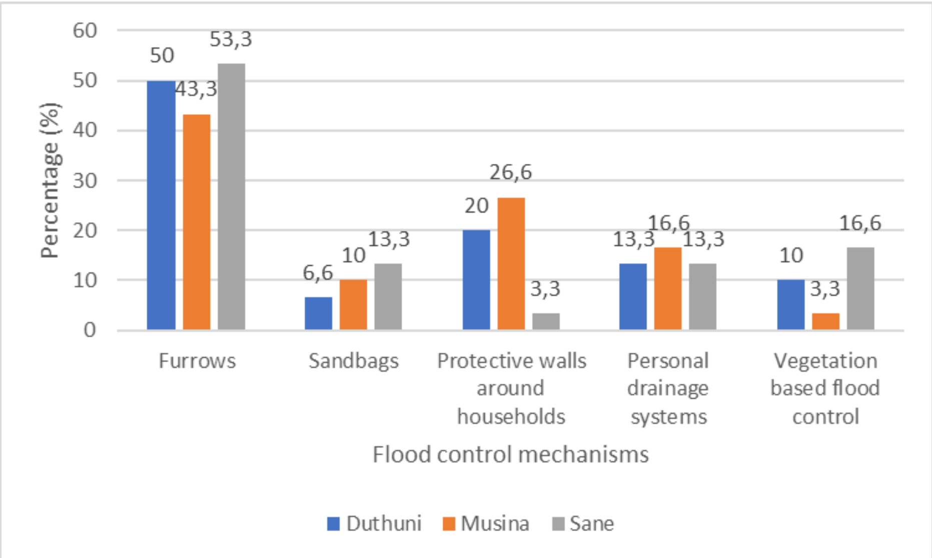
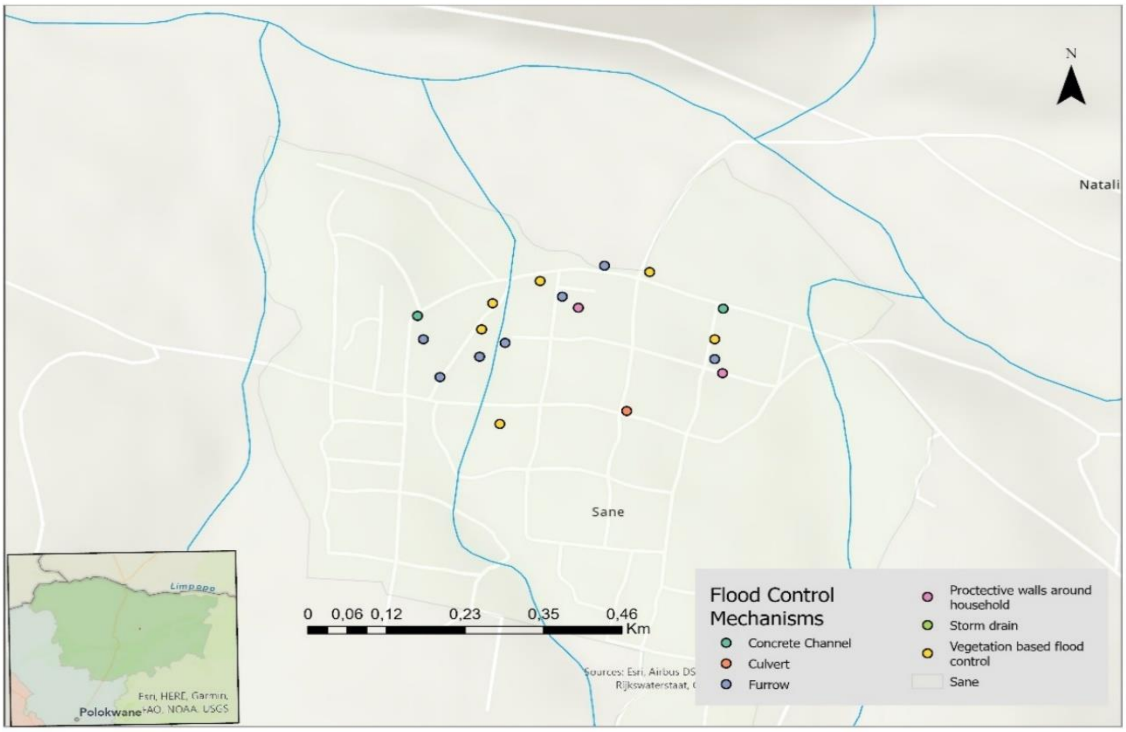
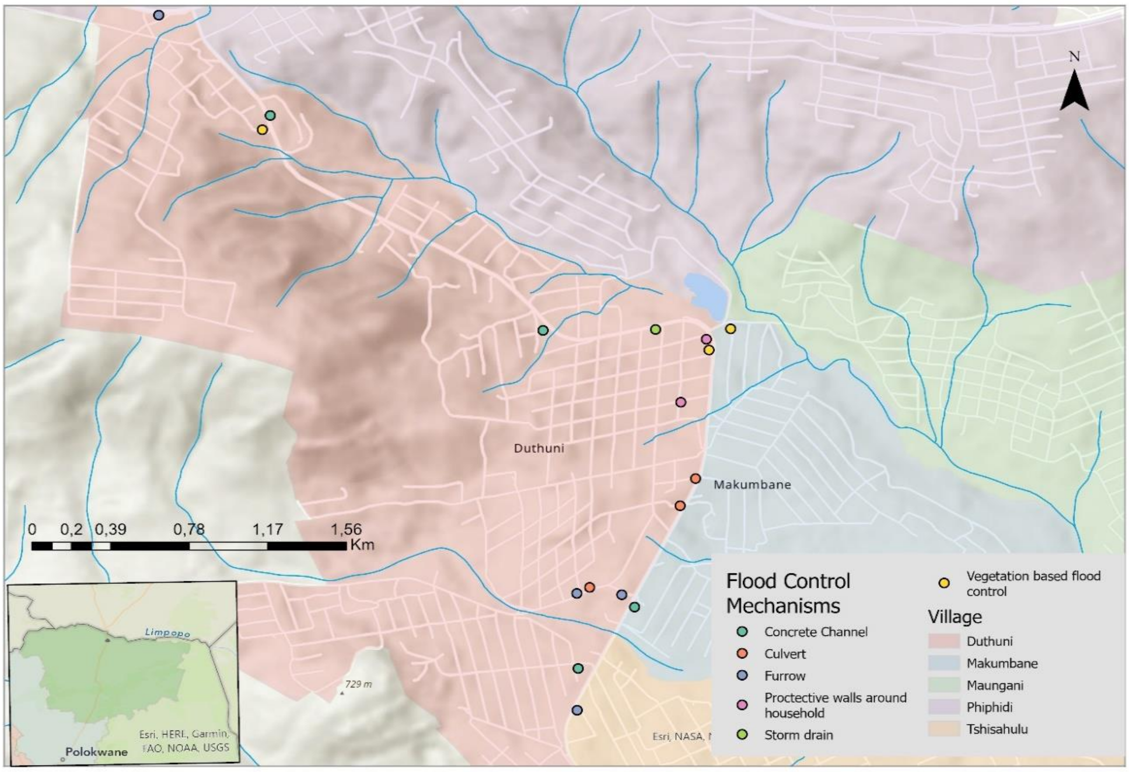


Figure 6: Flood control mechanisms at household level in Duthuni, Musina and Sane

Figure 6 presents the flood control mechanisms reported at the household level in the study areas. Five types of flood control mechanisms were reported and observed in the three study sites at the household level. These were furrows, vegetation-based flood control, sandbags, protective walls around households, and personal drainage systems. In Duthuni, the most popular flood control mechanism is furrows (50%). Protective walls around households were the second most commonly used mechanism (20%), followed by personal drainage systems at 13,3%. Sandbags and vegetation on flood paths were the least used mechanisms, at 10% and 6,6% respectively. In Musina, furrows were also the most popular mechanism, but they were used by a slightly smaller percentage (43,3%). Protective walls around households and personal drainage systems were used by 26,6% and 16,6% of households, respectively. Sandbags were reported by 10% of respondents, while vegetation on flood paths were used by only 3,3%. In Sane, the results were slightly different. The most commonly used mechanism were furrows, accounting for 53,3% of the respondents. Vegetation on flood paths was reported by 16,6% of the respondents. Sandbags and personal drainage systems were equally popular, each accounting for 13,3% of the respondents. Personal drainage systems were used by 3,3% of the respondents.

5.2.2 Maps displaying different flood control mechanisms and their locations within the study areas





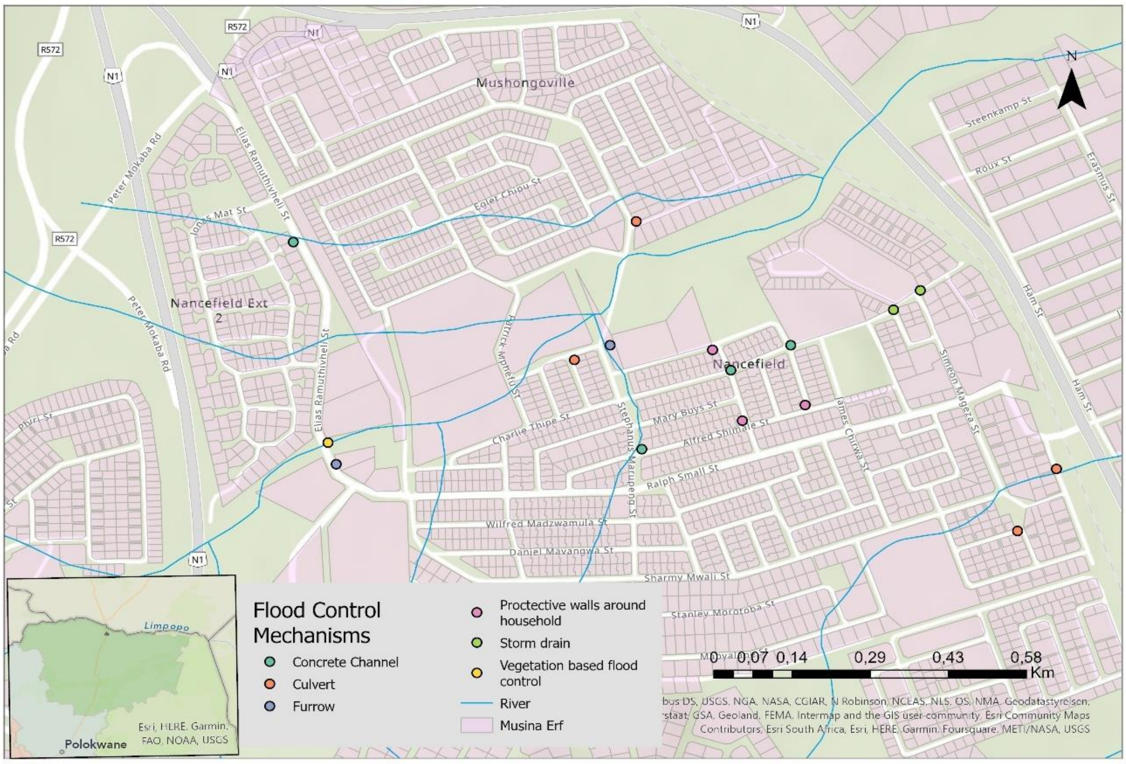


Figure 7: Location of Flood Control Mechanisms in Sane (Top Panel), Duthuni (Middle Panel), and Musina (Bottom Panel)

In the study areas of Sane Duthuni and Musina, various flood control measures have been implemented, including concrete channels, culverts, furrows, protective walls around households, storm drains, and vegetation-based flood control mechanisms. The maps above depict the nature and location of some of the flood control methods. It's important to note that these maps do not encompass all the flood control mechanisms present in these regions. Some strategies were not included in the mapping due to their seasonal deployment during rainy periods. These maps serve as an illustration of the partial distribution of the available flood control mechanisms found in the study areas.

5.2.3 Effectiveness of community-level flood control mechanisms in Duthuni, Sane and Musina

5.2.3.1 Furrows

a. Composition:

- Composition Analysis: The furrows in all three study sites - Musina, Duthuni, and Sane study areas - are primarily composed of loose soil, which is susceptible to erosion and displacement by heavy rainfall or increased water flow.

b. Structural Integrity:

- Overall Infrastructure Condition: In all three study sites - Musina, Duthuni, and Sane - the furrows primarily consist of soil channels, exhibiting a lack of structural strength and resilience.
- Lack of Reinforcing Materials: The absence of concrete or similar reinforcement materials in all study areas further exacerbates the vulnerability of the furrows to erosion, structural instability, and fragility.

c. Erosion and Wear:

- Erosion Levels: Erosion is evident in the furrows in all study areas.
- Wear and Tear: In these areas, the furrows deteriorate over time, and every time there is flooding, continuous exposure to floods and natural elements has caused them to be completely washed away.

d. Maintenance and Repairs:

- Maintenance: The current conditions in all three study areas underscore the necessity for prompt maintenance and potential structural improvements to ensure their long-term functionality and stability.
- Repair Recommendations: Consider implementing concrete or other suitable reinforcement measures to enhance the overall integrity of the furrows in the 3 study areas.

e. Environmental Considerations:

- Impact on Local Ecosystems: The furrows, due to their erosion and loose soil composition, may have adverse effects on local ecosystems, particularly wetlands and wildlife habitats. Erosion from the furrows can contribute to sedimentation in nearby water bodies, potentially harming aquatic ecosystems.

Figure 8: A roadside furrow in Sane

5.2.3.2 Vegetation-based flood control mechanisms

a. Composition:

- Composition Analysis: These mechanisms combine vegetation (trees, shrubs, and other native vegetation) and soil to regulate or decelerate flooding. These plants help stabilise the soil, reduce erosion, and absorb excess water.
- Reinforcement Materials: Vegetation-based mechanisms rely on the natural growth of plants to strengthen the soil and enhance its resistance to erosion and structural instability.

b. Structural Integrity:

- Overall Infrastructure Condition: In the three study areas, vegetation-based flood control mechanisms primarily depend on natural plantings, which demonstrate inherent strength and resilience due to their composition and soil. This natural synergy offers robust resistance to erosion and displacement caused by heavy rainfall or increased water flow.
- Specific Structural Issue Locations: Notably, these mechanisms do not incorporate concrete supports, emphasising their reliance on natural elements for structural stability.

c. Erosion and Wear:

- Erosion Levels: Erosion was observed in Musina, particularly in areas lacking adequate plant cover for soil protection, but not in Duthuni and Sane.
- Wear and Tear: In Musina, high water flows, especially during intense storms, have eroded the soil and dislodged some plants, weakening their ability to hold back water. Musina also

experiences periods of prolonged drought, which stress and weaken the vegetation, making it less effective in managing floods.

d. Maintenance and Repairs for Vegetation-Based Flood Control Mechanisms:

- Maintenance: The current condition of these vegetative flood control mechanisms in Musina and Duthuni underscores the necessity for timely maintenance and potential improvements to ensure their long-term functionality and stability. In Sane, vegetation-based flood control mechanisms are thriving.
- Repair Recommendations: In Musina and Duthuni, the recommendation should be to consider implementing additional vegetation or suitable reinforcement measures, such as increased plant diversity or root systems, to enhance the overall integrity of these mechanisms.

e. Environmental Considerations for Vegetation-Based Flood Control Mechanisms:

- Impact on Local Ecosystems: The use of vegetation-based flood control mechanisms in all study areas provides benefits to local ecosystems, particularly wetlands and wildlife habitats. These mechanisms not only resist erosion but also offer sustenance to animals and serve as habitats for various wildlife species.

5.2.3.3 Culverts

a. Composition Analysis:

- Analysis of the composition: In these study areas, the culverts are composed of concrete channels and masonry materials like bricks or stone.
- Reinforcement Materials: Steel bars and mesh are incorporated into the concrete channels in the culverts in Duthuni and Musina to augment their structural integrity.

b. Structural Integrity:

- Overall Infrastructure Condition: The culverts in the study areas are built with rigid materials, ensuring robust structural integrity and resilience.
- Specific Structural Issues: Certain culverts have been reinforced with steel bars and mesh; however, over time, they have shown signs of weakening, especially in Musina.

c. Erosion and Wear:

- Erosion Levels: The culverts in all three study areas have been observed to erode gradually.

- Wear and Tear: In all three study areas, continuous usage and exposure to flooding and other natural elements have resulted in visible signs of wear and tear on the culverts' surfaces.

d. Maintenance and Repairs:

- Urgent Need for Maintenance: The current condition of the culverts in all three study areas highlights the necessity for immediate maintenance and potential structural enhancements to ensure their long-term functionality and stability. Neglected or improperly maintained culverts in Musina (Figure 8) are deteriorating over time, leading to issues such as blockages, reduced flow capacity, and an increased risk of flooding.

- Repair Recommendations: Consistent maintenance, including repairs to the culverts and the removal of debris buildup, is essential.

Figure 9: A Culvert in Musina

e. Environmental Considerations:

- Impact on Local Ecosystems: Sediment Accumulation: A common issue across all three study areas is sediment and debris trapped in the culverts, which disrupts the natural flow of water. Accumulated sediment also reduces the capacity of the culverts, leading to localised flooding.

  Habitat Destruction: The construction of culverts in Sane and Duthuni disrupts natural habitats and can cause damage to wetlands, streams, and surrounding ecosystems.

Invasive Species Spread: Culverts inadvertently facilitate the spread of invasive species by providing a pathway for them to move to new areas, particularly in Duthuni.

5.2.3.4 Concrete Channels

a. Composition:

- Composition Analysis: Concrete channels are constructed using a specific concrete mix.

- Reinforcement Materials: In Duthuni and Musina, steel bars and mesh are integrated into the concrete channels to enhance their overall structural strength.

Figure 10: A concrete channel in Duthuni

b. Structural Integrity:

- Overall Infrastructure Condition: In Musina, the concrete channels are in excellent condition, showcasing their robust structural integrity.

- Specific Structural Issue: In Duthuni and Sane, there are concerns regarding the structural integrity of some channels, as they are still in the construction phase and not yet structurally sound enough to fulfill their intended purpose.

c. Erosion and Wear:

- Erosion Levels: Erosion has become a visible issue in several concrete channels in Musina.

- Wear and Tear: The continuous use and exposure to natural elements in all the study areas have led to noticeable signs of wear and tear on the surfaces of these concrete channels.

d. Maintenance and Repairs:

- Urgent Need for Maintenance: The current condition of concrete channels in Musina underscores the immediate requirement for maintenance and potential structural enhancements to ensure their long-term functionality and stability.
  In Duthuni and Sane, completing the construction of these channels is imperative for them to effectively serve their intended purposes.

- Repair Recommendations: In all study areas, a continuous repair strategy for concrete channels, as they begin to exhibit wear, is vital to maintaining their functionality.

e. Environmental Considerations:

- Impact on Local Ecosystems: In Duthuni and Sane, where some construction is still underway, there is a significant concern about habitat loss. The construction of concrete channels often involves clearing natural vegetation, leading to the destruction of habitats for various plants and animals. This, in turn, results in biodiversity loss and disruptions to local ecosystems.

  In Musina, given that these concrete channels discharge into rivers and wetlands, there is a risk to water quality. The channels transport pollutants such as oil, heavy metals, and pesticides from urban areas into nearby water bodies, potentially degrading water quality and harming aquatic life.

5.2.3.5 Storm Drains

a. Composition:

- Composition Analysis: The storm drains in the study areas are typically constructed from various materials, including concrete, metal (such as steel or aluminium), and plastic (such as PVC).

- Reinforcement Materials: In the study of Duthuni and Musina, it's common practice to incorporate steel reinforcing bars (rebar) or mesh within concrete storm drain structures to boost their resilience and longevity.

b. Structural Integrity:

- Overall Infrastructure Condition: In the two study areas where they are located, storm drains exhibit strong structural strength and resilience.

- Specific Structural Issue: In Musina, corrosion is a concern as it can weaken metal components such as steel or aluminium, thereby diminishing the structural integrity of storm drains.

c. Erosion and Wear:

- Erosion Levels: There is no observable erosion in the studied areas where storm drains are present.

- Wear and Tear: In Duthuni and Musina, continuous usage and exposure to natural elements and human activity have led to noticeable signs of wear and tear along the surfaces of the storm drains.

d. Maintenance and Repairs:

- Maintenance: In Duthuni and Musina, the storm drains remain functional, but regular maintenance is imperative to ensure their long-term functionality and stability.

- Repair Recommendations: Swift repairs when damage occurs, and consistent unclogging can significantly contribute to their continued functionality.

e. Environmental Considerations:

- Impact on Local Ecosystems: In Musina and Duthuni, where storm drains are present, habitat disruption has been observed. The construction and maintenance of storm drains have disrupted local ecosystems by altering the natural water flow. These changes have resulted in modifications to the physical characteristics of rivers, streams, and wetlands, impacting the habitats of aquatic species and wildlife that depend on these areas.

- Pollution and Contaminant Transport: Stormwater runoff can carry pollutants, such as oil, heavy metals, chemicals, and debris, into the storm drain system. If not properly treated or managed, these pollutants can be transported into underground systems, potentially contaminating groundwater and negatively impacting soil quality.

5.2.4 Effectiveness of flood control mechanisms at household level

5.2.4.1 Household Furrows

a. Composition and Vulnerability:

- Composition Analysis: Household furrows primarily consist of loose soil.

- Absence of Reinforcement Materials: The furrows do not have any concrete or comparable reinforcing materials.

b. Structural Integrity:

- Overall Infrastructure Condition: Within the confines of residential settings in Musina, Duthuni, and Sane, household furrows primarily consist of soil channels, showcasing limited structural strength and resilience.

- Specific Structural Issue: The lack of concrete or other reinforcing materials represents the most significant structural issue for household furrows in the study areas.

Figure 11: A Furrow at a household in Sane

c. Erosion and Wear:

- Erosion: Erosion is evident in household furrows across all study areas.

- Wear and Tear: These household furrows deteriorate gradually, becoming increasingly susceptible to complete erosion during floods.

d. Maintenance and Repairs:

- Maintenance: The current state of household furrows underscores the immediate need for maintenance and potential structural enhancements to ensure their long-term functionality and stability.

- Repair Recommendations: Consideration should be given to implementing concrete or other suitable reinforcement measures to improve the overall integrity of household furrows in all three study areas.

e. Environmental Implications:

- Impact on Local Ecosystems: Household furrows, given their susceptibility to erosion and loose soil composition, may adversely affect local ecosystems, particularly wetlands and wildlife habitats. Erosion from these furrows can lead to sedimentation in nearby water bodies, potentially harming aquatic ecosystems.

5.2.4.2 Sandbags

a. Composition:

- Composition Analysis: Sandbags used in the three areas are typically made of woven polypropylene or burlap material and are filled with sand.
- Reinforcing Materials: Sandbags, by design, do not incorporate reinforcing materials or structural support, and this holds true for sandbags found in Duthuni and in Sane. In Musina, they utilise trenching for support by digging a trench in front of the sandbag barrier to anchor the bags and prevent water from seeping underneath.

b. Structural Integrity:

- Overall Infrastructure Condition: The structural integrity of a sandbag barrier is achieved through the careful stacking and compaction of the bags. However, in all the study areas, only individual sandbags were used, and they were not stacked. In Musina and Sane, they were also not anchored, which means they lacked structural integrity.

c. Erosion and Wear:

- Erosion Levels: The sandbags in the three study areas are susceptible to erosion and displacement when exposed to heavy rain or fast-moving floodwaters. Over time, water wears away the bags or washes them away, compromising their effectiveness.

- Wear and Tear: The sandbags in all three areas degraded over time due to exposure to sunlight, moisture, and other environmental factors.

d. Maintenance and Repairs:

- Maintenance: There was no regular maintenance plan for the available sandbags in the study areas, even though it was evident that they needed regular inspections and proactive repairs or replacements to remain structurally sound and ready to serve their purpose when a flood event occurs.

- Repair Recommendations: Regular inspections are crucial, especially for sandbags that have been in place for an extended period, and it is recommended to periodically replace damaged bags. In areas like Duthuni and Sane, where the sandbags were not anchored, it is recommended to use stakes or other anchoring methods to secure the sandbag barrier in place and prevent it from being dislodged by floodwaters.

e. Environmental Considerations:

- Impact on Local Ecosystems: Residue and Litter: After a flood event, sandbags are left behind as litter, creating an unsightly and potentially hazardous environmental problem. This litter can persist for an extended period, especially if proper cleanup is not carried out. The removal of sandbags after a flood event can be challenging and expensive, particularly if they have become waterlogged and heavy. The removal process itself can cause further disruption to the environment.

5.2.4.3 Protective Walls

a. Composition:

- Composition Analysis: In Musina, a significant portion of the walls were constructed using reinforced concrete, while in Sane and Duthuni, the predominant choice for wall materials consisted of bricks or stones.
- Reinforcing Materials: In Musina, it's common to find reinforcement bars employed in concrete flood protection walls to enhance tensile strength and mitigate cracking when subjected to stress. Across all the study areas, anchoring systems, such as steel anchors and cables, are implemented to firmly anchor the wall to its foundation and withstand lateral forces during flood events.

b. Structural Integrity:

- Overall Infrastructure Condition: The protective walls in these areas, including Musina, Duthuni, and Sane, rely on their walls that have anchoring systems for their structural integrity, effectively shielding against erosion and environmental elements.
- Specific Structural Issue: In Sane, there is a notable issue with poor drainage behind these walls. This deficiency can lead to the accumulation of hydrostatic pressure, potentially causing wall failure. Proper drainage systems are crucial to releasing water pressure and preventing damage.

c. Erosion and Wear:

- Erosion Levels: There were no observed erosion problems affecting the protective walls in the areas examined.
- Wear and Tear: Over time, these protective walls naturally degrade and become especially vulnerable to complete destruction during floods, as they constantly face exposure to various environmental elements such as rain, wind, and sunlight.

d. Maintenance and Repairs:

- Maintenance: Regular maintenance of these protective walls is vital to ensure their ongoing effectiveness and structural integrity. Consistent upkeep can prevent wear and tear, address damage, and extend the walls' lifespan.
- Repair Recommendations: Conduct periodic visual inspections of the protective walls, ideally on a quarterly basis or after significant flood events. Look for signs of damage, erosion, cracks, or other issues that could compromise the walls' integrity.

e. Environmental Considerations:

- Impact on Local Ecosystems: The construction of protective walls disrupts and destroys natural habitats that previously existed in the area.

5.2.4.4 Personal drainage systems

a. Composition:

- Utilised Materials: Concrete is a widely favoured choice for constructing flood drainage systems, followed by plastic and PVC materials. Aluminium, steel, or PVC are used for gutters and downspouts.

- Reinforcing Materials: Drainage systems, commonly found in areas such as Musina, Duthuni, and Sane, predominantly incorporate concrete due to its capacity to withstand environmental stresses.

Figure 12: A personal drainage system in Duthuni

b. Structural Integrity:

- Overall Infrastructure Condition: The selection of materials and the quality of construction are pivotal factors in determining the overall condition of the drainage infrastructure. Drainage infrastructures that are well-constructed and employ durable materials are more likely to maintain their integrity over time. For instance, drainage systems in Musina are of higher quality, primarily constructed with materials like concrete, aluminium, and steel, in contrast to systems like those in Sane, which use plastic.

- Specific Structural Issues: In drainage systems with drainage pipes, the problem that emerges is clogging. Over time, debris, silt, and sediment can accumulate within the drainage pipes or channels, causing blockages that hinder the flow of water. This issue is evident in the drainage systems in Musina and Duthuni. Furthermore, in systems containing metal components, such as steel pipes or small household culverts, exposure to moisture can lead to corrosion, thereby weakening the structural integrity. This phenomenon has been observed in all three study areas.

c. Erosion and Deterioration:

- Erosion Assessment: No observable erosion concerns were identified affecting the flood drainage systems in the examined areas.

- Wear and Tear: Over time, these systems naturally deteriorate, making them susceptible to failure during floods due to prolonged exposure to environmental elements.

d. Maintenance and Restoration:

- Maintenance: Regular upkeep of flood drainage systems is essential to ensure their ongoing effectiveness and structural soundness. Consistent maintenance can prevent wear and tear, address damage, and prolong the systems' lifespan.

- Repair Recommendations: Regular maintenance is crucial for keeping the systems in good working order. This maintenance encompasses cleaning, debris removal, and promptly addressing any necessary repairs. Periodically conduct visual inspections of the flood drainage systems or following significant weather events to check for signs of damage, erosion, corrosion, cracks, or other issues that could compromise the integrity of the systems.

e. Environmental Considerations:

- Impact on Local Ecosystems: Habitat Disruption: The presence of flood drainage systems in certain areas may lead to the disruption or destruction of the natural habitats that once flourished there.

5.2.4.5 Vegetation-based flood control mechanisms within Households

a. Composition:

- Composition Analysis: These strategies entail combining plants such as trees and shrubs with the soil to effectively control and mitigate residential flooding. This vegetation plays a crucial role in stabilising the soil, diminishing erosion, and absorbing surplus water.

- Natural Reinforcement: Vegetation-based approaches depend on the organic growth of plants to fortify soil and enhance its resistance to erosion and structural instability.

b. Structural Strength:

- Overall Infrastructure Condition: Household flood control mechanisms centred around vegetation primarily rely on the inherent robustness and resilience provided by the composition of plants and the soil. This natural synergy offers substantial resistance to erosion and dislocation triggered by heavy rainfall or increased water flow.

c. Erosion and Deterioration:

- Erosion Levels: Evidence of erosion has been observed in all study areas, particularly in areas lacking sufficient plant cover to protect the soil.

- Environmental Degradation: Continuous exposure to flooding and other environmental elements in Musina and certain parts of Duthuni has led to noticeable degradation in the vegetative household flood control systems.

d. Maintenance and Restoration:

- Maintenance: The current condition of these vegetative household flood control systems in Musina and Duthuni underscores the need for regular maintenance and potential enhancements to ensure their long-term functionality and stability. In Sane, these mechanisms are flourishing.

- Recommendations for Repairs: Integrating additional indigenous vegetation or implementing suitable reinforcement measures, such as enhancing plant diversity, should be considered to enhance the overall durability of these household flood control systems in Musina and Duthuni.

e. Environmental Implications:

- Impact on Local Ecosystems: The utilisation of household flood control techniques centred around vegetation in all study areas offers advantages to local ecosystems, particularly wetlands and wildlife habitats. These methods not only combat erosion but also provide nourishment to animals and serve as habitats for various wildlife species.

5.2.5 Perceived effectiveness of community and household level flood control mechanisms

Figure 13 illustrates the perceived effectiveness of community-level flood control mechanisms in Duthuni, Musina, and Sane. The proportion of participants who perceived the effectiveness of furrows were 66.7% in Duthuni, 56.7% in Musina, and 76.7% in Sane. For vegetation-based flood control mechanisms, the proportions of participants who perceived effectiveness were 53.3% in Duthuni, 36.6% in Musina, and 63.3% in Sane.

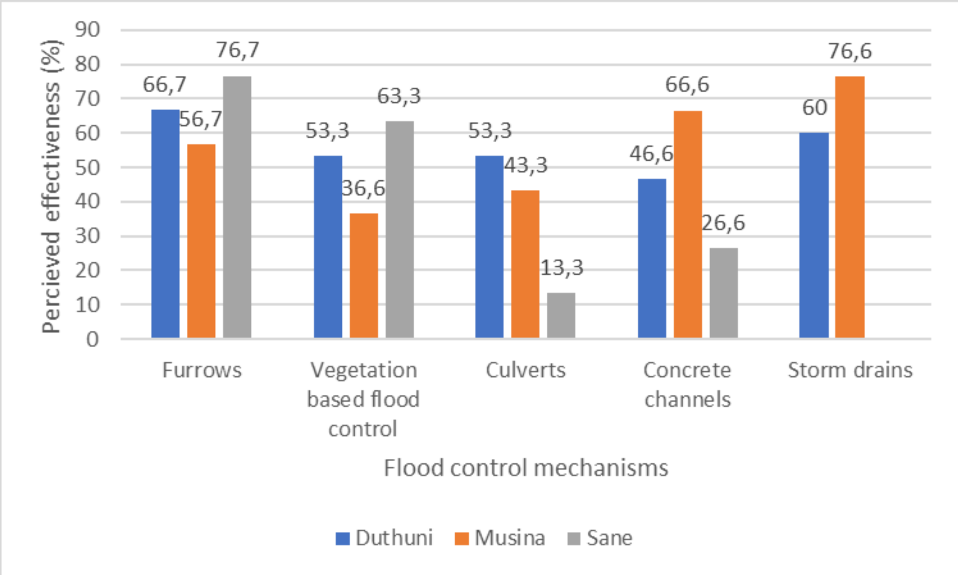


Figure 13: Perceived effectiveness of community level flood control mechanisms in Duthuni, Musina and Sane

Regarding culverts, the proportion of participants who perceived effectiveness was 53.3% (Duthuni), 43.3% (Musina), and 13.3% (Sane). In the case of concrete channels, the proportions of participants who perceived their effectiveness were 46.6% in Duthuni, 66.6% in Musina, and 26.6% in Sane. Finally, for storm drains, the proportions of participants who perceived their effectiveness were 60% in Duthuni and 76.6% in Musina.

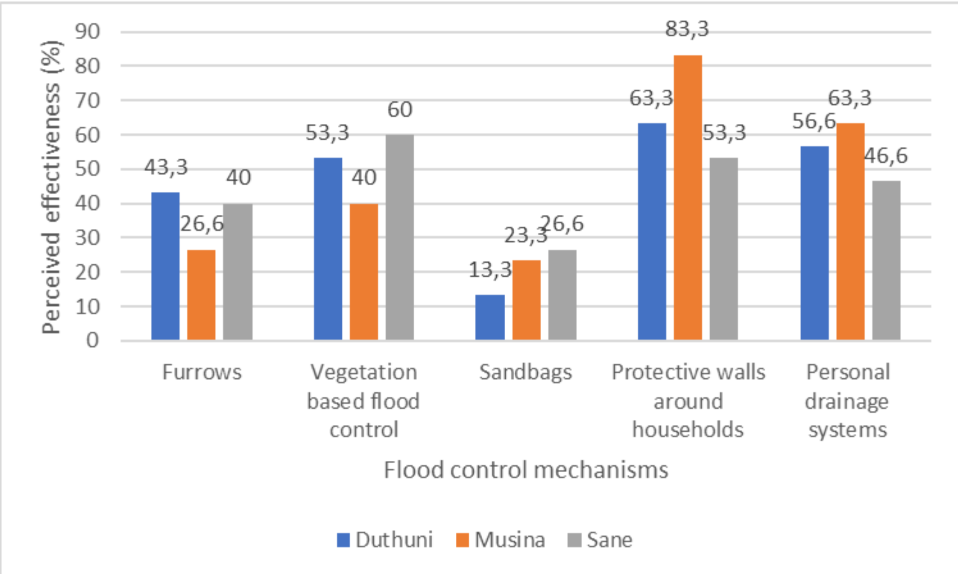


Figure 14: Perceived effectiveness of household level flood control mechanisms in Duthuni, Musina and Sane

Figure 14 illustrates the perceived effectiveness of household-level flood control mechanisms in Duthuni, Musina, and Sane.The proportion of participants who perceived the effectiveness of furrows was 43.3% in Duthuni, 26.6% in Musina, and 40% in Sane. Regarding vegetation-based flood control mechanisms, the proportion of participants who perceived their effectiveness was

53.3% in Duthuni, 40% in Musina, and 60% in Sane. For sandbags, the proportion of participants who perceived their effectiveness was 13.3% in Duthuni, 23.3% in Musina, and 26.6% in Sane. Concerning protective walls, the proportion of participants who perceived their effectiveness was 63.3% in Duthuni, 83.3% in Musina, and 53.3% in Sane. As for personal drainage systems, the proportion of participants who perceived their effectiveness was 56.6% in Duthuni, 63.3% in Musina, and 46.6% in Sane.

5.2.6 Perceived adaptability of community and household level flood control mechanisms

Figure 15 shows the perceived adaptability of community-level flood control mechanisms in Duthuni, Musina, and Sane. The percentage of respondents who perceived the adaptability of furrows was 56.67% in Duthuni, 16.67% in Musina, and 76.67% in Sane. For vegetation-based flood control methods, 73.33% of participants in Duthuni, 43.33% in Musina, and 90% in Sane perceived adaptability.

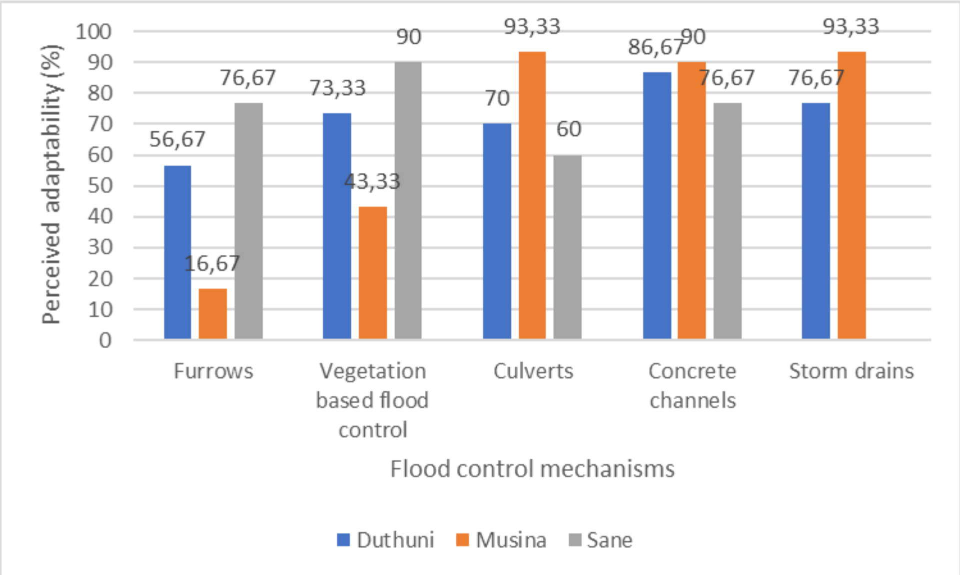


Figure 15: Perceived adaptability of community level flood control mechanisms in Duthuni, Musina and Sane

Culverts were perceived as adaptable by 70% of participants in Duthuni, 93.33% in Musina, and 60% in Sane. In the case of concrete channels, adaptability was perceived by 86.67% in Duthuni, 90% in Musina, and 76.67% in Sane. Finally, storm drains were perceived as adaptable by 76.67% of participants in Duthuni and 93.33% in Musina.

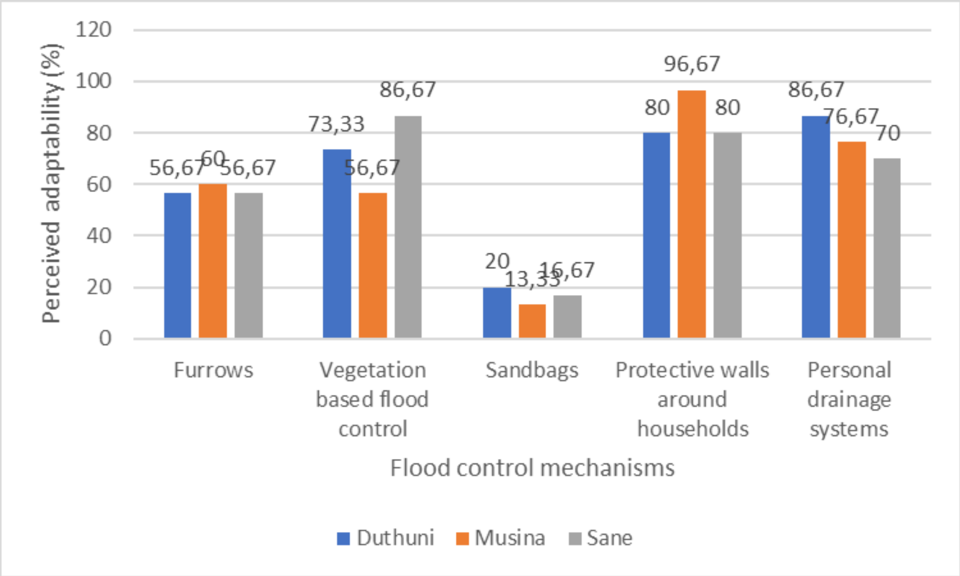


Figure 16: Perceived adaptability of household level flood control mechanisms in Duthuni, Musina and Sane

Figure 16 shows the perceived adaptability of household-level flood control mechanisms in Duthuni, Musina, and Sane. The adaptability of furrows was perceived by 56.67% of respondents in Duthuni, 60% in Musina, and 56.67% in Sane. As for vegetation-based flood control mechanisms, 73.33% of respondents in Duthuni, 56.67% in Musina, and 86.67% in Sane perceived them as adaptable. Regarding sandbags, only 20% of respondents in Duthuni, 13.33% in Musina, and 16.67% in Sane perceived them as adaptable. Protective walls around households were perceived as adaptable by 80% of respondents in Duthuni, 96.67% in Musina, and 80% in Sane. Lastly, personal drainage systems were perceived as adaptable by 86.67% of respondents in Duthuni, 76.67% in Musina, and 70% in Sane.

5.3 Preferred flood coping measures in Duthuni, Musina and Sane

Table 5 displays the percentages of people who reported a preference for specific flood coping measures in the study areas. Constructing more road drainage systems (culverts and concrete channels) with a maintenance plan was reported to be preferred by 26.6% of respondents in Duthuni, 26.6% in Musina, and 23.7% in Sane.

Table 5: Percentages of People Reporting Preferences for Specific Flood Coping Measures in the Study Areas.

Preferred flood coping measures	**Duthuni**	**Musina**	**Sane**
Constructing more road drainage systems (Culverts and concrete channels) with a maintenance plan	26.6	26.6	23.7
Building protective walls around households (subsidised)	23.3	23.6	16.6
Temporary relocation to safer areas in times of floods	20	13.3	10
Personal drainage systems(subsidised)	16.8	16.6	0
Effective early warning systems	10	3.3	13.3
Education on different flood control mechanisms that the residents can employ	3.3	0	0
Collecting and storing rainwater/floodwater and constructing retention ponds to help with farming water	0	10	13.2
A raised porch	0	6.6	0
Disaster relief that includes constructing emergency flood control mechanisms	0	0	10
Education on how to protect oneself when floods hit	0	0	6.6
Have municipal help on standby in times	0	0	3.3
Building houses with stone and cement to replace those built with mud	0	0	3.3

Building protective walls around households was reported to be preferred by 23.3% of respondents in Duthuni, 23.6% in Musina, and 16.6% in Sane. Temporary relocation to safer areas in times of floods was reported to be preferred by 20% of respondents in Duthuni, 13.3% in Musina, and 10% in Sane. Personal drainage systems (subsidised or with help from the government) were reported to be preferred by 16.8% of respondents in Duthuni and 16.6% in Musina.

Effective early warning systems were reported to be preferred by 10% of respondents in Duthuni, 3.3% in Musina, and 13.3% in Sane. Education on different flood control mechanisms that residents can employ was reported to be preferred by 3.3% in Duthuni. Collecting and storing rainwater/floodwater and constructing retention ponds to help with farming water were reported to be preferred by 10% of the respondents in Musina and 13.2% in Sane. A raised porch was reported to be preferred by 6.6% of the respondents in Musina. Disaster relief that includes constructing emergency flood control mechanisms was reported to be preferred by 10% of respondents in Sane.

Education on how to effectively protect oneself when floods hit was reported to be preferred by 6.6% of respondents in Sane. Having municipal help on standby in times of floods was reported to be preferred by 3.3% of respondents in Sane. Building houses with stone and cement to replace those built with mud was reported to be preferred by 3.3% of respondents in Sane.

5.4 Discussion

Beginning with Sane, it emerges as a rural village primarily relying on natural and traditional flood control methods (Statistics South Africa, 2022). In the community-level context, furrows and vegetation on flood paths are the most prevalent strategies, reflecting a preference for sustainable, nature-based solutions over engineered infrastructure like concrete channels and culverts. At the household level, Sane continues to prioritise traditional approaches, with furrows being the most popular method. This preference is also prevalent in countries such as Japan, where traditional methods are prioritised in rural areas amidst all the new developments (Itsukushima, et al., 2021). In Sane, as in many rural areas, the community's commitment to prioritising nature-based solutions extends beyond flood control methods to encompass a holistic approach that values the intrinsic connection between people and the environment (Seddon, et al., 2021).

Moving on to Musina, a township presenting a more developed and urbanised scenario compared to Sane, concrete channels and culverts take precedence as community-level flood control mechanisms. This suggests a more engineered approach to flood control, accompanied by the occasional use of storm drains. This inclination for modern solutions stems from the increased complexity of urban landscapes, which demand innovative strategies to address the challenges posed by urbanisation, climate change, and population growth (Lehmann, 2023). At the household level in Musina, furrows remain popular, though to a slightly lesser extent than in Sane. Protective walls around households have become more prevalent, further indicating the need for structural protection. Personal drainage systems are also adopted, showcasing a mixture of traditional and modern methods.

Duthuni, being a developed village, strikes a balance between natural and engineered flood control mechanisms at the community level. Concrete channels, culverts, and furrows are commonly used, emphasising a combination of strategies. The presence of vegetation-based flood control mechanisms is lower, suggesting a shift towards more engineered solutions. Many areas, similar to Duthuni, undergo a transition towards engineered solutions as they progress in development (Boardman & Vandaele, 2020). This enables them to assess and compare these engineered solutions with nature-based alternatives, facilitating informed decisions on the most suitable approach for their specific circumstances (Turkelboom, et al., 2021). At the household level, Duthuni also leans towards furrows as the primary flood control mechanism, suggesting a need for traditional methods. Conventional approaches, such as using furrows, serve as supportive mechanisms since they can often be promptly constructed.

Protective walls around households are the second most common approach, indicating a structural component in flood control. In summary, these findings underscore the regional variation in flood control mechanisms influenced by the level of development, local preferences, and historical practices. The choice of flood control measures is guided by factors such as geography, available resources, and community traditions (Siebeneck, et al., 2015). When assessing the effectiveness of these flood control mechanisms, various factors had to be considered. These factors encompassed the composition, structural integrity, erosion and wear, maintenance and repairs, and environmental considerations of the flood control mechanisms. This comprehensive evaluation ensured that the chosen flood control methods were both durable and environmentally sustainable (Sha, et al., 2021).

In all three study areas, both community-level and household furrows serve as common flood control mechanisms. They are primarily composed of loose soil, making them susceptible to erosion and displacement by heavy rainfall or increased water flow. The absence of reinforcement materials further exacerbates their vulnerability (Kandpal & Henry, 2016). Erosion is evident in the furrows in all study areas, and continuous exposure to floods and natural elements has caused them to be completely washed away. One notable drawback is the potential for furrows to become overwhelmed during extremely heavy rainfall, especially in areas prone to intense storms. In such cases, the furrows may not provide sufficient water detention, leading to overflow and subsequent flooding (Munyai, 2017). The findings underscore the necessity for prompt maintenance and potential structural improvements to ensure their long-term functionality and stability, with a recommendation to consider implementing concrete or other suitable reinforcement measures.
Vegetation-based flood control mechanisms, which combine vegetation and soil to regulate flooding, exhibit variations in effectiveness in the study areas. Musina experiences erosion in areas with inadequate plant cover, while Duthuni and Sane rely on these mechanisms with relatively better results. Maintenance is required, especially in Musina and Duthuni, where vegetation-based mechanisms are deteriorating. Vegetation flood control can deteriorate due to factors like deforestation, climate change, and poor land-use practices (Handayani, et al., 2020).

Deforestation disrupts natural buffers, making areas more susceptible to flooding (Swanson & Bohlman, 2021). Climate change alters precipitation patterns and intensifies storms, affecting ecosystems' ability to manage water flows (Hettiarachchi, et al., 2018). Improper land use, such as agriculture and urban development, contributes to soil erosion and reduces vegetation cover, leading to a loss of soil fertility, increased sedimentation in waterways, and greater vulnerability to natural disasters like floods and landslides (Handayani, et al., 2020).

The recommendation in the study area includes implementing additional vegetation or suitable reinforcement measures to enhance their overall integrity. These mechanisms have a positive impact on local ecosystems, providing stability and habitat for wildlife. Solutions, such as reforestation, sustainable land-use planning, and climate change mitigation, which aim to restore and enhance natural flood control mechanisms, have been reported to be effective in various regions (Bustamante, et al., 2019). Recognizing the importance of preserving ecosystems and implementing conservation measures is crucial for the establishment of resilient communities.

Culverts in all three study areas are composed of concrete channels and masonry materials, with some reinforcement in the form of steel bars, stones, and mesh. However, over time, they have shown signs of weakening, especially in Musina. Culverts have been reported to become ineffective due to sedimentation and debris. Over time, sedimentation and debris can accumulate inside culverts, reducing their capacity and impeding the smooth flow of water (Conesa-García & García-Lorenzo, 2013). Sediment buildup can lead to blockages, diminishing the culvert's ability to convey water efficiently (Jaeger, 2019). Another contributing factor is poor maintenance. Inadequate or infrequent maintenance can result in the deterioration of culverts. The lack of regular inspection and cleaning allows debris, vegetation, and other materials to accumulate, hindering the culvert's functionality and potentially causing it to fail during heavy rainfall events (Venner & Berger, 2014). The findings in the study areas highlight the necessity for immediate maintenance and potential structural enhancements, with recommendations emphasising consistent maintenance and the removal of debris buildup.

Concrete channels, as a flood control mechanism, exhibit variations in structural integrity. In Musina, they are in excellent condition, while in Duthuni and Sane, there are concerns regarding their structural integrity, as some are still under construction. The structural integrity of concrete channels becomes even more critical because these channels play a key role in managing and controlling water flow during periods of high-water levels (Wahalathantri, et al., 2016). Regular repairs are vital to maintaining their functionality.

Storm drains, composed of materials such as concrete and metal, exhibit strong structural integrity in Musina and Duthuni. Regular maintenance is essential to ensure their long-term functionality, with repair recommendations emphasising prompt repairs. Inspection is a fundamental aspect of this maintenance routine, involving regular checks for signs of damage, blockages, or deterioration in storm drain infrastructure (Li, 2015). Debris, including leaves, branches, trash, and sediment, should be routinely cleared from inlet grates and storm drain channels using methods such as mechanical sweepers or vacuum trucks. Additionally, sediment and trash removal from the bottom of storm drain basins is necessary to maintain optimal functionality (Remde, 2017).

Sandbags used in all three areas, though a flexible flood control measure, require regular inspections and proactive repairs or replacements. They have the potential to cause habitat disruption and create litter after a flood event (Lendering, et al., 2016). Additionally, the displacement of sandbags during a flood event can contribute to litter and debris, which may require post-flood cleanup efforts to minimise environmental impacts (Gomeseria, 2021). Consequently, their drawbacks outweigh their benefits.

Protective walls are essential in flood control in the study areas; they help protect households, prevent erosion, and minimise environmental disruption by redirecting or containing floodwaters. Additionally, these walls serve as critical infrastructure to safeguard essential public utilities and residences. Their construction and maintenance play a pivotal role in ensuring the resilience of communities against the devastating impacts of flooding (Chung & Adeyeye, 2018).

Across all study areas, maintenance and regular inspections are crucial to ensuring the long-term functionality and stability of these flood control mechanisms while minimising their negative impact on local ecosystems. Regular inspections can detect wear and tear on flood control mechanisms, identifying issues such as erosion, structural damage, or clogging that might otherwise go unnoticed. By promptly addressing these problems, the functionality of these structures is preserved, ensuring they continue to perform effectively in flood mitigation (Adamo, et al., 2021).

In addition to the findings of the observation analysis, the study also looked at the perceived effectiveness of flood control mechanisms in these areas. These offer valuable insights into how local communities view these methods and their efficacy in mitigating floods. These perceptions can be influenced by various factors, such as the local environment, community practices, and past experiences.

In Duthuni, furrows are generally considered effective as flood control mechanisms. Sane also regards furrows as effective. However, in Musina, an area with more advanced infrastructure like culverts and concrete channels, furrows are considered slightly less effective than other mechanisms. This difference in perception may be attributed to the prevalence of traditional, nature-based flood control methods in areas with less advanced infrastructure. In both Duthuni and Sane, participants generally perceive vegetation-based flood control mechanisms as effective. In Musina, where engineered solutions are more common, these methods are perceived as less effective. This suggests a preference for traditional and nature-based methods in areas where they align with local culture and ecology. Balancing these preferences with the need for more engineered solutions may be a challenge for local authorities (Coombes & Viles, 2021).

Perceptions of the effectiveness of culverts vary across the study areas. In Musina, culverts are considered effective. In Duthuni, they are considered somewhat less effective. Sane, with a lower use of culverts, has the lowest perception of effectiveness. This suggests that familiarity with and reliance on culverts might influence the perception of their effectiveness (Qi & Barclay, 2022). It is crucial to consider the availability of culverts when weighing these perceptions.

In Duthuni and Sane, where concrete channels are less commonly utilised compared to Musina, participants tend to perceive them as less efficient. However, it's worth noting that the majority of the concrete channels in Duthuni and Sane are still under construction, which could explain this perception. In Musina, the extensive use of concrete channels has allowed residents to witness their effectiveness over time, while in Duthuni and Sane, the ongoing construction may contribute to the differing perceptions of their efficiency. In Duthuni and Musina, areas with more development, storm drains are considered effective. This is likely due to the emphasis on engineering and stormwater management in these regions, making storm drains well-received and reliable solutions (Gyllenbäck, 2019). Due to their unavailability in Sane, it was not possible to gauge their effectiveness.

With Sandbags, Protective Walls, and Personal Drainage Systems: In general, sandbags are perceived as less effective in all areas, with the highest perception of their effectiveness in Sane. Protective walls are highly regarded in Musina and Duthuni, likely due to the preference for more structured and engineered solutions in these areas (Gyllenbäck, 2019). Personal drainage systems have moderate perceived effectiveness across the board, with the highest perception in Musina.

When evaluating flood control mechanisms in different study areas, it's essential to consider not only their effectiveness but also their perceived adaptability. The adaptability of flood control mechanisms is closely tied to the resilience of these communities, as it plays a pivotal role in their ability to recover and thrive in the face of changing environmental conditions (Liao, et al., 2016).
In Duthuni, furrows and vegetation-based flood control methods are perceived as relatively adaptable. The community regards furrows as somewhat effective, while vegetation-based methods are viewed more favourably. In Musina, there is a noticeable shift in perceptions. Furrows are perceived as less adaptable, potentially because of the availability of the preferred structural flood control infrastructure and resources (Schoonees, et al., 2019). Culverts are regarded as highly adaptable in this region. On the other hand, Sane, being a rural village with limited infrastructure, presents unique adaptability perceptions. Furrows are perceived as highly adaptable, indicating the community's reliance on more traditional flood control methods. Vegetation-based methods are also regarded positively in this area.

These distinctions in adaptability perceptions are not solely influenced by geographical factors but are closely tied to the developmental stage of each region. It highlights the importance of tailoring flood control strategies to the specific conditions and available resources in different communities (Klijn, et al., 2021). As such, the level of development serves as a critical factor in shaping preferences for flood control mechanisms, emphasising the need for region-specific solutions.
Residents have also proposed preferred measures, which encompass the solutions they desire and believe could effectively assist and protect them from floods. One commonly preferred measure across all three areas is the construction of more road drainage systems, including culverts and concrete channels. This approach was favoured by residents in all three areas, indicating the significance of ample and efficient water drainage systems in managing flood-related issues.

Protective walls around households were another favoured strategy in all the study areas. The survey participants even recommended that the government consider providing subsidies for these structures, as they tend to be more costly to build. These walls offered a sense of security and protection, particularly in regions prone to natural disasters. Temporary relocation to safer areas during floods was another preferred measure, albeit to varying degrees. The willingness to relocate temporarily is perhaps influenced by the extent of flood risk and available resources in these areas, highlighting the importance of local infrastructure and community support in facilitating such transitions (Sina, et al., 2019).

Personal drainage systems, whether subsidized or supported by the government, found favor in Duthuni and Musina. These measures empower individuals to take proactive steps in flood mitigation, particularly in more developed areas. Residents consistently seek ways to shield themselves from the consequences of floods, making personal drainage systems a valuable method for achieving this goal (Morss, et al., 2016).

Effective early warning systems were considered crucial, but their levels of favourability differed. In regions where residents cited a lack of existing early warning systems, such as Sane, the preference tends to be higher. The differing preferences underscore the unequal access to information and resources in these regions. Early warning systems help communities prepare for potential flooding events by providing advance notice. This allows individuals, businesses, and authorities to take proactive measures to reduce risks, such as reinforcing infrastructure, implementing evacuation plans, and securing valuable assets (Perera, et al., 2019). Education on flood control mechanisms was one of the preferred methods in Duthuni, indicating the potential for improving awareness in this area. Education can play a crucial role in raising public awareness about the risks and consequences of flooding. Teaching communities about flood preparedness, evacuation plans, and emergency response procedures can help minimise the impact of floods on individuals and property (Cerulli, et al., 2020). Sane respondents also suggested collecting and storing rainwater and floodwater and constructing retention ponds as a means of enhancing farming water resources. In Musina, residents suggested raised porches, likely to mitigate flood damage to their homes.

In the Sane area, there were several suggestions made. Another proposal involved the development of emergency flood control systems, indicating a requirement for external support in this domain. Some residents were interested in receiving education on how to better safeguard themselves during floods, hinting at the necessity for long-term solutions. Meanwhile, some people were looking for municipal assistance during flood incidents, and there were also calls for replacing traditional mud houses with more flood-resistant stone and cement buildings.

5.5 Chapter summary

The study of flood control mechanisms in the areas of Sane, Musina, and Duthuni has revealed a complex interplay between community preferences, infrastructure development, and the effectiveness of various flood control measures. Each region's unique combination of natural, traditional, and engineered approaches highlights the need for tailored solutions that consider the local environment and resources.

The study underscores the importance of understanding the local context and the community's historical practices when planning flood control strategies. In Sane, a rural village deeply connected to nature, there is a strong preference for sustainable, nature-based solutions like furrows and vegetation-based methods. In contrast, Musina, a more urbanised area, leans towards engineered solutions such as concrete channels and culverts. Duthuni, a developed village, strikes a balance between these approaches, reflecting a combination of strategies to address flood control.

The effectiveness and adaptability of these flood control mechanisms are closely tied to their condition, maintenance, and the community's perception of their usefulness. Addressing erosion, structural integrity, and ecological impact is essential to ensuring these measures continue to protect communities effectively. Furthermore, the perceived adaptability of these measures in different regions highlights the need for region-specific flood control strategies that are adaptable to climate change.

Residents in these areas have also expressed their preferences for flood coping measures, specifying the measures they would like to see installed and which they believe could be effective. They have shown a strong commitment to improving flood resilience within their communities, indicating a collective interest in safeguarding their homes and the environment. These expressed preferences are invaluable for local authorities and planners working to enhance flood preparedness and response strategies.

This study emphasises the importance of considering the diversity of factors influencing flood control strategies, including regional development, community preferences, and environmental conditions. To effectively address flood-related issues, it is crucial to implement flood control mechanisms that not only protect communities but also align with their specific needs and circumstances. This research provides valuable insights into the dynamic relationship between communities and flood control, facilitating the development of more resilient and targeted strategies for the future.

Chapter 6: Conclusions and recommendations

6.1 Introduction

The study aimed to analyse the relationship between extreme rainfall patterns and flood incidents while also evaluating the effectiveness of flood control mechanisms in the Vhembe district study areas. The objectives of this study were to investigate trends in extreme rainfall and their relationship to flood occurrences, as well as to characterise the nature and effectiveness of flood control mechanisms in the Vhembe district area. Based on the findings of the study, the following conclusions were drawn:

6.2 Trends in extreme rainfall and their relationship to flood occurrences in Vhembe District

In summary, Chapter 4 conducts a thorough examination of trends in extreme rainfall and their association with flood incidents in the Vhembe District. It underscores the importance of comprehending rainfall patterns for evaluating precipitation frequency, identifying vulnerabilities, and raising awareness among the local population, focusing on the 30-year period from 1991 to 2020.

The scrutiny of rainfall variability in the Vhembe District reveals distinct seasonal patterns, with December, January, and February consistently exhibiting the highest average precipitation across all areas. The data underscores DJF as the wettest season, emphasising the vulnerability of these regions to flooding during this period, particularly in Duthuni, which consistently experiences the highest average precipitation during DJF.

An analysis of monthly rainfall variability emphasises the significance of the months from November to February, characterised by higher median values and substantial precipitation. January emerges as the most variable month, with implications for flood risk assessment and preparedness. The study delves into significantly wet days, indicating the frequency of extreme precipitation events exceeding the 95th percentile and providing insights into the potential impact of climate change on rainfall patterns.

The investigation into flood occurrences in Duthuni, Musina, and Sane between 2000 and 2020 reveals annual flooding, with fluctuations in the number of events over the two decades. The data suggests a correlation between daily rainfall amounts exceeding 20 mm and flooding events, emphasising the importance of understanding this relationship for disaster preparedness and long-term climate resilience.

Furthermore, the study uncovers a substantial number of heavy precipitation days, indicating the region's susceptibility to intense rainfall events. The analysis of flood occurrences strengthens the link between extreme rainfall and flooding, highlighting the imperative for enhanced flood coping mechanisms, early warning systems, and flood control methods to mitigate the adverse impacts of future extreme rainfall events. The anticipated increase in such events calls for heightened preparedness to minimise vulnerability and damage caused by larger floods in the future.

In conclusion, there is a pressing need for local authorities and communities to recognise and address the heightened flood risk during the DJF season. The study's findings offer valuable insights for disaster preparedness, community planning, and climate resilience. Understanding the interplay between heavy rainfall, flooding, and local factors is crucial for effective adaptation and mitigation measures, especially in the context of anticipated increases in extreme rainfall events due to climate change.

6.3 Nature, effectiveness, and adaptability of flood control mechanisms in Vhembe district

The examination of flood control mechanisms in the regions of Sane, Musina, and Duthuni has uncovered a complex interplay involving community preferences, infrastructure development, and the efficacy of various flood control measures. The distinctive combination of natural, traditional, and engineered approaches in each region underscores the requirement for customised solutions that take into account the local environment and available resources.

This study underscores the importance of comprehending the local context and the historical practices of the community when formulating flood control strategies. In the rural village of Sane, deeply connected to nature, a strong preference exists for sustainable, nature-based solutions such as furrows and vegetation-based methods. Conversely, Musina, a more urbanized area, leans towards engineered solutions like concrete channels and culverts. Duthuni, a developed village, strikes a balance between these approaches, reflecting a combination of strategies to address flood control.

The effectiveness and adaptability of these flood control mechanisms are closely linked to their condition, maintenance, and the community's perception of their usefulness. Addressing erosion, structural integrity, and ecological impact is essential to ensuring the ongoing effectiveness of these measures in protecting communities. Furthermore, the perceived adaptability of these measures in different regions underscores the need for flood control strategies tailored to specific regions that are adaptable to climate change.

Residents in these areas have also conveyed their preferences for flood coping measures, specifying those they believe would be effective. Their strong commitment to improving flood resilience within their communities demonstrates a collective interest in safeguarding their homes and the environment. These expressed preferences are invaluable for local authorities and planners working to enhance flood preparedness and response strategies.

This study emphasises the importance of considering the diversity of factors influencing flood control strategies, including regional development, community preferences, and environmental conditions. To effectively address flood-related issues, it is crucial to implement flood control mechanisms that not only protect communities but also align with their specific needs and circumstances. This research provides valuable insights into the dynamic relationship between communities and flood control, facilitating the development of more resilient and targeted strategies for the future.

6.4 Recommendations

1. Community Engagement and Participation:

a. Local Authorities: Actively involve local communities in decision-making processes for flood control measures and tailor strategies based on specific community conditions and resources.

b. Educational Institutions: Implement targeted education programmes to familiarise residents with effective flood control methods and collaborate with community leaders for region-specific solutions.

c. Local Authorities and Community Organisations**:** Launch public awareness campaigns on flood risks, emphasising the correlation between heavy rainfall and flooding and targeting communities and local authorities.

2. Capacity Building, Knowledge Dissemination, and Infrastructure Enhancement:

a. Government Agencies: Conduct tailored training programmes covering flood preparedness, early warning systems, and maintenance. Enforce regular inspection, cleaning, and reinforcement of culverts and concrete channels.

b. Community Leaders: Provide practical guidance on implementing and sustaining flood control measures. Collaborate with relevant agencies for immediate maintenance and structural improvements.

3. Resource Allocation, Infrastructure, and Community Engagement:

a. Government Authorities: Allocate financial resources evenly to address regional disparities and enhance flood resilience. Implement educational programmes in collaboration with local schools and community organisations. Prioritise infrastructure projects based on specific needs and vulnerabilities.

b. Infrastructure Agencies: Provide subsidies for protective walls around households to overcome cost barriers.

4. Integration of Natural Methods and Innovative Measures:

a. Environmental Organisations: Prioritise the preservation and restoration of wetlands and riparian zones for natural flood control. Collaborate with local authorities to explore and implement innovative flood control measures.

b. Agricultural Agencies: Collaborate with local authorities to implement natural flood control methods. Facilitate public-private partnerships for the development and implementation of advanced flood control solutions.

5. Collaboration, Interdisciplinary Research, and Early Warning Systems:

a. Research Institutions: Foster partnerships between researchers, policymakers, and communities for holistic flood control solutions. Explore and implement effective early warning systems in collaboration with meteorological departments.

b. Government Agencies: Engage stakeholders from diverse fields to integrate knowledge for comprehensive flood control strategies. Collaborate with local community leaders and NGOs to ensure widespread access to timely and accurate flood-related information.

6. Policy Formulation, Implementation, and Preferred Measures:

a. Advocacy Groups: Actively advocate for integrating robust flood control mechanisms into local, regional, and national policies. Regularly monitor and evaluate the effectiveness of flood control measures to inform policy adaptations.

b. Government Authorities: Prioritise the construction of road drainage systems, including culverts and concrete channels. Facilitate temporary relocation strategies based on regional flood risks and available resources.

7. Government Action, Assistance, and Promoting Sustainable Practices:

a. National and Regional Governments: Provide timely assistance and support during flood incidents. Collaborate with housing authorities to explore and implement the replacement of traditional mud houses with more flood-resistant structures.

b. Environmental Agencies and Conservation Organisations: Promote sustainable land-use planning and reforestation efforts and encourage the collection and storage of rainwater/floodwater. Collaborate with local agricultural departments for the construction of retention ponds to enhance farming water resources.

6.5 Study Limitations

1. Unavailability of Rainfall Data:

- Limitation: Lack of local rainfall data from SAWS (South African Weather Service) for the study areas forced reliance on the NASA POWER database.
- Impact: Differences in data collection methods and spatial coverage could influence study results.
- Mitigation: Validation efforts were made, but potential biases may exist.

2. Dated Development Data:

- Limitation: Reliance on 2011 data due to the unavailability of recent statistics.
- Impact: Findings might not reflect current conditions or recent changes in the studied variables.
- Mitigation: Acknowledged the limitation while highlighting the necessity of available data.

3. Data Collection Methods and Representativeness:

- Limitation: Use of existing sources instead of purposive sampling for development data.
- Impact: Potential subjectivity and lack of representativeness.
- Mitigation: Decision made for broader population representation, recognising associated trade-offs.

6.6 Areas for further research

1. Studies to assess the physical parameters and effectiveness of flood control mechanisms, including their quantity and distribution in specific areas.

2. Research focused on optimising the design and evaluating the performance of flood control mechanisms based on the findings of the physical parameter assessments.

3. Investigation into flood vulnerability factors to understand elements contributing to susceptibility, such as geographic location, infrastructure quality, land use patterns, population density, and socio-economic factors.

4. Investigation into the socio-economic implications of flooding, including the economic cost of damages and the long-term effects on affected communities.

6.7 Chapter summary

This chapter synthesizes the extensive analysis conducted in this study on the relationship between extreme rainfall patterns and flood incidents and the overall effectiveness of flood control mechanisms in the Vhembe district study areas. The investigation into the relationship between flooding and extreme rainfall establishes a connection, highlighting distinct wet and dry seasons with intense rainfall occurrences during specific months. The study emphasises the susceptibility of the region to heavy precipitation days, underscoring the need for improved flood coping mechanisms, early warning systems, and flood control methods.

The examination of the nature, effectiveness, and adaptability of flood control mechanisms in the Sane, Musina, and Duthuni regions reveals a nuanced interplay influenced by community preferences, infrastructure development, and efficacy. Tailored solutions, taking into account specific environmental and resource dynamics, are crucial for sustainable flood control. The study underscores the importance of understanding the local context and historical practices when formulating flood control strategies. The identified preferences of each region, be they nature-based solutions in rural areas or engineered solutions in urbanised regions, provide valuable guidance for developing targeted and effective strategies.

The recommendations provided address key areas for improvement and suggest actionable steps. These include community engagement and participation, capacity building, knowledge dissemination, infrastructure enhancement, resource allocation, and the integration of natural methods and innovative measures. The study emphasises collaboration, interdisciplinary research, and the development of effective early warning systems. Advocacy for policy integration, government action, assistance during flood incidents, and promotion of sustainable practices are also crucial elements highlighted in the recommendations.

However, the study acknowledges certain limitations, such as the unavailability of local rainfall data and reliance on dated development data. Mitigation strategies, including validation efforts and acknowledging limitations, are outlined. Furthermore, areas for further research are identified, focusing on assessing the physical parameters and effectiveness of flood control mechanisms, optimising design, evaluating performance, understanding vulnerability factors, and exploring socio-economic implications.

In essence, this chapter underscores the complex nature of the relationship between extreme rainfall and flooding, the need for context-specific flood control strategies, and the importance of collaborative efforts to enhance resilience and mitigate the impacts of future extreme rainfall events in the Vhembe district study areas.

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APPENDICES

Appendix A: Permission Letter for Duthuni (From the Thulamela Municipality)

Department Of Corporate Services

Private Bag X5066
Thohoyandou
0950
Limpopo Province
Tel: 015 962 7500
Fax: 015 962 4020

THULAMELA MUNICIPALITY

Ref : 4/3/4/1
Enquiries : Mabasa N.H
Tel : 015 962 7514
Fax : 015 962 4020

To : Ms Munzhedzi L
From : THULAMELA MUNICIPALITY
Date : 02 August 2022

Subject : PERMISSION TO CONDUCT RESEARCH AT THULAMELA MUNICIPALITY

1. The above matter refers.
2. Kindly note that permission to conduct research has been granted.
3. Contact Human Resource Section for more information.
4. Hoping that this will meet your favourable considerations.

Makumule

ACTING MUNICIPAL MANAGER
MAKUMULE M.T

Appendix B: Permission Letter for Sane (From the Makhado Municipality)

MAKHADO MUNICIPALITY

MAKHADO MUNICIPALITY
PEACE HARMONY PROSPERITY

Vision: A dynamic hub for socio-economic development by 2050
Mission: To ensure effective utilization of economic resources to address socio–economic imperatives through mining, agriculture and tourism

INTERNAL MEMORANDUM

Ref no.: 5/3/1 & 5/4/2
Enquiries: T Manebaneba

TO: **THE ACTING MUNICIPAL MANAGER**

FROM: **CORPORATE SERVICES DEPARTMENT (HUMAN RESOURCE DIVISION)**

DATE: **26 JULY 2022**

SUBJECT: REQUEST TO ALLOW MS MUNZHEDZI L PERMISSION TO CONDUCT REASEARCH UNDER THE TITLE: AN EVALUATION OF FLOOD CONTROL MECHANISMS TO WITHSTAND AND ADAPT TO FLOODING IN VHEMBE DISTRICT, LIMPOPO PROVINCE

STRATEGIC OBJECTIVE

Good Governance and Administrative Excellence

PURPOSE
To seek approval by the Municipal Manager in respect of Miss Munzhedzi L to be granted a permission to conduct study research based on the subject mentioned above.

DETAILS
Miss Munzhedzi L of student No: 15001495 who is currently enrolled for Masters degree of Environmental Science in Ecology and Resource Management at the University of Venda is hereby requesting a permission to conduct research on an Evaluation of flood control mechanisms to withstand and adapt to flooding in Vhembe District; Limpopo Province. Attached herewith please find a copy of the request letter on that regard marked **Annexure "A"** for your perusal.

COMMENT
It is therefore recommended for Miss Munzhedzi L to be granted a permission to conduct the above-mentioned research, subject to best practice and conventions for students that undertake research on council's records viz.

1. Research activities will not disturb the normal operation of the Municipality.
2. Prompt and timeous arrangements must be made with the Departmental Head concern when assistance is required.
3. Copy of the research findings / thesis must be submitted to the Municipality
4. The Municipality has no power over research conducted with community members and this part will be performed with the community at their own free will.
5. Research will be for a period of six months which can be extended for a further period determined by the Municipal Manager.
6. Confidential records / information must not be reflected in thesis documents.
7. The collection of data for research will be conducted based on prior arrangements to be made before the meeting with the Acting Director Community Services.
8. The Municipality is indemnified against any claims for damages by the applicant which may result directly or indirectly from the research activity.
9. Research information may not be used for any form of publication media other than the applicant's studies expect with permission of the Municipality.
10. The Authorization is granted in line with provisions of the Municipality Access to Information Manual read with the Promotion to Access to Information Act, and the National Archives Act and approved by the relevant Head of the Department (HOD) with regards to the classification of information.

FINANCIAL IMPLICATIONS
None

Tel: 015 519 3000 | Fax: 015 516 1195 | E-mail : municipal.manager@makhado.gov.za |
Address : Civic Centre, 83 Krogh Street, Private Bag X2596, Makhado, 0920|
| www.makhado.gov.za | Call Centre : 015 516 2990/ 2994/ 2996

MAKHADO MUNICIPALITY

Vision: A dynamic hub for socio-economic development by 2050
Mission: To ensure effective utilization of economic resources to address socio–economic imperatives through mining, agriculture and tourism

MAKHADO MUNICIPALITY
PEACE HARMONY PROSPERITY

SUBJECT: REQUEST TO ALLOW MS MUNZHEDZI L PERMISSION TO CONDUCT REASEARCH UNDER THE TITLE: AN EVALUATION OF FLOOD CONTROL MECHANISMS TO WITHSTAND AND ADAPT TO FLOODING IN VHEMBE DISTRICT, LIMPOPO PROVINCE

POLICY
It's part of Training and Development

LEGAL IMPLICATIONS
None

RISK IMPLICATIONS
None

ENVIRONMENTAL IMPLICATIONS
To promote good Governance

CHANGE MANAGEMENT IMPLICATIONS
It is therefore recommended for Miss Munzhedzi L to be granted a permission to conduct the above-mentioned research.

CONSIDERATION (RECOMMENDATION)
That the acting Municipal Manager grants permission to Miss Munzhedzi L to conduct the above-mentioned research.

……………………………………… 27/07/2022 ………………
MR. T MANEBANEBA — DATE
SKILLS DEVELOPMENT FACILITATOR

RECOMMENDED / NOT RECOMMENDED

………………………………………………………………

……………………………………… 29/07/2022 ………………
MR. N DAGADA — DATE
ACTING DIRECTOR CORPORATE SERVICES

RECOMMENDED / ~~NOT RECOMMENDED~~

……………………… Supported ………………………

……………………………………… 2022/07/29 ………………
MR. N G RALIPHADA — DATE
ACTING CHIEF FINANCIAL OFFICER

APPROVED / ~~DECLINED~~

……………………… Approved ………………………

……………………………………… 2022/07/29 ………………
MR. K M NEMANAME — DATE
ACTING MUNICIPAL MANAGER

Tel: 015 519 3000 | Fax: 015 516 1195 | E-mail : municipal.manager@makhado.gov.za |
Address : Civic Centre, 83 Krogh Street, Private Bag X2596, Makhado, 0920|
| www.makhado.gov.za | Call Centre : 015 516 2990/ 2994/ 2996

Appendix C: Permission Letter for Musina (From the Musina Municipality)

MUSINA
LOCAL MUNICIPALITY

OPIBUS LOCA FETA

Postal Address:
Musina Local Municipality
Private Bag X611
Musina
0900

Physical Address:
21 Irwin Street
Musina
0900

Information Center
(015) 534 6100
info@musina.gov.za
www.musina.gov.za

ENQUIRIES SPEAK TO
RIKA LE ROUX

REFERENCE NO
95/4/A
20 July 2022

Dr. Nthaduleni Nethengwe
University of Venda – Research Department
Private X5050
Thohoyandou
0950

RESEARCH PROJECT – Ms Munzhedzi L – MASTERS OF ENVIRONMENTAL SCIENCES IN ECOLOGY AND RESOURCES MANAGEMENT DEGREE.

1. Your letter dated 11 July 2022 on the above subject matter is acknowledged and bears reference.

2. Permission is herewith granted to **Ms Munzhedzi Lily** at University of Venda to conduct a research project on the topic:

   "An evaluation of flood control mechanisms to withstand and adapt to flooding in Vhembe District, Limpopo Province.

3. Hoping that you find the above in order.

Regards,

TN TSHIWANAMMBI
MUNICIPAL MANAGER

To be the vibrant, viable and sustainable gateway city to the rest of Africa

University of Venda

Appendix D: Household questionnaire

I am Lily Munzhedzi from the University of Venda. I am conducting research for my Master's project with SAF-ADAPT. My objective is to evaluate the existing flood control mechanisms in order to determine their ability to withstand and adapt to flooding in the selected areas of the Vhembe district. You have been purposively selected to participate in this research. Participation is not mandatory, and you may choose not to continue with the interview or elect not to provide an answer at any time. There are no right or wrong answers. All information will be kept confidential and will not be shared with anyone else. Additionally, all data will be aggregated, ensuring that no individuals are identifiable. There will be no payments or harm caused by participating.

Consent given: Site:
Stakeholder group: Interview no:

1. **Background Information**

1.1) Gender: Male [ ] Female [ ]

1.2) Age: Under 18 [ ] 18-24 [ ] 25-34 [ ] 35-44 [ ] 45-55[x] 56-70 [ ] 70 and above[ ]

1.3) Education (highest qualification) No education [ ] Primary school [ ] Grade 10 [ ] Matric certificate [ ] Higher Diploma [ ] Undergraduate degree [ ] Postgraduate degree [ ]

1.4) Source of income: Grants [ ] Employed [ ] Self-employed [ ] Pension [ ]

2. Trends in flood occurrence in the Vhembe district

2.1 Have you ever been affected by floods?

....

....

2.2 From as far back as you can remember, on which days have you experienced flooding in this area?

....

....

2.3 What are the leading causes of flooding in your area?

....

....

3. **To characterise the nature and effectiveness of flood control mechanisms in the Vhembe district area.**

3.1 Are there any flood control mechanisms implemented in your area?

....

3.1.1 If yes, which ones are in place?

....

....

3.1.2 Are they effective?

....

3.1.3 Are the aforementioned flood control mechanisms adaptable?

....

3.2 Are there any flood control mechanisms implemented in your household?

....

3.2.1 If yes, which ones are in place?

....

3.2.2 Are they effective?

....

3.2.3 Are the aforementioned flood control mechanisms adaptable?

....

3.3 What flood prevention and coping measures are implemented in your area?

....

3.4 Are you confident in the preparedness of your community for flood events? Please provide an explanation.

....

....

3.6 Is your household adequately prepared for flood events? Please provide an explanation.

....

....

3.7 What flood coping measures would you recommend for your area?

....

....