UNIVERSITY FOR DEVELOPMENT STUDIES

ASSESSMENT OF FLOOD VULNERABILITY AND ADAPTATION STRATEGIES IN THE TAMALE METROPOLIS

JUSTICE AGYEI AMPOFO

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DEPARTMENT OF ENVIRONMENT AND SUSTAINABILITY SCIENCES

ASSESSMENT OF FLOOD VULNERABILITY AND ADAPTATION STRATEGIES IN THE TAMALE METROPOLIS

BY

JUSTICE AGYEI AMPOFO

MPhil Environment and Resource Management, BSc Real Estate and PGDE

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THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENT AND SUSTAINABILITY SCIENCES, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY (Ph.D.) IN ENVIRONMENTAL MANAGEMENT AND SUSTAINABILITY

MARCH, 2025

DECLARATION

I, hereby, declare that this thesis is the result of my own original work towards the award of a Doctor of Philosophy (Ph.D.) and that no part of it has been presented for a degree in this University or elsewhere. The work of others, which served as sources of information for this study, has been duly acknowledged in the form of references.

Candidate

Signature: ____________________ Date: 12/03/2025

Name: Justice Agyei Ampofo

I hereby declare that the preparation and presentation of the thesis were supervised following the guidelines on the supervision of theses laid down by the University for Development Studies.

Principal Supervisor

Signature-____________________ Date 12/03/2025

Name: Prof. Ebenezer Owusu-Sekyere

Co-Supervisor

Signature____________________ Date 12th March, 2025

Name: Dr. Raymond Adongo

Head of Department

Signature____________________ Date 12/03/2025

Name: Prof. Ebenezer Owusu-Sekyere

DEDICATION

Glory to God! With love and deep appreciation, I dedicate this research to my beloved wife, Agartha Maame Yaa Antwi, my precious daughter, Godiva Antwiwaa Ampofo, and my entire family.

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I am incredibly appreciative to Almighty God for giving me the strength and life to get to this point. This would never have been possible without God. My sincere appreciation goes out to my supervisors for their great advice and help in getting this work done. My primary supervisor, Prof. Ebenezer Owusu-Sekyere, a professor at the University for Development Studies in the Department of Environment and Sustainability Sciences. My co-supervisor, Dr. Raymond Adongo is a senior lecturer at the University for Development Studies in the Department of Ecotourism and Hospitality Management

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ABSTRACT

This study assessed flood vulnerability and the effectiveness of existing adaptation strategies to mitigate the negative impacts of flooding in the Tamale Metropolis. The study employed a descriptive study design with a mixed research approach, conducting surveys in flood-prone areas of the Tamale Metropolis. Four hundred participants were surveyed using questionnaires, while expert opinions on flood-related issues were gathered through interviews and semi-structured questionnaires. The findings were analyzed using frequency and percentage, time-series analysis, flood vulnerability index, and Kendall's Coefficient of Concordance and presented using charts, tables, and maps. The study revealed the causes of flooding to be rainfall, the soil type and the nature of the land in the area. Regarding socioeconomic flood vulnerabilities, the study found that the Tamale Metropolis exhibits a moderate level of awareness and preparedness for flood risks, with a Social Sub-Index score of 1.6. However, the flood vulnerability map revealed that high vulnerability areas, covering 14.413 sq km, include urban built-up areas with poor road networks. Medium vulnerability spans 227.56 sq km, while low and no/very low vulnerability areas cover 64.019 sq km and 309.58 sq km, respectively. Furthermore, the study identified flood barriers and sandbags as the top adaptation strategies for addressing annual flooding in flood-prone zones in the area. The study concluded that while there is moderate economic development and accessibility, insufficient resources and opportunities expose residents to vulnerability during flooding. The study also determined a moderate level of flood vulnerability across the study area. It is recommended that the government, through the town and country planning department, develop and implement land use and zoning regulations that consider the identified hydrological and socio-economic factors.

TABLE OF CONTENTS

DECLARATION..**Error! Bookmark not defined.**

DEDICATION i

ACKNOWLEDGEMENT.. iii

ABSTRACT iv

TABLE OF CONTENTS v

LIST OF TABLES xiv

LIST OF FIGURES xvi

ABBREVIATION AND ACRONYM xvii

CHAPTER ONE...1

INTRODUCTION..1

1.1 Background of Study 1

1.2 Problem Statement...4

1.3 Questions for the research...6

1.3.1 Main Question for the research 6

1.3.2 Specific Questions for the research...7

1.4 Objectives of the Research 7

1.4.1 Main Objective...7

1.4.2 Specific Objectives...7

1.5 Scope of Study 8

1.6 Significance of the Study 9

1.8 Study Outline 10

CHAPTER TWO 11

LITERATURE REVIEW 11

2.1 Introduction 11

2.2 Theoretical Preposition 11

2.2.1 Resilience Theory 11

2.2.2 Adaptation Theory 16

2.3 Definition of Concepts 17

2.4 Concept of Vulnerability 18

2.5 Vulnerability assessment methods and frameworks 23

2.6 Methodologies and models used to assess flood vulnerability 25

2.6.1 Vulnerability Indices 26

2.6.2 Social Vulnerability Index (SoVI) 26

2.6.3 Physical Vulnerability Index (PVI) 28

2.6.4 Environmental Vulnerability Index (EVI) 29

2.7 GIS-Based Approaches 30

2.7.1 Flood Hazard Mapping 30

2.7.2 Risk Assessment 32

2.7.3 Flood Hazard Assessment 32

2.7.4 Assessment of Flood Exposure 33

2.7.5 Flood Vulnerability Assessment 33

2.7.6 Quantifying Flood Risk..33

2.7.7 Scenario Planning..34

2.7.8 Evolution of Flood Vulnerability Scenarios 34

2.8 Concept of Floods 35

2.9 Flooding in Global Perspective...36

2.10 Flooding in Ghana 38

2.11 Types of Floods 40

2.11.1 Riverine (fluvial) Flooding 41

2.11.2 Overland (Pluvial) Flooding 42

2.11.3 Groundwater Floods or the Failure of Artificial Water Systems 43

2.11.4 Coastal Floods/Storm Surge..43

2.11.5 Localized Flooding..44

2.12 Factors Causing Flooding 44

2.12.1 Factors causing flooding in urban areas 44

2.12.2 River Floods 45

2.12.3 Wet Season Flooding in Low Land and Coastal Cities..46

2.12.4 Flooding in Urban Areas 46

2.12.5 Urbanisation 47

2.12.6 High Rainfall Intensities 47

2.12.7 Nature of Terrain..48

2.12.8 Erosion, sediment transport, and attenuation of waste in rivers, streams, and drainage systems..48

2.12.9 Obstructions 49

2.13 Environmental and socio-economic impact of flooding.................................49

2.14 General Adaptation Strategies Used in Flood Management...........................54

2.15 Existing Adaptation Strategies Used in Reducing flood-related Vulnerabilities 58

2.15.1 Flood Mitigation Strategies...58

2.15.2 Land Use Changes on Vulnerability Mitigation 59

2.15.3 Early Warning Systems...60

2.15.4 Flood Barriers and Drainage Systems...60

2.15.5 Land Use Planning 63

2.15.6 Public Awareness and Education 64

2.15.7 Integrated Adaptation Strategies 66

2.16 Conceptual Framework..67

CHAPTER THREE 70

METHODOLOGY 70

3.0 Introduction..70

3.1 Profile of Study Area 70

3.2 Research Philosophy and Approach for the Research 72

3.2.1 Research Philosophy 72

3.2.2 Approach for the Research 73

3.3 Design for the Research 74

3.4 Study Population 74

3.5 Sample Size and Sampling Procedure 75

3.5.1 Sampling Size...75

3.5.2 Sampling Procedure 76

3.6 Types, Sources of Data and Methods of Data Collection 78

3.6.1 Types and Sources of Data 78

3.7 Data Collection Process 78

3.7.1 In-depth Personal Interview 79

3.7.2 Personal Questionnaire Administration Process 80

3.8 Instruments for Data Collection...80

3.8.1 Questionnaire 81

3.8.2 Interview Guide 81

3.9 Pretesting 82

3.10 Reliability Test...83

3.11 Data Analysis...83

3.11.1 Analysis of flood-vulnerable communities and the factors contributing to flooding occurrences within the Tamale Metropolis 84

3.11.2 Analysis of the hydrological factors contributing to flooding in the Tamale Metropolis 85

3.11.3 Investigating the effects of flooding on the environment, social, and economic dynamics within the Tamale Metropolis 89

3.11.4 Analysis of the adaptation strategies employed by residents of the Tamale Metropolis to mitigate the effects of flooding..93

CHAPTER FOUR 96

RESULTS AND DISCUSSION...96

4.0 Introduction...96

4.1 Demographics Characteristics of Respondents...96

4.1.1 Sex of Respondents 97

4.1.2 Age of Respondents 97

4.1.3 Marital Status of Respondents 98

4.1.4 Educational Level of Respondents...99

4.1.5 Duration of respondents staying in the flood prone areas........................100

4.1.6 Respondents' source of information on flooding 102

4.1.7 Frequency of respondents accessing information on flooding.................104

4.2 Identify flood-vulnerable communities and the factors contributing to flooding occurrences within the Tamale Metropolis..106

4.2.1 Mean annual rainfall pattern of Tamale Metropolis 107

4.2.2 Soil type of Tamale Metropolis..110

4.2.3 Elevation of Tamale Metropolis...112

4.2.4 Slope of Tamale Metropolis...114

4.2.5 Drainage Density of Tamale Metropolis...116

4.2.6 Flow Accumulation of Tamale Metropolis 118

4.2.7 Land use dynamics of the Tamale Metropolis 119

4.2.8 Distance to Stream of the Tamale Metropolis..122

4.2.9 Topographic Wetness Index (TWI) for the Tamale Metropolis 124

4.3 Effects of flooding on the environment, social, and economic dynamics within the Tamale Metropolis 126

4.3.1 Socio-economic flood vulnerabilities indicators....................................126

4.3.1.1 Social Flood Vulnerability Index 126

4.3.1.2 Economic Vulnerability Index 128

4.3.1.3 Environmental Vulnerability Index..130

4.3.1.4 Overall Vulnerability Index 132

4.4 Effective Flood Adaptation Strategies used by residents in the Tamale Metropolis..133

4.4.1 Flood Mitigation Strategies used by residents in the Tamale Metropolis133

4.4.2 Effectiveness of existing adaptation strategies used by residents of the Tamale Metropolis in reducing flood-related vulnerabilities............................139

4.4.3 Preferred Adaptation Strategies for Reducing Flood-Related Vulnerabilities...143

4.5 Flood Vulnerability Index (FVI) for Tamale Metropolis 147

4.5.1 Weight Assignment using AHP 148

4.5.2 Flood vulnerability mapping...151

4.4.2.3 Flood Vulnerability Map...154

4.5.3 Validation of flood vulnerability map...156

CHAPTER FIVE 158

SUMMARY, CONCLUSION AND RECOMMENDATION...............................158

5.1 Introduction...158

5.2 Summary of findings 158

5.2.1 Socio-demographic characteristics of respondents 159

5.2.2 Identification of flood-vulnerable communities and the factors contributing to flooding occurrences within the Tamale Metropolis 159

5.2.3 Effects of flooding on the environment, social, and economic dynamics within the Tamale Metropolis 160

5.2.4 Effective flood mitigation strategies used by residents in the Tamale Metropolis 161

5.2.5 Flood Vulnerability Index (FVI) for Tamale Metropolis.........................161

5.3 Conclusions for the Study 162

5.4 Study Contribution 163

5.4.1 Theoretical Contribution 163

5.4.2 Practical/Policy Implication 164

5.5 Recommendation 165

5.6 Direction for Future Research 167

5.7 Limitation of the Study 167

REFERENCES 169

APPENDIX 218

APPENDIX A: QUESTIONNAIRE FOR HOUSEHOLDS 218

APPENDIX B: INTERVIEW GUIDE FOR INSTITUTIONS 228

LIST OF TABLES

Table 3.1: Sample zones and communities for the Study 77

Table 3.2: Saaty scale for pairwise comparison 86

Table 3.3: Random index (RI) for different matrix sizes 88

Table 3.4: Interpretation of flood vulnerability index 93

Table 4.1: Demographics Characteristics of Respondents (N=400) 101

Table 4.2: Respondents source of information on flooding 104

Table 4.3: Frequency of respondents accessing information on flooding 105

Table 4.4: Social Vulnerability Index 128

Table 4.5: Economic Vulnerability Index 129

Table 4.6: Environmental Vulnerability Index...131

Table 4.7: Overall Vulnerability Index 133

Table 4.8: Adaptation strategies in reducing flood-related vulnerabilities 138

Table 4.9A: Perceived effectiveness of adaptation strategies in reducing flood-related vulnerabilities 142

Table 4.9B: Preferred Adaptation Strategies 147

Table 4.10: Pairwise matrix of flood factors 149

Table 4.11: Normalized matrix of Flood Factors 150

Table 4.12: Estimating the principal Eigenvalue and consistency ratio (CR)..........151

Table 4.13: AHP ranking of the flood factors with corresponding reclassification scale 153

LIST OF FIGURES

Figure 2.1: Vulnerability framework.....25

Figure 2.2: Conceptual framework showing flood vulnerability and adaptation strategies.....69

Figure 3.1: Map of Tamale Metropolis.....72

Figure 4.1: Satellite image of flood prone areas in Tamale Metropolis.....107

Figure 4.2: Mean annual rainfall.....109

Figure 4.3: Mean annual rainfall.....110

Figure 4.4: Soil types in the Tamale Metropolis.....112

Figure 4.5: Elevation in the Tamale Metropolis.....113

Figure 4.6: Slope in the Tamale Metropolis.....115

Figure 4.7: Drainage Density in the Tamale Metropolis.....118

Figure 4.8: Stream Order in the Tamale Metropolis.....119

Figure 4.9: Land Use and Land Cover for the Tamale Metropolis for 2024.....122

Figure 4.10: Distance to Stream for the Tamale Metropolis.....124

Figure 4.11: Topographic Wetness Index (TWI) for the Tamale Metropolis.....125

Figure 4.12: Final vulnerability map for the Tamale Metropolis.....155

Figure 4.13: Validation Map for the Tamale Metropolis.....157

ABBREVIATION AND ACRONYM

AHP	Analytical Hierarchy Process
CI	Consistency Index
CR	Consistency Ratio
EVI	Environmental Vulnerability Index
DFID	Department for International Development
FVI	Flood Vulnerability Index
GSS	Ghana Statistical Services
GIS	Geographic Information System
MMDAs	Metropolitan, Municipal and District Assemblies
NGO	Non-Governmental Organisation
NADMO	National Disaster Management Organisation
PCM	Pairwise Comparison Matrix
PVI	Physical Vulnerability Index
RI	Random Index
SPSS	Statistical Package for Social Sciences
SoVI	Social Vulnerability Index
TWI	Topographic Wetness Index
UDS	University for Development Studies
UNDP	United Nations Development Programme
USAID	United States Agency for International Development

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Floods are natural disasters that have been occurring throughout history and continue to pose significant challenges to humanity. A flood is commonly defined as the excessive overflow of water onto land that is typically devoid of moisture, often resulting from intense precipitation, thawing snow, or the failure of dams (Hrushikesh et al., 2023). This natural occurrence entails profound ramifications, including the loss of human lives, destruction of vital infrastructure, displacement of communities, as well as enduring economic and environmental consequences (Glago, 2021; Onwuka et al., 2015).

Floods manifest in diverse forms, including river floods, flash floods, coastal floods, and urban floods (Sowmya et al., 2015). River floods are the most common type and typically result from prolonged periods of heavy rainfall or snowmelt that cause rivers to exceed their capacity (Pomeroy et al., 2016). Flash floods, on the other hand, occur suddenly and with little warning, often in mountainous regions or areas with poor drainage systems (Kieu & Van Tran, 2021). Coastal floods are caused by storm surges or tsunamis, while urban floods are a result of inadequate drainage systems in cities (Natarajan & Radhakrishnan, 2020).

The global impact of floods is significant, comprising approximately 43% of all recorded natural disasters worldwide between 1998 and 2017 (Tembata et al., 2020). Within the same timeframe, floods affected over 2.3 billion individuals and resulted in more than 157,000 deaths globally (Ganguly & Cahill, 2020). The economic losses associated with flooding during this period surpassed $662 billion (Kurt, 2023). Nevertheless, the frequency and intensity of floods are projected to escalate due to climate change. Additionally, the adverse consequences of flood events induced by climate change have led to elevated global temperatures and more frequent and intense rainfall occurrences, overwhelming existing infrastructure and natural drainage systems (Hassan et al., 2022; Pradhan-Salike & Pokharel, 2017).

In Africa, the situation is no different. As a continent with diverse geographical features and climatic conditions, Africa is susceptible to experiencing flood vulnerabilities (Alfieri et al., 2017). However, heavy rainfall is the primary cause of floods in Africa. These heavy rains, in turn, pose a significant flood risk, particularly in regions that lack adequate water management systems (Nkwunonwo et al., 2016). Also, rapid urbanization, coupled with limited infrastructure development, often results in insufficient drainage capacity, which becomes problematic during periods of heavy rainfall when water accumulates in urban areas, leading to flooding (Miller & Hutchins, 2017). Deforestation is another contributing factor to the flood vulnerability of African countries. The removal of forests disrupts the natural balance of ecosystems and reduces the capacity of vegetation to absorb excess water resulting in amplified surface runoff and increasing the likelihood of flooding (Gunnell et al., 2019). These floods in Africa have led to a loss of human lives, displacement and homelessness, damage to infrastructure, agricultural losses, spread of waterborne diseases (Mugambiwa & Makhubele, 2021).

The general impact of floods in Africa has a direct bearing on the flood situation in Ghana. From 1991 to 2018, floods constituted roughly 38% of all recorded disasters in Ghana, with the Upper East, Upper West, Northern, and Volta regions being among the most flood-prone areas in the country (Ntim-Amo et al., 2022). However, other regions in the country typically experience flooding during the peak rainy season. In 2015, intense rainfall led to severe flooding in Accra, the capital city of Ghana. This event resulted in over 150 fatalities and displaced thousands of individuals. Furthermore, floods affected over 1.7 million people nationwide, with an estimated annual cost of approximately $200 million in Ghana in terms of infrastructure damage, productivity loss, and emergency response efforts (myjoyonline.com, 2023).

Tamale is characterized by a Sahelian climate. The climate of the city is distinguished by an extended period of low rains and a shorter duration of increased rainfall, typically observed between May and September (Chagomoka et al., 2018). This situation makes Tamale more vulnerable to flooding during the rainy season. However, this phenomenon of flooding in Tamale is worsened by urbanization and population growth (Kosoe et al., 2021). The rapid growth of the city's metropolitan area has generated an increased need for housing and infrastructure, which has therefore resulted in the invasion of open spaces and natural watercourses (Mensah et al., 2018). The exponential growth of the population and the unregulated urbanization it entails have exerted significant pressure on the city's drainage infrastructure, exacerbating the problem of flooding. Insufficient storm water management in various regions of the city results in the pooling of water on roadways, residential zones, and agricultural grounds during periods of intense rainfall (Kaur & Gupta, 2022). This not only causes inconvenience to the local population but also leads to property damage and agricultural losses.

In the long term, floods have far-reaching consequences. Floods led to the displacement of communities, loss of livelihoods, increased poverty levels, and social unrest (Dube et al., 2022). The destruction of infrastructure, such as roads, bridges, and buildings, hampers economic development and recovery (Islam et al., 2016). Flooding also carries pollutants and contaminants, posing risks to public health and the environment (Crawford et al., 2022). In response to the persistent issues of flooding, both local and national governments have implemented a range of flood adaptation strategies in dealing with the adverse effects of flooding on their livelihoods. This study therefore seeks to assess the flood vulnerability and adaptation strategies in Tamale's prone areas.

1.2 Problem Statement

In recent years, areas within Tamale Metropolis have witnessed a surge in the frequency of flooding incidents, primarily due to intense raining, resulting in substantial ramifications (Atanga & Tankpa, 2021). The key drivers behind these recurring flood events encompass deficiencies in the existing drainage infrastructure, unregulated construction practices, pervasive littering, and inadequate solid waste management (Mariango, 2017). These factors collectively obstruct the seamless movement of water, rendering the Metropolis highly susceptible to flooding (Rogers et al., 2020).

The Tamale Metropolis has experienced a notable influx of inhabitants driven by the scarcity of land within the Tamale Metropolis. This migration has given rise to the emergence of informal settlements characterized by substandard living conditions. These settlements, characterized by a lack of proper building permits and inadequate sanitation facilities, significantly amplify vulnerability to flooding (Korah et al., 2017). Moreover, the rising demand for residential and commercial properties has spurred several real estate developers to undertake construction activities in locations inherently prone to water-related hazards, thereby exacerbating the Metropolis's susceptibility to flooding (Sukanya & Tantia, 2023). The practice of erecting structures in flood-prone areas has consistently exposed the Metropolis to the risks associated with flood events (Abubakari & Twum, 2019). Consequently, the annual recurrence of floods has led to the loss of human lives and extensive damage to both private and commercial assets. Evidence suggests that Tamale has witnessed periodic flooding, which has caused enormous casualties and property loss. For example, Atanga and Tankpa (2021) quoted that the 2019 Tamale flood left more than 1,200 individuals displaced, with four deaths reported. In the same way, Korah et al. (2017) stated that the 2015 flood inundated more than 500 homes, leaving some families homeless. In the 2021 flood disaster, a total of about 1,800 individuals were affected, with damages to infrastructure placed in terms of several million Ghanaian cedis (Sukanya & Tantia, 2023).

Moreover, Rogers et al. (2020) describes that floods in the Metropolis have persistently affected business operations, with business centers and markets facing significant financial losses. The Northern Regional National Disaster Management

Organization (NADMO) approximated that the floods in 2022 led to more than GHS 2 million in lost goods and properties. Moreover, poor drainage systems have worsened such effects, leading to road washouts and loss of vital infrastructure (Abubakari & Twum, 2019).

These occurrences lead to substantial socio-economic and environmental ramifications, which have an impact on the livelihoods and overall welfare of the local population. Despite the Tamale Metropolis being prone to flooding, very limited studies exist that examines the full degree of flood vulnerability and assesses the effectiveness of adaption strategies in this area. The existence of this information gap highlights the pressing necessity for a comprehensive study of flood vulnerability and adaptation strategies used in addressing flooding vulnerability in the area. Therefore, this study seeks to assess flood vulnerability and adaptation strategies that can be employed in response to recurrent flooding incidents in the Metropolis.

1.3 Questions for the research

1.3.1 Main Question for the research

What are the factors influencing the susceptibility of communities to flooding in the Tamale Metropolis, and what effective mitigating strategies are used to address these vulnerabilities?

1.3.2 Specific Questions for the research

1. Which communities within the Tamale Metropolis are most vulnerable to flooding?
2. What are the primary factors contributing to flood occurrences in the Tamale Metropolis?
3. How does flooding events impact the environmental, social, and economic conditions in the Tamale Metropolis?
4. What flood mitigation strategies are currently being utilized by residents in the Tamale Metropolis, and how effective are these strategies in reducing the impact of flooding?
5. What key factors should be considered in developing Flood Vulnerability Index (FVI) in the area?

1.4 Objectives of the Research

1.4.1 Main Objective

To assess the susceptibility of communities to flooding and the adaptation strategies employed in the Tamale Metropolis.

1.4.2 Specific Objectives

1. To identify the communities within the Tamale Metropolis that are most vulnerable to flooding.
2. To examine the primary factors contributing to flood occurrences in the Tamale Metropolis.

3. To assess the effects of flooding on the environment, social structures, and economic dynamics within the Tamale Metropolis.
4. Examine the flood mitigation strategies utilized by residents in the Tamale Metropolis.
5. To identify and analyze the key factors that should be considered in developing a Flood Vulnerability Index (FVI) for the Tamale Metropolis.

1.5 Scope of Study

The study concentrated on flood-prone areas within the Tamale Metropolitan area or its immediate surroundings. Specific neighbourhoods or communities that are prone to flooding were identified and analyzed. The study sought to understand the nature of flood vulnerability situations in the selected areas. It also involved assessing the factors that contribute to vulnerability, such as topography, climate patterns, and land use. It also involved examining the historical incidence of flooding in these areas. Furthermore, the study assesses the social aspects of vulnerability, including demographic characteristics, socioeconomic status, and access to resources. The aim is to determine which groups within these areas are most susceptible to the impacts of flooding. Finally, the study explored the various strategies and measures that residents and local authorities have adopted to cope with or adapt to the recurrent flooding. These included infrastructure development, early warning systems, community-based initiatives, and policy interventions.

1.6 Significance of the Study

One of the biggest challenges faced by municipalities worldwide is flooding, which is the most common natural disaster (Kasei et al., 2019). In both the Tamale Metropolis and Ghana as a whole, flood levels are rising, making it crucial to develop a comprehensive management plan to reduce the impact of flooding. Flooding is a recurring disaster with widespread economic, social, and environmental consequences globally. Tamale, the capital city of Ghana's Northern Region, is particularly vulnerable to flooding due to its location and inadequate infrastructure, including a deficient drainage system, inadequate waste management, and a disorganized road network (Alhassan, 2015).

Conducting a study on flood vulnerability in Tamale's high-risk areas is essential for better understanding the situation and identifying specific vulnerabilities that make certain areas more prone to flooding. This knowledge can help policymakers, urban planners, and disaster management agencies develop targeted strategies to reduce flood risk. The findings of this study would provide valuable insights into the specific needs and challenges faced by affected communities. This information would enable policymakers to design effective adaptation strategies to address these issues. Additionally, the findings of this study would contribute to the existing literature on flood vulnerability and adaptation strategies. They would also help in the development of evidence-based policies, guidelines, and frameworks that promote sustainable urban planning, infrastructure development, and community resilience.

1.8 Study Outline

There are five chapters in this thesis. The study is introduced in chapter one with a review of the background, problem statement, goals, and questions of the research, as well as a significance of the study. In order to establish a theoretical approach and conceptual framework for the research, chapter two undertakes a thorough review and analysis of pertinent literature. The study's methodology is covered in detail in chapter three. It clarifies the tools used to gather the required data, the sampling process, research design, and techniques for gathering and analysing data. In chapter four, the research findings are presented and a comprehensive discussion is held in relation to the study's goals. Chapter five, the last chapter, provides a summary, conclusions, implications, and suggestions based on the study results.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter offers an extensive examination of research that is pertinent to the current study. The chapter is divided into three sections. The first section covers the theoretical framework that form the basis of the study, namely Resilience Theory and Adaptation Theory. The second section then reviews empirical studies relevant to the current investigation. The final section introduces the conceptual framework that underpins the study.

2.2 Theoretical Preposition

2.2.1 Resilience Theory

The theory of resilience originated in the 1970s within the field of ecology, stemming from the research conducted by C.S. Holling. Holling defined resilience as a measure of the ability of systems to withstand changes and disturbances while maintaining stable relationships between populations or state variables (Holling, 1973). The theory of resilience has generated various perspectives and inputs from many scholars, as noted by Dugan & Coles in 1989.

According to Walsh (2016), the theory of resiliency is the ability to effectively deal with life situations that are disruptive, stressful, or challenging. This process enables individuals to develop additional protective and coping skills that surpass their pre-existing abilities before experiencing the disruptive event. In a similar vein, Sullivan et al. (2018), provided a description of resiliency as the process of self-restoration or personal development, whereas Neenan (2017), offered a definition that characterizes it as the ability to recover from adversity, endure suffering, and engage in self-repair.

Resiliency is conceptualized as a form of positive adaptation characterized by the exhibition of socially competent behavior or the achievement of success in accomplishing specified tasks over a particular period of life (Masten & Tellegen, 2012). In essence, resilience is described as the capacity of a system to effectively absorb and adapt to disruptions while maintaining its fundamental function and structure (Woods, 2017). Resilience is also defined as the ability to adapt and undergo transformation while preserving one's fundamental identity (Folke et al., 2010).

In the analysis of ecological systems by Windle (2011), it is proposed that the characterization of behavior can be most effectively accomplished by considering two separate properties: resilience and stability. Resilience plays a crucial role in maintaining the continuity of interactions within a given system. It represents the capacity of these systems to withstand and adapt to alterations in state variables, driving variables, and constraints while remaining functional and enduring. In this definition, resilience refers to the inherent characteristic of a system to endure and potentially avoid extinction. In contrast, stability refers to the capacity of a system to return to a state of equilibrium following a temporary disruption.

The theory of resilience is frequently examined and analysed within the framework of a two-dimensional construct that involves the experience of adversity and the subsequent beneficial adaptation to that adversity (Prince-Embury, 2012). The concept of resilience is a subject of investigation in several studies and academic journals.

However, there is limited agreement among researchers regarding the definition of adversity and the specific criteria for determining favourable adjustment results. According to Cicchetti (2010), the examination of resilience theory has primarily concentrated on two key aspects. Firstly, it has explored the attributes, known as risk factors, of households, families, and environments that make them susceptible to experiencing difficulties after being exposed to adversity. Secondly, it has investigated the qualities of protective factors that serve as a safeguard against significant maladjustment in these households.

The model proposed by Sharifi (2016), has gained significant recognition as an ecological framework for comprehending the process of resilience. Several researchers have employed this theoretical framework to examine the concept of resilience (Wang & Gordon, 2012; Morales & Trotman, 2004; Werner & Johnson, 2002). The triadic approach elucidated the intricate interplay between risk and protective factors at three distinct levels: individual, family, and environmental. The model additionally highlights the concept of resilience as a dynamic process that enables individuals to exert influence on their surroundings and, in turn, be influenced by them.

Cicchetti and Valentino (2015) proposed an interactive ecological-transactional model of development that emphasizes the dynamic interplay of many contextual factors, such as culture, neighbourhood, and family, in shaping individuals' development and adaptive processes through time. These ecological models emphasize the convergence of diverse influences on an individual's development and how risk and protective factors can interact to either promote or impede an individual's resilience.

The notion of resilience as a dynamic process encompasses the recognition that resilience either increases or decreases over time, contingent upon the interactions occurring between an individual and their environment, as well as the interplay between risk and protective factors in an individual's life (Lowerre-Barbieri et al., 2017; Sippel et al., 2015). Hence, it is plausible that an individual's resilience may vary across different situations, contingent upon the specific circumstances and the comparative potency of protective variables with risk factors at any given point in time (Henry, Sheffield-Morris & Harrist, 2015).

According to Bonanno and Diminich (2013), resilience is understood as a consistent pattern of behaviour and adaptability over some time, wherein individuals demonstrate positive adjustment despite exposure to various risk factors, acute stressors, or ongoing adversity. According to Serfilippi and Ramnath (2018), the prevailing perception of resilience as an attribute inherent to individuals, families, or communities is deemed insufficient. The understanding and enhancement of resiliency cannot be effectively achieved by solely focusing on individual-level issues. It is imperative to give due consideration to structural inadequacies within society to implement social policies that address the needs of families, enabling them to develop resilience, expertise, and improved functionality under challenging circumstances.

In the context of flood vulnerability in Tamale's prone areas, residents and communities demonstrate responses to environmental changes through a variety of physical, behavioral, environmental, and hereditary adaptations. These adaptations are critical for restoring their ability to effectively cope with future unpredictable flood events. Just as Holling emphasized the importance of perseverance in the face of environmental challenges, a resilient approach to flood management in Tamale's vulnerable areas would prioritize flexibility in decision-making, localized assessments of situations, and diversity. Such an approach requires the capacity to construct systems capable of assimilating and adapting to unforeseen flood events. The primary goal of addressing flood vulnerability in Tamale's prone areas is to create and maintain thriving social, economic, and ecological systems. The sustainability of these communities is intrinsically linked to their dependence on ecosystem services for sustenance and stability. Therefore, this needs to work towards establishing resilient socio-ecological systems within the framework of flood vulnerability management.

To effectively address flood vulnerability, it is imperative to grasp the concept of resilience. Social and ecological systems in flood-prone areas exhibit nonlinear behavior and have distinct thresholds in their dynamics. These areas are characterized by interconnected, complex, and ever-changing integrated structures. The concept of resilience thinking is inherently connected to systems thinking, just as it is to sustainable development. When considering the interplay between human and natural systems in flood-prone areas, often referred to as social-ecological systems, it is essential to adopt a holistic perspective that encompasses the entire system.

In this context, resilience is associated with systems thinking, and three essential concepts are important (Uddin, Routray & Warnitchai, 2019): Residents and communities in flood-prone areas are closely connected to the ecological systems in which they are located. Social-ecological systems are complex adaptive systems that react to changes in a non-linear and unpredictable way. Resilience thinking offers a conceptual framework to see the social-ecological system in flood-prone areas of Tamale as a unified entity that functions across different interconnected time and space scales. This study primarily aims to comprehend how systems adapt and demonstrate resilience in the face of external flood disturbances.

2.2.2 Adaptation Theory

The theory of adaptation is founded upon the core principle of natural selection, as originally postulated by Charles Darwin in his seminal publication "On the Origin of Species" in the year 1859 (Bajema, 1985). In an era of increasing climate-related disasters, adaptation theory has emerged as a critical framework for understanding and addressing the challenges faced by flood victims. Floods, which result from a complex interplay of natural and human factors, pose significant threats to individuals, communities, and societies. As these events become more frequent and severe due to climate change, the need for effective adaptation strategies becomes ever more pressing.

Adaptation theory recognizes that the environment is dynamic and constantly evolving. Whether the changes are driven by climate shifts, natural disasters, or other environmental factors, entities must respond to these changes to maintain their functionality and well-being. Adaptation encompasses a spectrum of responses, from incremental adjustments to transformative changes in strategies, behaviors, and systems (Park et al., 2012).

Flood victims, whether individuals or entire communities, often find themselves in a precarious position due to their vulnerability to flooding. Vulnerability in the context of floods is influenced by several factors such as geographic location, socio-economic status, infrastructure, and access to early warning systems (Perera et al., 2020). Also, flood victims who have experienced multiple flooding events usually develop adaptive capacities based on their prior encounters with floods. These capacities could include knowledge about effective evacuation routes, access to emergency supplies, and awareness of community resources. In the context of Tamale's metropolis, assessing flood vulnerability and developing adaptation strategies is crucial for protecting the city's residents, infrastructure, and economy from the impacts of flooding. This involves a range of measures, such as building flood defenses, improving drainage systems, and implementing early warning systems.

2.3 Definition of Concepts

Flood: A flood is the inundation of water onto typically arid terrain, frequently triggered by intense precipitation, snowmelt, or the abrupt discharge of water from a reservoir or dam.

Vulnerability: The degree to which a system, community, or region is vulnerable to harm or damage from an external hazard, like flooding, is known as vulnerability.

Adaptation Strategies: Adaptation strategies are measures and actions taken to reduce the negative impacts of flooding and enhance the resilience of communities and systems to such events.

Prone Areas: Prone areas are regions or specific locations within Tamale that are particularly susceptible to flooding.

2.4 Concept of Vulnerability

The concept of vulnerability emerged from scholarly investigations in the field of social sciences throughout the 1970s, specifically concerning the evaluation of risks associated with disasters. During that period, vulnerability primarily pertained to the susceptibility of buildings and structures to risks, and the subsequent damage incurred as a result of physical forces. The field of disaster and risk research has undergone a notable progression of paradigms over the past few decades, specifically the behavioural paradigm (Gill & Ritchie, 2018) and the physical vulnerability paradigm (Koca-Atabey et al., 2011).

The concept of vulnerability lacks a universally accepted definition, leading different academic disciplines to formulate their interpretations of its meaning. In this context, it is imperative to engage in a discourse on the conceptualization of vulnerability as delineated in scholarly literature, as well as to delve into the understanding of other terminologies that bear relevance to the notion of vulnerability. Birkmann (2006) asserts in his publication "Measuring vulnerability to Natural hazard" that researchers from several disciplines endeavour to quantify vulnerability, but encounter challenges in providing a clear definition.

According to Turner et al. (1996), vulnerability is a complex notion that encompasses various dimensions, including biophysical, social, political, and ethical issues. The authors assert that while there is a prevailing focus on the vulnerability of the poor to floods, it is important to recognise that the rich are equally susceptible to such disasters, mostly due to the significant economic losses they may incur (Van der Geest, 2018). However, it should be noted that the impoverished population does experience economic hardships. The comparison primarily focused on the ability to accumulate wealth and valuable assets, with the observation that those with lower socioeconomic status possess a diminished capacity to acquire assets, resulting in comparatively lesser losses during flood events (Turner et al., 1996). According to the research conducted by Mahanta and Das (2017), it is posited that floods contribute to the vulnerability of individuals and communities to poverty.

This implies that individuals are at an increased risk of experiencing poverty as a result of a lack of assets. The interplay between individuals' susceptibility to floods as a result of poverty and their susceptibility to poverty as a consequence of floods introduces an additional dimension of indirect vulnerabilities that has significant importance in the field of vulnerability studies. The characterization of vulnerability as a multidimensional construct implies that there exist multiple elements that contribute to the determination of individual or collective susceptibility. The examination of the susceptibility to poverty resulting from floods is of utmost importance in the field of disaster studies, as it elucidates the interconnectedness of various processes and consequently establishes a self-perpetuating cycle. Moreover, there exists a correlation between poverty and disasters, indicating that by first addressing poverty concerns, the individuals impacted will acquire the capacity to effectively manage and respond to catastrophes. Additionally, by mitigating the consequences of disasters in certain regions, the overall impact can be diminished. The improvement in the socio-economic position of impacted individuals will consequently lead to a reduction in levels of poverty. The mitigation of disasters entails a decrease in the adverse consequences caused by floods, resulting in either a reduction in the number or complete elimination of losses. Consequently, communities will be able to amass their assets without significant hindrance. The significance of comprehending vulnerability is in recognising that vulnerability to floods is a complex phenomenon influenced by several causes and processes, both direct and indirect, which necessitate thorough examination.

According to Bauer and Scholz (2010), the Southern African region is experiencing a faster increase in temperature compared to other parts of the world. This region, despite being one of the most impoverished and susceptible areas globally, is particularly affected. Insufficient resources, including financial means, contribute to increased vulnerability in the region, hindering effective responses to climate change impacts. At both the community and national levels, vulnerability depends on institutional capacity, which includes factors like national wealth, cultural aspects, and level of indebtedness (Turner et al., 1996). Therefore, this statement emphasizes the significant role of knowledge, economic markets, and policy failure in intensifying vulnerability in climate-sensitive regions. These factors also highlight the complexity of adapting to climate change, as weather events are unpredictable and can impact the success of adaptation initiatives over time. Adeagbo et al. (2016) define the term "degree of loss" as the level of damage suffered by a particular element or group of elements at risk as a result of a natural event of a specific intensity. This extent is measured on a scale from 0 (no damage) to 1 (complete destruction).

Various physical, social, economic, and environmental factors affect the human condition and determine the likelihood and extent of harm from a particular hazard. A community's susceptibility to the effects of hazards is determined by a mix of physical, social, economic, and environmental factors or mechanisms (Papathoma-Köhle et al., 2017).

Social vulnerability, as defined by Mezzina et al. (2022), is the inherent capacity of individuals and social groups to effectively react to external stressors that affect their lives and well-being. This concept focuses on the socioeconomic and institutional constraints that impede the ability to deal with, recover from, or adjust to such stressors.

This study is in line with Weichselgartner and Kelman's (2015) conceptualization of vulnerability, which highlights the incorporation of social factors and environmental hazards. Moreover, susceptibility to climate change can be seen as including the temporal fluctuations in these factors.

Adger and Brown (2009) suggest that the basic elements of vulnerability include:

Exposure: The nature and degree to which a system experiences environmental or socio-political stress

Sensitivity: Sensitivity is the ability of a human or natural system to withstand impacts without suffering long-term damage or undergoing major changes. Physical systems can be analysed using impact response models to evaluate sensitivity. However, ecological and social systems require a more detailed interpretation because of the complex nature of defining harm and state change.

Adaptive capacity: The system's capacity to adapt to environmental disturbances and increase its ability to handle a broader range of unpredictability.

The concept of risk refers to the likelihood of adverse outcomes, encompassing various detrimental consequences such as fatalities, injuries, property damage, livelihood disruptions, economic ramifications, and environmental degradation (Kelman, 2018). These outcomes arise from the interplay between natural or human-induced hazards and conditions of vulnerability. Nevertheless, the risk is commonly conceptualised as the outcome resulting from the multiplication of the probability of a hazard occurring and the magnitude of its potential repercussions. The relationship between hazard events and the vulnerability of exposed elements can be conceptualized as a function, where vulnerability represents the inherent and ever-changing characteristic of items at risk.

Hinkel (2011), has put forward different categorizations of vulnerability, with comparable terminology. To facilitate comprehension, this discussion will focus solely on four distinct categories of vulnerability.

Physical vulnerability: Physical vulnerability refers to the inherent susceptibility of the built environment and its inhabitants to potential physical impacts. This category includes all tangible cultural assets, such as infrastructures and buildings.

Economic vulnerability: The potential consequences of hazards on economic assets and processes, including business interruption and downstream effects such as heightened poverty and job loss, are of significant concern. The susceptibility of various economic sectors to external shocks or disruptions.

Social vulnerability: Refers to the susceptibility of certain groups, including individuals from low-income backgrounds, single-parent households, women, people with disabilities, children, and the elderly, to the potential consequences of various events. This concept encompasses factors such as public awareness of risks, the capacity of these groups to independently manage and recover from disasters, and the effectiveness of institutional frameworks established to support their coping mechanisms.

Political-Institutional vulnerability: The components encompass intangible aspects like the framework of governance and the process of decision-making, as well as organizations dedicated to managing disasters and mitigating risks.

2.5 Vulnerability assessment methods and frameworks

According to Roncancio, Cutter and Nardocci (2020), the conceptual framework of social vulnerability encompasses both exterior and interior dimensions of vulnerability. The external facet pertains to the encounter with risks and shocks, encompassing the exposure to hazards as a fundamental element of vulnerability. The term "internal side" pertains to the psychological and emotional processes involved in managing and adapting to adverse situations, including the ability to predict, cope with, withstand, and recuperate from the effects of danger. Vulnerability arises from the dynamic interplay between an individual's exposure to external stressors and their capacity to cope with these stressors.

Turner et al. (2003) provide a detailed representation of model vulnerability, shown in Figure 2.1. The model operates at various spatial scales, such as global, regional, and local levels, and includes functional and temporal dimensions to enable interactions among different entities. Vulnerability is determined by exposure to risks, sensitivity, and resilience of the system facing these hazards. Exposure sensitivity is influenced by the complex and ever-changing interaction between human and environmental factors.

This study focuses on the analysis and exploration of vulnerability within the broader and interconnected context of the human environment. The paradigm explicitly incorporates exposure, sensitivity, and resilience as components of vulnerability, specifically categorised as coping response, impact response, and adaptation response. This model possesses three advantages: There are three key aspects to consider about this framework. Firstly, it examines the interconnectedness between the human and environmental systems. Secondly, it aids in the discovery of crucial interactions within this system, which can provide valuable insights for decision-makers. Lastly, it is flexible in its approach, allowing for the incorporation of both quantitative and qualitative data.

However, this methodology encompasses a broad range of vulnerabilities, as it does not provide any guidance on how to assess vulnerability in a specific localized situation.

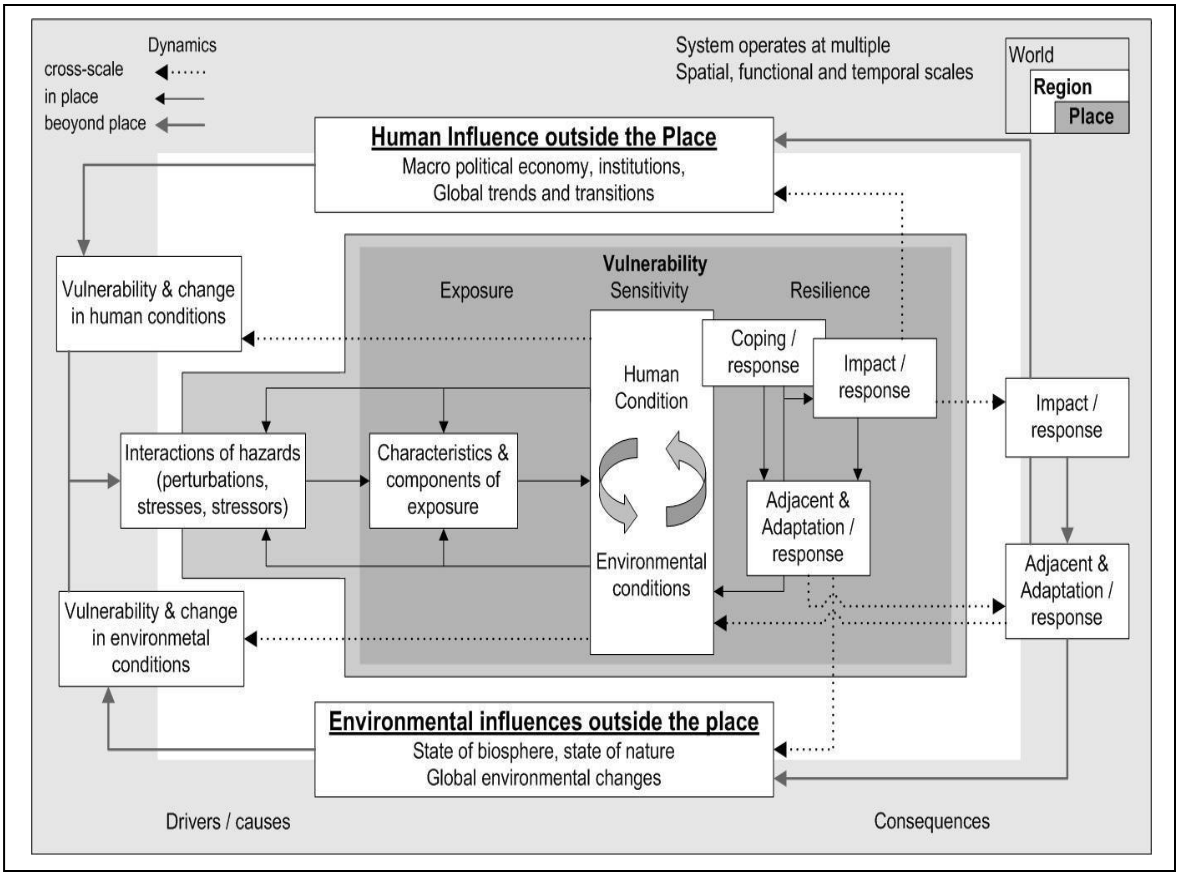

Figure 2.1: Vulnerability framework

Source: Turner et al (2003)

2.6 Methodologies and models used to assess flood vulnerability

Assessing flood vulnerability is a critical component of disaster risk reduction and preparedness. To evaluate flood vulnerability, various methodologies and models are employed, often involving vulnerability indices and Geographic Information Systems (GIS)-based approaches. These tools provide valuable insights into the potential impact of floods on communities, infrastructure, and the environment.

2.6.1 Vulnerability Indices

Vulnerability indices are analytical tools used to quantify and assess the vulnerability of communities, regions, or systems to various hazards, such as natural disasters, climate change, or socio-economic challenges. These indices provide valuable insights into the factors that contribute to vulnerability and help inform strategies for risk reduction, resilience building, and disaster management.

2.6.2 Social Vulnerability Index (SoVI)

The Social Vulnerability Index (SoVI) is a widely employed instrument utilised for the evaluation of social dimensions of vulnerability across diverse populations (Spielman et al., 2020). The assessment considers multiple variables, including income, education, age, and health, in order to ascertain the degree of susceptibility within a specific demographic. The application of the Social Vulnerability Index (SoVI) is particularly advantageous in the identification of communities that exhibit heightened susceptibility to floods as a result of their socioeconomic circumstances.

The Social Vulnerability Index (SoVI) was created as a method to comprehensively comprehend and effectively tackle the societal aspects of vulnerability. Natural catastrophes such as flooding have the potential to impact any society, albeit with varying degrees of vulnerability (Chaudhary & Piracha, 2021). However, certain communities may exhibit heightened susceptibility to these events as a result of their specific social and economic circumstances. The Social Vulnerability Index (SoVI) offers a thorough evaluation of social vulnerability by taking into account many criteria including income, education, age, and health (Mah et al., 2023).

The role of income in assessing vulnerability is significant since it directly impacts a community's capacity to effectively anticipate and respond to adverse events and subsequently restore normalcy. Low-income communities sometimes face a dearth of financial resources that hinders their ability to effectively implement mitigation measures or undertake post-flood reconstruction efforts (Wilson, Tate & Emrich, 2021). This phenomenon has the potential to result in extended periods of recovery and heightened susceptibility to subsequent calamities. Communities characterized by lower educational attainment may have constraints in terms of accessing pertinent information pertaining to flood hazards and adopting appropriate preparedness strategies. Insufficient understanding can impede individuals' capacity to adequately address and recuperate from occurrences of floods (Rana et al., 2020).

Age is another crucial factor considered by SoVI. Elderly individuals may have distinct obstacles in the context of flood situations, including but not limited to restricted physical mobility or the presence of chronic health ailments that impede their ability to evacuate or avail themselves of emergency services (Sung & Liaw, 2020). Furthermore, it is worth noting that older individuals may have a reduced availability of resources, hence intensifying their susceptibility.

The assessment of vulnerability encompasses health as a crucial component. Communities with higher rates of chronic illnesses or limited access to healthcare services may be more susceptible to the impacts of flooding (Parker, Wellbery & Mueller, 2019). These populations may experience greater health risks during and after flood events, making them more vulnerable overall. By considering these factors collectively, SoVI provides a comprehensive understanding of the societal aspects of vulnerability in relation to flooding. It helps identify communities that are more susceptible to the impacts of flooding due to their socioeconomic conditions. This information is crucial for policymakers, emergency management agencies, and community organizations to develop targeted interventions and allocate resources effectively.

2.6.3 Physical Vulnerability Index (PVI)

Physical Vulnerability Index (PVI) is a methodology designed to evaluate the physical attributes of the constructed environment, encompassing elements such as building construction, infrastructure, and land utilization (Rahman et al., 2023). The objective of this study is to quantitatively assess the vulnerability of structures and infrastructure to potential flood-related damages. Through the examination of these parameters, the PVI offers significant and noteworthy perspectives regarding the susceptibility of a certain region to occurrences of floods.

Building construction is a significant factor that is considered in the calculation of the PVI. The vulnerability of buildings to floods is significantly influenced by their quality and resilience. Buildings that possess weak foundations, insufficient structural design, or substandard construction materials are prone to experiencing damage in the case of flooding (Kikwasi & Mbuya, 2019). Moreover, the susceptibility of a building is greatly influenced by the inclusion or exclusion of flood-resistant attributes such as raised foundations, flood barriers, or waterproofing measures.

Furthermore, the manner in which land is utilised within a certain geographical region have a significant impact on its susceptibility to flooding events. Areas and regions characterised by substantial urbanisation and the prevalence of impermeable surfaces such as concrete or asphalt have diminished natural drainage capabilities, hence augmenting the vulnerability to flood occurrences (Oswald et al., 2023). Conversely, regions characterised by well managed green spaces or unaltered floodplains have the potential to serve as effective natural flood prevention measures through their capacity to absorb surplus water (Sobieraj, Bryx & Metelski, 2022).

In order to establish the Physical Vulnerability Index (PVI), a range of data sources are employed. These data sources encompass geographic information system (GIS) data, satellite imagery, aerial pictures, topographic maps, and historical flood records (Murthy, 2020). Through the integration of these datasets and the application of suitable algorithms and models, researchers and planners have the capability to produce a full evaluation of the physical susceptibility of a particular region to flooding.

2.6.4 Environmental Vulnerability Index (EVI)

Is a widely employed instrument utilised for the evaluation of an area's susceptibility to environmental hazards, with a special emphasis on floods. This study assesses a range of ecological and environmental variables that could influence susceptibility to flooding, encompassing elements such as natural barriers, biodiversity, and soil composition. The index offers a thorough evaluation of the vulnerability of a given metropolis to environmental hazards, aiding policymakers and researchers in the identification of high-risk areas and the prioritisation of mitigation strategies.

2.7 GIS-Based Approaches

Geographic Information System (GIS) is a powerful tool that helps in obtaining, storing, analysing, and visualising spatial data (Ammar & Dadi, 2021). GIS-based approaches utilise Geographic Information Systems (GIS) technology to tackle complex challenges and support informed decision-making in various fields such as urban planning, environmental management, transportation, agriculture, and public health.

2.7.1 Flood Hazard Mapping

Geographic Information Systems (GIS) are extensively employed in the cartographic representation of areas susceptible to flooding. Through the examination of topography, rainfall data, river discharge, and historical flood events, Geographic Information Systems (GIS) have the capability to generate flood hazard maps that effectively delineate regions susceptible to flooding (Ogato et al., 2020). The creation of a flood hazard map utilising Geographic Information Systems (GIS) entails a series of sequential procedures:

1. **Data Collection**: The initial stage involves the acquisition of pertinent data, including topographic maps, rainfall data, river flow data, and historical flood event data. The aforementioned data is crucial in the identification of regions that exhibit a susceptibility to floods.

2. **Data Preprocessing**: After the collection of data, it is necessary to undergo a preprocessing stage in order to guarantee its accuracy and consistency. The process involves the elimination of any instances of missing or duplicated data, as well as the transformation of the data into a format suitable for utilisation inside Geographic Information System (GIS) software.

3. **Flood Inundation Modelling**: Following the preprocessing of data, the subsequent stage involves the development of a flood inundation model utilising Geographic Information Systems (GIS). This entails utilising the available data to model the hydrological behaviour of water in the specified region during a flood occurrence.

4. **Cartographic Production**: Following the development of the flood inundation model, the subsequent phase involves the production of a flood danger map. The presented map illustrates the geographical regions that are susceptible to flooding, along with the corresponding levels of flood intensity.

5. **Validation of the Flood Hazard Map**: Ultimately, it is imperative to undertake a thorough validation process to ascertain the accuracy and dependability of the flood hazard map. This can be achieved through a process of comparing the cartographic representation of flood-prone areas with empirical data on past flood events, and subsequently making appropriate modifications as needed.

The utilisation of Geographic Information Systems (GIS) for flood hazard mapping offers numerous advantages. The benefit is in the capability of Geographic Information Systems (GIS) to facilitate the amalgamation of diverse data sources, so enabling a more comprehensive comprehension of the flood hazard (Arvidsson, Johansson & Guldåker, 2021). Moreover, GIS have the capability to generate maps that exhibit a high level of detail and precision. This attribute becomes invaluable in the identification of regions that possess a heightened susceptibility to floods.

2.7.2 Risk Assessment

Floods are a prevalent and highly destructive category of natural disasters, capable of inflicting substantial economic, social, and environmental consequences. Comprehending the potential hazards associated with floods is of utmost importance for communities in order to proactively implement strategies aimed at mitigating and adapting to the resulting consequences. The utilisation of "GIS" enables the evaluation of flood risk through the integration of data pertaining to flood hazard, exposure, and susceptibility. This entails the process of calculating the probability of a flood occurrence and evaluating its potential ramifications in relation to economic, social, and environmental effects (Foudi, Osés-Eraso & Tamayo, 2015).

2.7.3 Flood Hazard Assessment

The initial stage in evaluating the potential for flooding involves the identification of regions that are susceptible to inundation. The likelihood of flooding in a specific location can be assessed by the examination of topographic maps, hydrological data, and flood maps. G.I.S have the capability to generate a flood hazard map, which delineates the geographical regions susceptible to flooding. This map is constructed by considering many parameters, including but not limited to river flow, storm surge, and rainfall intensity (Shen et al., 2019).

2.7.4 Assessment of Flood Exposure

After the identification of flood-prone locations, the subsequent stage involves evaluating the vulnerability of individuals, infrastructure, and assets to these flood-related risks. The identification of flood risk exposure can be achieved by the examination of population data, land use patterns, and infrastructure information, which collectively provide insights into the extent of vulnerability for individuals and assets. G.I.S is utilised to generate an exposure map, which visually represents the spatial distribution of individuals, infrastructure, and property in relation to areas prone to flooding.

2.7.5 Flood Vulnerability Assessment

The consideration of communities' vulnerability to flood risk is a crucial factor to take into account. The assessment of communities' capacity to recover from flood occurrences is conducted through the analysis of socioeconomic data, encompassing variables such as income levels, education levels, and access to healthcare (Bergstrand et al., 2015). G.I.S have the capability to generate a vulnerability map, which visually represents regions exhibiting elevated degrees of vulnerability. This map is constructed by considering various characteristics, including population density, infrastructure quality, and economic activity.

2.7.6 Quantifying Flood Risk

After conducting an assessment of flood danger, exposure, and susceptibility, the utilisation of G.I.S facilitates the quantification of flood risk. The utilisation of a risk assessment methodology that considers the probability of a flood occurrence and its potential ramifications in relation to economic, social, and environmental effects might facilitate this process. G.I.S have the capability to generate a risk map that visually represents regions characterised by elevated levels of flood risk. This is achieved by integrating many criteria like flood hazard, exposure, and vulnerability.

2.7.7 Scenario Planning

Scenario planning is a strategic technique utilised by planners and decision-makers to engage in the exploration of diverse future possibilities and assess the probable consequences of alternative actions or occurrences (Cairns, Goodwin & Wright, 2016). G.I.S have a significant role in enabling scenario planning, specifically in the assessment of flood susceptibility and the evaluation of various techniques' efficacy in mitigating vulnerability.

2.7.8 Evolution of Flood Vulnerability Scenarios

G.I.S facilitate the creation of diverse flood vulnerability scenarios by the integration of geographical data pertaining to elements including terrain, land use, hydrology, infrastructure, and population distribution. Through the process of overlaying these datasets and conducting an analysis of their interrelationships, urban planners possess the ability to construct all-encompassing models that effectively mimic prospective flood occurrences and their corresponding repercussions on various geographical regions. By adopting G.I.S, urban planners have the ability to integrate historical flood data into their analyses. This enables them to effectively identify regions that are susceptible to flooding and gain a comprehensive understanding of the patterns and intensity of previous flood occurrences. The provided data is employed to build scenarios that forecast potential flood hazards in the future, considering variables like climate change predictions, urban development strategies, and alterations in land utilisation patterns.

2.8 Concept of Floods

Floods occur due to the swift build up and discharge of drainage waters from higher to lower areas, triggered by intense precipitation (Wang et al., 2019). Floods often happen when the volume of water in a stream exceeds the capacity of its channel, causing it to spill over onto nearby areas (Cunningham et al., 2011). Flooding is the overflow of water onto land that is usually dry. Heavy rainfall is the main factor causing flooding, but other types of floods can also be connected to current weather conditions indirectly. A thorough description of flooding should include practices that are not limited to meteorological events (Frame et al., 2020). Flooding has substantial repercussions, resulting in around 20,000 fatalities and affecting a minimum of 20 million individuals globally, especially those who are homeless, in diverse manners (Das & Samanta, 2022). Flooding is considered one of the most common environmental disasters worldwide, following epidemics and transportation accidents. The reason for this is the geographical distribution and enduring appeal for human habitation of river floodplains and low-lying coasts (Das & Samanta, 2022). Floods can affect the social, economic, and political well-being of a population.

Floods are notable natural events where water exceeds the boundaries of rivers or designated retention areas. As a result, the overflow spreads into areas with human settlements, infrastructure facilities, and economic activity. Floods can turn into a disaster when a region is exposed to the hazard without enough warning or the capacity to take defensive actions, leading to casualties, property and infrastructure damage, loss of livelihoods, and compromised environmental safety.

2.9 Flooding in Global Perspective

In September 2023, Greece experienced a major flood event called Storm Daniel, which led to the tragic deaths of six people and left several others missing (Zachariah et al., 2023). Brazil experienced its most severe natural disaster in the last forty years, leading to the unfortunate death of more than 31 individuals (de Oliveira, Lee & Quintana-Domeque, 2023). In September 2023, Madrid, Spain experienced a major flood that led to the deaths of three people and the disappearance of three others. The event was caused by an unusually high level of rainfall, resulting in widespread flooding in the central region of Spain. Typhoon Doksuri in China caused severe flooding, resulting in 29 fatalities and significant economic losses totalling tens of billions (Manandhar et al., 2023).

In the calendar year 2021, a total of 206 notable flood calamities transpired, constituting more than 56% of the aggregate tally of noteworthy occurrences of major natural calamities (Chahim, 2021). The flood disasters led to a regrettable loss of 4,393 lives, or approximately 42% of the overall fatalities. Additionally, an estimated 29.2 million of individuals were impacted by flooding accounting for 28% of the population, being affected. This is a decrease from the previous year's figure of 33.21 million in 2020. The direct financial damages surpassed USD 74.6 billion, accounting for nearly 30% of the whole direct economic losses stemming from the accident. The frequency of flood disasters in the year 2021 showed a significant rise of 48% compared to the average frequency seen over the preceding three decades (1991-2020) (Bokwa et al., 2021). Nevertheless, it is important to acknowledge that there was a 35% reduction in the number of fatalities attributed to these flood disasters. Likewise, there was a substantial decrease of 71% in the number of individuals affected by these occurrences. In contrast, the flood disasters resulted in a significant increase of 118% in direct economic losses. The occurrence of flood-related calamities in 2021 witnessed a 41% increase compared to the mean value observed in the previous decade (2011-2020). In contrast, there was a notable reduction of 9% in the fatality rate associated with these calamities, accompanied by a 43% fall in the number of affected individuals (Hamidifar & Nones, 2021). In the year 2021, a flood catastrophe occurred, leading to a mortality rate above 1,000 persons. India, among various other Asian nations, had substantial flooding that led to the loss of numerous lives as a consequence of the inundation produced by excessive precipitation during the monsoon period (Dewan, 2015).

According to Felima (2009), Haiti, a Caribbean nation, saw the highest number of fatalities due to flooding in 2004, making it the most severe flood event worldwide. The study additionally indicated that there was a prolonged period of intense precipitation lasting for a duration of fourteen (14) days. This excessive rainfall resulted in the swelling of rivers and subsequent overflow of river banks, primarily occurring in the southern regions next to the Dominican Republic. The floods resulting from persistent rainfall were responsible for a death toll exceeding 2,400 individuals (Felima, 2009). From 2001 to August 2010, the floods that occurred in Pakistan resulted in the loss of a minimum of 1,200 people, so earning the distinction of being the second most severe flood globally (Balgah et al., 2015).

The floods in Africa between 1996 and 2005 had notable detrimental impacts on the continent (Somorin, 2010). A total of 290 flood disasters were recorded throughout the African continent throughout the course of the seven-year period. According to Board (2010), the recorded number of fatalities was roughly 8,183 individuals, with approximately 23 million people being affected by the event. Additionally, the economic losses associated with the incident were estimated to be at $1.9 billion. Numerous media outlets and humanitarian organisations operating in the Sub-Saharan African region have documented a significant number of occurrences of flooding.

2.10 Flooding in Ghana

The phenomenon of flooding in Ghana has emerged as a reoccurring peril on an annual basis. Researchers are presently involved in experimental efforts targeted at flood management with the objective of reducing the loss of human life and property. During the preceding decade, floods have led to the unfortunate loss of several lives and inflicted significant harm upon both public infrastructure and private property (Amoateng et al., 2018).

Salami, Von Meding, and Giggins (2017) assert that Ghana has achieved a notable standing in the rankings of African countries that confront substantial vulnerability to diverse weather-related hazards, specifically those linked to natural disasters such as floods and droughts. Urban areas exhibit a considerable susceptibility to flood-related destruction owing to the high density of assets and inhabitants within confined geographical limits, as well as the existence of inadequately planned infrastructure. Urban flooding is a phenomenon characterized by the accumulation of floodwaters resulting from the excessive entry of stormwater that exceeds the capacity of the drainage system to either absorb water into the soil or efficiently convey it elsewhere.

The primary objective of the water derived from the Bagre Dam in Burkina Faso is to enhance the irrigation of agricultural lands during periods characterised by reduced precipitation, hence providing crucial assistance to farming endeavours within the region (Musah et al., 2013). Moreover, it assumes a pivotal function in the restoration of water levels in the Akosombo Dam, particularly during periods of severe depletion. However, the dam saw an excess in 2007 as a result of substantial precipitation. Consequently, the water that had been accumulated in the dam was subsequently released into the White Volta River, ultimately entering Ghana at a volumetric flow rate of 900 m^3 per second. This discharge of water resulted in the occurrence of floods (Agodzo, Bessah & Nyatuame, 2023). The flood had a substantial influence on the entirety of the nation, particularly focusing on the northern regions (Rain et al., 2011). The flooding led to significant damage to residential buildings, water distribution systems, and sewage infrastructure, as well as the destruction of bridges, educational facilities, and streets. Moreover, the torrential downpour resulted in substantial harm to agricultural production and livestock. A significant number of homes were subjected to involuntary displacement. As stated by Yelfaanibe and Zetter (2018), the displaced family sought sanctuary in educational institutions and religious organisations. Furthermore, the occurrence of floods has given rise to health concerns, specifically the possibility of disease outbreaks. The National Disaster Management

Organisation (NADMO) faced difficulties in providing adequate food and other forms of aid to the individuals impacted by the floods (NADMO, 2007).

The causation of the recent floods in Ghana cannot be solely ascribed to intense and prolonged precipitation, as has been noted. The worsening of this problem has been intensified by human activities, such as the building and control of dams, as well as the release of pollutants to obstruct the natural movement of water bodies (Rain et al., 2011). The flooding disaster in Accra in July 1995 had a substantial effect on both human lives and property. The event also led to the disturbance of crucial utility services and public facilities, including water supply, telephone services, electricity, transport routes, and railways (Azolibe & Okonkwo, 2020). Heavy rains on June 21, 2023, caused flooding in the Greater Accra, Western, and Ashanti regions of Ghana. Significant disruptions in the transport infrastructure in the Greater Accra region caused subsequent traffic congestion. Over the last ten years, there has been a continuous increase in the amount of surface water runoff in the Tamale metropolis. This phenomenon is caused by the quick growth of housing, industry, infrastructure, and economic development (Issah, 2017).

2.11 Types of Floods

Floods are a common natural disaster that has substantial direct and indirect effects on both people and the environment (Cianconi, Betrò & Janiri, 2020). They are usually the result of a mix of meteorological and hydrological extremes, like intense precipitation and flows (Afriyie, Ganle & Santos, 2018). Nevertheless, human activities also play a role in causing floods. Unplanned urban expansion in floodplains and dam failures can result in flooding (Miguez et al., 2015). These classifications take into account a range of environmental and societal factors, causes, and socio-economic impacts. Floods can be classified as riverine, overland, coastal, groundwater floods, or the failure of artificial water systems (Jha, Bloch & Lamond, 2012). Furthermore, floods can be categorised and described as flash floods, urban floods, semi-permanent floods, or slow-rise floods, based on the speed and intensity of the flooding (Jha, Bloch & Lamond, 2012).

2.11.1 Riverine (fluvial) Flooding

Coastal rivers characterized by small, steep headwaters exhibit relatively rapid fluctuations in flood levels. Riverine floods occur when water levels surpass the capacity of a stream or river, overwhelming its natural or man-made banks. By examining the causes, timing, and depth variations across different areas, one can discern the diverse nature of riverine flooding. Prolonged rainfall in a particular region can lead to a gradual rise in river levels over an extended period (Legese, Gumi & Bule Hora, 2020). Additionally, the presence of rocks transported downstream during the flood can impede the water's escape, forcing the river to breach its embankments (Oppong, 2011). Some river flows exhibit a slow descent with relatively gentle gradients, persisting for several months (Talling, Paull & Piper, 2013). The construction of roads and buildings on floodplains, where rivers naturally overflow when their capacity is exceeded, can also contribute to the occurrence of fluvial floods. This can be attributed to the development of impermeable land on the floodplain, which heightens the risk of flooding due to obstructions. In situations where a river is forced to traverse a narrow channel, a phenomenon known as the bottleneck effect can accelerate the flow of water (Acharya & Chettri, 2012).

2.11.2 Overland (Pluvial) Flooding

Pluvial flooding occurs when the urban drainage system becomes inundated due to an abnormally heavy rainfall, causing the water to be unable to be effectively drained. Additionally, pluvial flooding can transpire when intense precipitation cannot be adequately absorbed by the soil, diverted through surface runoff, or directed via the drainage system. This type of flooding is typically instigated by slow-moving thunderstorms. Pluvial floods materialize subsequent to brief, but intense, rainfall events that surpass the drainage system's capacity to expeditiously evacuate the water or allow it to infiltrate the ground (Muneerudeen, 2017). Pluvial floods are commonly defined as occurring within a span of six hours or less. The occurrence of pluvial flooding is contingent upon prolonged periods of heavy rainfall. It arises when the urban (sub) surface drainage system is overwhelmed by precipitation, impeded from reaching the system due to various factors, primarily attributable to human activities (Ali et al., 2021). While natural disasters primarily instigate pluvial flooding, it can also arise from the failure of flood defenses and inadequacies in the drainage network system. With the advent of climate change and extensive development in flood-prone areas, the frequency of pluvial flooding is anticipated to escalate (Young & Essex, 2020).

2.11.3 Groundwater Floods or the Failure of Artificial Water Systems

Dam failure is a rare occurrence, but it can have serious consequences, such as downstream flooding and the presence of debris. To mitigate the risks associated with dam failure, it is important to have effective dam protection measures in place, as exemplified by the Victoria Dam in Sri Lanka, Western Australia. Early warning systems can be implemented to alert residents living downstream about potential risks. In addition, levee failure is typically the result of floods surpassing their capacity to control, leading to catastrophic outcomes. Dam failure can be attributed to poor decision-making during the design and construction phase, inadequate maintenance, or mismanagement within the organization responsible for the dam (Primo et al., 2021). Furthermore, natural hazards like earthquakes or excessive flow rates can also contribute to dam failure (Allen & Stogaitis, 2022).

2.11.4 Coastal Floods/Storm Surge

Storm surges happen when sea levels rise significantly above their usual tidal range due to the influence of intense low-pressure systems in the open ocean. Reduced atmospheric pressure leads to decreased force on the sea, causing sea level to rise. This occurrence may result in the inundation of low-lying coastal regions, along with powerful winds blowing towards the shore (Spanger-Siegfried et al., 2014). The storm leads to the elevation of water levels and the creation of high waves due to a low-pressure system causing a rise in sea level. The wind's impact may be more significant than the contribution to the heightened sea level (Xie et al., 2019). Coastal flooding initiates when waves penetrate inland, overflow, or breach the defenses of an unprotected coastline. The waves consistently assault the shore, causing erosion in the case of sandy coasts. Consequently, dunes may eventually collapse. During high tide, water can flow in and subsequently recede during low tide. Once the defenses are breached, the seawater advances more slowly over a wider area (Esteban et al., 2020).

2.11.5 Localized Flooding

This phenomenon commonly occurs due to a combination of an inadequate drainage system and highly compacted soil in the presence of pedestrian paths and roads between buildings or shelters. Following intense rainfall, these paths and roads transform into streams, exacerbating the issue (Kusi-Appiah, 2017). The accumulation of waste and debris in the limited number of drains further compounds the problem by obstructing their flow. Another type of localized flooding arises when minor urban streams rapidly rise after heavy precipitation, typically passing through small culverts beneath roads. Despite their adequacy at the time of design, these culverts experience increased water flow that surpasses their capacity as a result of ongoing structural developments in the area and the heightened intensity of storms, potentially influenced by factors like climate change.

2.12 Factors Causing Flooding

2.12.1 Factors causing flooding in urban areas

Due to the rise in volume after heavy rainfall, small streams located in urban areas easily overflow their scale (Kilsdonk, Bomers & Wijnberg, 2022). Also, city authorities have relatively small and insufficient culverts for easy water flow. These floods may appear to be adequate in size when compared to the typical water flow from streams of this nature. However, gradual changes in urban development, as well as variations in rainfall duration and intensity over a specific duration, often lead to increased water flows that exceed the capacity of these culverts (Gore & Banning, 2017). Additionally, these drainage systems often become clogged with solid waste, which is often dumped by local residents, resulting in a reduction in their passage size and hindering the free flow of water into them (Kusi-Appiah, 2017).

2.12.2 River Floods

Urban development contributes to extensive land use, particularly in relation to the construction of buildings and infrastructure. However, this development can often have detrimental consequences, such as when rivers overflow their banks and flood adjacent floodplains. The resulting floods not only lead to significant socioeconomic losses, but also pose a threat to human life (Miguez et al., 2015). In certain developing countries, efforts have been made to artificially enhance the protection of flood-prone areas through the construction of levees. Nevertheless, there remains a potential risk of these levees being breached, which can result in major urban flooding (Ferdous et al., 2019).

In the Tamale metropolis, the Gumani and Dungu areas are especially prone to flooding. The vulnerability is caused by the development of houses and buildings in the floodplain. The areas most affected by this flooding are where buildings are located near river banks and within the floodplain itself.

2.12.3 Wet Season Flooding in Low Land and Coastal Cities

Flooding is observed in lowland and coastal cities. In some areas, the wet season flooding can last for eight weeks or more. This can be attributed to the combination of rainfall and river water. Consequently, the water levels increase in swamplands that would ordinarily remain submerged during certain times of the year. Additionally, storm surges pose a risk of inundating the low-lying areas along the coast (Nortsu, 2018).

2.12.4 Flooding in Urban Areas

Flooding is recognized as a widespread environmental hazard. This phenomenon represents a natural or anthropogenic response of a system to an excessive accumulation of water within a specified timeframe. Natural causes of flooding pertain to those events that occur without direct human intervention (Keating et al., 2017). A prime illustration of natural flood causes is the escalation in global temperatures, which fosters the melting of glaciers and ice caps, thereby triggering premature ice thawing in rivers and lakes. This also raises the water level and allows the banks of the river or reservoirs to overflow and, thus, cause floods (Allen et al., 2021). The floods triggered by the direct acts and inactions of humans define the human causes of flooding. Hence, there is some kind of direct/indirect human control (O'Shea, Bates & Neal, 2020).

2.12.5 Urbanisation

Daily, there is a substantial increase in the number of individuals migrating from rural to urban areas. As urbanization continues to expand, there is a growing demand for the construction of buildings and structures to accommodate various activities, including shelter (Eduful, 2019). This surge in urban development has led to an elevated risk of flooding, particularly in cases where there are inappropriate or poorly maintained facilities, substandard shelters, and limited resilience among the urban poor (Jaszcz & Połap, 2022). In certain situations, the construction of buildings and infrastructure mirrors the design of streams and other primary drainage systems. However, these drainage channels are ill-equipped to handle the substantial amounts of silt that accompany the runoff during rainfall events (Ketter, 2018). Many individuals, due to their ignorance or blatant disregard for construction regulations, construct buildings haphazardly, exposing themselves to the hazards of erosion and flooding.

2.12.6 High Rainfall Intensities

In the Tamale Metropolis, the phenomenon of heavy rainfall is typically attributed to the occurrence of flooding. The Tamale Metropolis suffers from a lack of a proper drainage network system, which invariably exacerbates the issue of flooding following intense rainfall (Kayaga et al., 2021). Importantly, it is worth acknowledging that human activities are exacerbating this situation. Consequently, the soil becomes saturated, particularly in areas that lack paving, and is unable to retain water beyond its saturation point, resulting in escalated surface runoff (Huang et al., 2018).

2.12.7 Nature of Terrain

In low-lying areas or lowlands, flooding is prevalent. This is due to the fact that rivers flow at a slower pace in such regions, leading to floods when there is a sudden or unexpected rise in water levels (Gilmer, 2019). Conversely, on steep slopes, there is a decrease in the amount of water that can infiltrate the soil. Consequently, the excess water runs off swiftly into rivers. Steep slopes also facilitate the erosion of soil, further contributing to the elevation of river levels. Both of these scenarios can result in a rapid increase in river levels. On the other hand, relatively gentle slopes or flat terrain enable water to infiltrate the soil more easily, thereby extending the time it takes for water to reach rivers (Zhang et al., 2018).

2.12.8 Erosion, sediment transport, and attenuation of waste in rivers, streams, and drainage systems

Unpaved roads and pathways facilitate gullying and erosion between buildings on the land and the soil. This results in the degradation of road sections and infrastructure, as well as hindering the drainage of water into drains. Erosion leads to sediment distribution. The sediment is carried by the floodwaters, clogging drains and limiting future possibilities. Sediments, weeds, and waste have been observed in water channels and near culverts (Reich & Lake, 2015). Grass and weed growth is commonly observed in various locations near rivers and streams (Holmes et al., 2005). This prevents obstruction of water flow and the potential flooding of banks during heavy rainfall.

2.12.9 Obstructions

Obstructed waterways result in increased water levels upstream, leading to more extensive flooding in surrounding areas. The accumulation of debris or inadequate infrastructure can cause water to overflow onto roads, residential areas, and agricultural fields (Douglas, 2017). Flood obstructions alter the natural flow of water, leading to erosion in some areas and sedimentation in others. This leads to the depletion of fertile soil, erosion of riverbanks, and alterations in the overall topography (Erena & Worku, 2018). When floodwaters encounter barriers such as bridges or culverts, the sheer force of the water can result in structural damage or even complete collapse. Water, telephone, and power utilities running through drainage pipes can obstruct the flow of water in the channels. Sediments and debris transported by fast-moving water quickly get stuck, reducing the drainage systems' ability to support flow (Mourad, Nordin & Andersson-Sköld, 2022).

2.13 Environmental and socio-economic impact of flooding

Floods have a variety of negative impacts and dangers that result from the flooding event. The effects include negative impacts on individuals' physical and emotional well-being, daily lives, health, and property, as well as on public infrastructure, facilities, the environment, ecological processes, industrial development, and the competitiveness of the affected economy. Assessing the impact and harm of flooding can be difficult because of the possibility of further consequences in following years and the time needed to observe specific effects. Flooding, a natural event that is difficult to prevent entirely, is mainly caused by human actions and environmental alterations in many instances (Nicholson & Egan, 2020). Floods can lead to unexpected natural or human-caused dangers or be a crucial part of a series of interconnected events over time (Cutter et al., 2018).

Adeagbo et al. (2016) reported that floods displace over 3 million people annually and affect the personal and economic well-being of an additional 60 million individuals. Severe floods cause widespread damage and create striking visuals that endure for long periods after they occur (Johnston et al., 2021). In the 2000s, most deaths caused by disasters were due to hydro-meteorological events such as droughts, windstorms, and floods. More precisely, floods caused nearly two-thirds of these deaths (Erickson et al., 2019). Dube, Nhamo, and Chikodzi (2022) stated that floods are the most frequently observed events that affect rural and urban communities.

Floods, regardless of their classification, have significant effects on individuals, infrastructure, and personal property. According to Jha, Bloch and Lamond (2012), the global death toll directly attributed to documented flood disasters in 2010 exceeded 8,000 individuals. According to a study conducted by Jonkman and Kelman in 2005, it was shown that drowning accounts for around two-thirds of direct fatalities resulting from flood events. One-third of the deaths are caused by factors like physical trauma, heart attack, electrocution, carbon monoxide poisoning, or fire (Jha, Bloch & Lamond, 2012). Pollutant discharge poses substantial public health risks for individuals affected by flooding events. The combination of flood waters and untreated sewage can greatly increase the occurrence of waterborne diseases. Contaminated floodwaters can contaminate drinking water, leading to waterborne illnesses like diarrhoea and cholera, which can result in fatalities in the affected population (Edokpayi, Odiyo & Durowoju, 2017).

Floods present substantial dangers to health, welfare, and human survival overall. Flooding in the Tamale Metropolis can lead to physical injury, illness, health-related issues, and in extreme situations, death (Issah, 2017). Sprains and strains are commonly reported flood-related injuries (Kapfudzaruwa et al., 2020). During floods, people may hold onto objects carried by fast-flowing water, which can lead to being trapped and injured if buildings collapse (Špitalar et al., 2019). Injuries can occur prior to, during, and following floods, including accidents that occur amidst the rainfall. It is challenging to accurately quantify the overall impact of health issues related to floods (Mizelle, 2014). Flooding can result in electrical system malfunctions, which can lead to electrical shocks and other forms of secondary damage (Gordon et al., 2020). Typhoid fever and malaria are prevalent among Tamale residents during and after flooding. The presence of both floodwater and untreated sewage raises the probability of waterborne disease epidemics. These illnesses can lead to fatalities and substantial psychological suffering, as well as the destruction of homes and property. Loss of property and grief can lead to increased levels of stress, depression, and anxiety. Children and the elderly are especially susceptible to drowning and other dangers associated with floods. (Peden et al., 2017).

Rapidly rushing floodwaters have the potential to displace entire structures and populations. According to Jha, Bloch, and Lamond (2012), floods in South-Eastern Brazil in January 2011 displaced over 100,000 individuals and caused significant damage to critical infrastructure. The economic losses associated with floods should not be underestimated. For example, flooding in Lomé resulted in estimated financial burdens of $15.5 million in the social sector and $19 million in infrastructure (Yorose, 2019). The detrimental consequences of floods on human settlements are severe. Therefore, it is essential to recognize the importance of integrating risk mitigation measures at all stages of disaster management, including the response phase. Flood-related fatalities have the potential to result in demographic shifts. In affluent nations, a higher proportion of males, including both men and boys, are more likely to experience fatalities resulting from floods (Escobar-Carias et al., 2022).

Another consequence of floods is the potential for affected individuals to experience psychological stress and concerns about food scarcity. There are also concerns about the loss of significant assets, including homes, clothing, household goods, and economically valuable trees (Adedeji, Odufuwa & Adebayo, 2012). It is common practice among farmers to transfer rice seedlings from upland nurseries to mangrove swamps around mid-July. However, newly transplanted rice seedlings are facing issues of rotting due to the presence of floods and silt accumulation in the cultivated swamps.

Flooding has a major impact on the urban environment, as floods damaged many buildings and infrastructure (Amoako & Frimpong-Boamah, 2015). As a result of fear of what is now an annual event, both completed and uncompleted buildings and infrastructure are abandoned in Tamale metro. When it rains in Tamale, roads are also flooded, and in the event of flooding, commuting is almost impossible in general. This indirectly impacts citizens' everyday routines as well as significant disturbances in the lives of individuals and corporations. Not only do floods directly impact individuals, houses, facilities and the environment, but they also have indirect consequences, such as losses caused by business interruptions. Harm to business premises and facilities, expense and travel time rises, as well as sales losses, are indirect consequences of floods that are most frequently difficult to measure (Hardoy, Mitlin & Satterthwaite, 2013). This constitutes a large percentage of the total cost to communities of flood damage (Bempah & Øyhus, 2017). During and after the floods, companies often shut down temporarily and may often take up to months to recover and return to regular trading. Often this is due to the inability to access highways and roads, the time to clean up, and often the lack of access to or failure to provide essential facilities such as water supplies and electricity cuts. During the rains, kids are unable to drive from their homes to schools. This is attributable to flooded roads and paths and the school premises.

Cholera, diarrhea and typhoid fever and often deaths are mainly caused by a lack of pure drinking water, insufficient drinking water storage and handling, inadequate hygiene practices, and the degradation of sewage and sanitation facilities that lead to pollution of drinking water in areas affected by floods (Gibson & Shelley, 2020). The available evidence indicates that the perceived risk of an outbreak following a flood event may have been exaggerated. According to Owoaje et al. (2016), the occurrence of natural disasters that do not lead to displacement is seldom linked to a heightened susceptibility to epidemics. The primary risk factor for outbreaks of epidemic diseases following natural catastrophes is displacement. This aligns with other research conducted on the topics of natural disasters and complex situations (Kouadio et al., 2012; Watson, Gayer & Connolly, 2007).

There is an interruption in the supply of water and pollution that results in health problems. Waste disposal and sanitation systems could be overloaded, leading to drinking water sources being polluted and poisoned (Aglanu & Appiah, 2014). A significant source of environmental contamination is the wastewater that combines with floodwater. Flooding has posed a significant impediment to Ghana's economic progress over the last decade, prompting both national governments and international organizations to allocate substantial financial resources in the form of aid to aid flood victims in their recovery efforts. These resources are used to provide essential relief items, such as blankets, food supplies, and household necessities (Amoateng et al., 2018).

2.14 General Adaptation Strategies Used in Flood Management

Flood management is concerned with the coordination of resources and responsibilities in addressing various aspects of emergencies, such as hazard avoidance, disaster prevention, and mitigation. The likelihood of failure, or risk, depends on three factors: danger, vulnerability, and exposure (Nekooie & Gholizadeh, 2023). Flood management encompasses preparedness before a disaster, response during flood events, and recovery efforts following an incident (Casagrande et al., 2015). Risk studies explore topics related to recognizing and evaluating risks, as well as assessing risk perception and management, including risk analysis (Castro et al., 2017).

Flood protection is widely recognized as an effective approach to addressing flood control issues. It involves various measures such as floodplain management, maintenance operations for flood control, ensuring safety in flood-prone areas, implementing other flood hazard mitigation operations, and disaster preparedness in cases where flood mitigation operations cannot completely prevent flooding (Kiedrzyńska, Kiedrzyński & Zalewski, 2015). Historically, flood control policies primarily focused on managing floodwaters, often through the construction of levees along rivers to contain floods. Traditional strategies for floodplain management also centered on regulating building construction and the development of floodplain structures (Schindler et al., 2020).

During the first half of the previous century, flood control measures, including the construction of levees, dams, and localized protective structures, formed the dominant strategy for addressing floods. Lennon, Scott and O'Neill (2014) introduced an alternative perspective, which centres on the concept of human adaptation to flood events. The current methodology involves the comprehensive examination of many viable approaches in order to determine the most cost-efficient and effective plan for addressing a particular flood scenario (Kapetas & Fenner, 2020). This strategy must align with the policies, priorities, and financial resources accessible to the governing agency.

According to Burrel, Davar and Hughes (2007), it is essential to assess the feasibility (including technical capability, available money, and cost-benefit analysis), suitability, and environmental repercussions of potential mitigation strategies when addressing a recognised flood threat. When assessing different courses of action, it is imperative to take into account the effects of floods on both the local region and the broader watershed.

The presence of a flood hazard gives rise to a certain level of risk, the extent of which is determined by the susceptibility of both the constructed and natural surroundings to potential damage. Risk assessment is the assessment of the likelihood of a hazardous event leading to a specific level of harm or the estimation of the economic consequences arising from said event (Cardona, 2013).

Shi (2020) acknowledged the importance of improving floodplain management and flood hazard mitigation at the community level. To accomplish this, they suggested increasing public awareness of flood risks and enhancing community resilience through strategies like relocating buildings, flood-proofing, and making investments to strengthen economic, human, and social capabilities. It is crucial to ensure the accuracy and up-to-date of flood risk maps, as well as to diligently monitor and enforce laws and programmes related to floodplain land use. Wenger (2015) suggested using economic mechanisms to efficiently handle flood risk. User taxes, flood insurance, and user payment principle are the factors mentioned. Furthermore, it has been proposed that incorporating flood warning and forecasting services should remain a crucial component of flood hazard mitigation strategies. Moreover, it is recommended to improve the collection of hydrometric data in conjunction with these services.

Löschner (2018) outlines that the core principles of flood risk management involve fairly addressing flood-related issues within and among communities, as well as balancing human and environmental interests by employing broad strategies that include legal frameworks, administrative practices, economic tools, educational programmes, and engineering solutions. Reid (2016) suggested that focusing on natural resource management could be beneficial for developing techniques to mitigate and adapt to catastrophes. This method has the potential to decrease susceptibility, preserve biodiversity, and improve carbon sequestration ability. Understanding flood-risk-related interests is important for understanding future strategic adaptations.

Davies (2015) states that designing and planning for flood alleviation and management requires assessing the future likelihood of inherently unpredictable events. Moreover, the uncertainties regarding future climate change add to the increased unpredictability in this situation. The person emphasised the importance of engineers and other project stakeholders having knowledge of established guidelines to implement a suitable precautionary approach for anticipated climate change. Poff et al. (2016) presented a dynamic framework for floodplain management designed to adapt to changing conditions like land use changes, channel adjustments, economic progress, and the effects of climate change and uncertainty. This dynamic strategy allows for the gradual implementation of zoning, levee construction, and other decision-making processes, rather than dealing with them immediately. The dynamic model is constructed based on the principles of a Markov process. Olsen et al. (2000) suggest expanding the current model, which focuses on a single floodplain, one objective, and stationary conditions, to include multiple floodplains, non-stationary conditions, and multiple objectives.

2.15 Existing Adaptation Strategies Used in Reducing flood-related Vulnerabilities

The concepts of adaptation strategies encompass actions that have longer-term implications and are more likely to entail substantial modifications in livelihood activities or geographical locations (Eriksen et al., 2021; Hegger et al., 2016). In response to flood events, individuals promptly undertake measures to ensure their survival and aid their respective households.

Efficient adaptation methods encompass the mitigation of current and anticipated susceptibility to climate change. These strategies encompass both coping mechanisms and modifications to existing practices and procedures in response to projected shifts in climatic conditions. These acts can be implemented by various entities, including individuals, households, governments, and other relevant parties (Manyena, Machingura & O'Keefe, 2019). Adaptation strategies encompass various policy initiatives aimed at mitigating vulnerability and bolstering adaptive capacity, which refers to the capacity of individuals and systems to effectively respond and adapt to the impacts of climate change.

2.15.1 Flood Mitigation Strategies

An essential component of employing geographic information systems (GIS) in scenario planning involves the capacity to evaluate the impacts of various flood prevention strategies. Planners have the ability to replicate several tactics, such as constructing levees or flood walls, incorporating green infrastructure measures like rain gardens or permeable pavements, or adopting land use rules that give precedence to the protection of floodplains (Tredway & Havlick, 2017). The use of geographical data pertaining to infrastructure networks allows Geographic Information Systems (GIS) to simulate and analyse the possible effects of these actions on flood routing, water flow patterns, and the overall decrease of susceptibility. This enables decision-makers to assess the efficacy of various techniques in mitigating flood risk and then allocate investments in a prioritized manner (Mobley et al., 2020).

2.15.2 Land Use Changes on Vulnerability Mitigation

An additional significant utilization of Geographic Information Systems (GIS) in the context of scenario planning is the evaluation of the impacts of alterations in land use on the susceptibility to flooding. Planners possess the ability to replicate various land use scenarios through the manipulation of parameters such as zoning restrictions, urban expansion plans, and conservation (Sakieh et al., 2015). Geographic Information Systems (GIS) offer a range of analytical tools that facilitate the examination of the impact of alterations in land use patterns on various elements such as surface runoff, infiltration rates, and floodplain encroachment (Ogato et al., 2020). Through the process of comparing several scenarios, decision-makers have the capacity to discern specific places where alterations in land use may either heighten or diminish susceptibility to floods. This enables them to make well-informed decisions regarding future development plans.

2.15.3 Early Warning Systems

Geographic Information System (GIS) technology plays a pivotal role in the advancement of early warning systems. Real-time monitoring and forecasting of flood events facilitate prompt evacuation and catastrophe response. Geographic Information Systems (GIS) have the capability to generate intricate cartographic representations of regions susceptible to flooding, discern populations that are particularly susceptible to such events, and monitor fluctuations in water levels and precipitation patterns (Tehrany, Pradhan & Jebur, 2015). The aforementioned data is utilised for the purpose of issuing timely alerts to vulnerable populations, so affording them the opportunity to make necessary preparations and effectively respond to the impending flood occurrence.

2.15.4 Flood Barriers and Drainage Systems

Floods are classified as natural calamities that possess the potential to inflict substantial harm upon both human life and infrastructure. To address the consequences of flooding, a range of strategies have been devised, such as the implementation of flood defenses and the establishment of drainage infrastructure. Flood barriers refer to tangible constructions that are strategically constructed to impede or minimise the ingress of floodwaters into designated regions (Naumann & Golz, 2018). Various materials, including concrete, steel, and sandbags, are utilised in the construction of these barriers. Commonly, they are constructed adjacent to riverbanks, coasts, or in proximity to vital infrastructure to serve as a tangible obstruction against the escalation of water levels.

The benefit associated with flood barriers is their capacity to effectively control the flow of water. These buildings can divert or confine floodwaters, thereby mitigating the risk of excessive inundation in susceptible regions. In coastal regions, the implementation of flood barriers can serve as a protective measure for low-lying populations, shielding them from the potentially devastating impacts of storm surges triggered by hurricanes or tsunamis (Hatzikyriakou & Lin, 2017). In a similar vein, flood barriers situated along riverbanks serve the purpose of regulating the movement of water in instances of intense precipitation or the thawing of snow, so mitigating the potential for downstream flooding.

Embankments are a conventional structural approach employed for flood management purposes. Riverine levees are man-made embankments or ridges that are built beside rivers or other water bodies to confine water within its natural course during periods of high-flow occurrences. Embankments can be constructed using various materials such as compacted earth, rocks, or concrete, and are frequently augmented with flora to improve their stability.

The construction of embankments serves various functions in the realm of flood management. First and foremost, flood barriers serve as a tangible obstruction that effectively inhibits the discharge of floodwaters onto neighbouring land regions (Yasitli, 2021). Additionally, embankments serve the purpose of preserving the natural flow pattern of rivers by containing water inside its assigned channel. The implementation of erosion prevention measures serves to mitigate the occurrence of erosion and thus minimises the potential hazards posed to adjacent infrastructure, including roads and buildings.

In conjunction with flood barriers and embankments, drainage systems play a crucial role in the management of floods. These systems have been specifically engineered to efficiently gather and redirect surplus water in urban areas, thereby mitigating the risk of flooding in regions with lower elevation. Drainage systems commonly comprise an interconnected arrangement of pipes, culverts, and channels, which facilitate the conveyance of water towards predetermined outlets, such as rivers or reservoirs. The basic purpose of drainage systems is to effectively eliminate surplus water and prevent its accumulation in susceptible regions. These systems serve the purpose of mitigating the potential harm to infrastructure and mitigating the adverse effects of flooding disasters by facilitating the discharge of floodwaters (Echendu, 2022). The implementation and upkeep of well-designed drainage systems can greatly enhance the capacity of metropolitan regions to withstand and recover from flood events.

Although flood barriers and drainage systems have demonstrated their effectiveness in flood management, it is crucial to acknowledge that these classic structural methods are not devoid of limits. To begin with, the building and upkeep of large structures might incur substantial expenses, necessitating a considerable allocation of financial resources. Furthermore, the efficacy of these structures may be constrained in instances of severe flood occurrences that exceed their intended design capacity.

In addition, it is important to consider that conventional structural interventions can potentially result in unforeseen repercussions for the natural environment. One instance where the construction of embankments can have a significant impact is in the alteration of river ecosystems. This is mostly achieved by the modification of flow patterns and the subsequent disruption of habitats. In a similar vein, the implementation of drainage systems has the potential to result in the expeditious release of water into rivers, hence potentially giving rise to downstream flooding events or ecological imbalances (Varma et al., 2021).

2.15.5 Land Use Planning

Proper land use planning and zoning regulations are essential non-structural strategies for reducing exposure to flood risks. By avoiding construction in high-risk areas, communities can minimize the potential for damage to properties and infrastructure, as well as the risk of loss of life.

Building codes and flood risk

Building codes are another important tool for reducing flood risks. Building codes can help ensure that structures are built to withstand flood events and minimize damage to properties and infrastructure. Studies have shown that building codes can significantly reduce flood losses and promote flood-resistant construction. For example, a study in Southern Ghana found that buildings constructed under strict building codes experienced less damage during flood events compared to buildings without such codes (Abass, 2022; Kidido et al., 2021).

Land use planning and flood risk management

Land use planning is essential for managing flood risk and is a critical component of flood risk management. Effective land use planning practices help identify flood-prone areas and prevent development in those locations. Numerous studies have consistently shown that land use planning is effective in reducing flood risks and improving flood resilience. A study in Kumasi confirmed the important role of land use planning in decreasing flood risks by identifying high-risk zones and discouraging development in those areas (Korah & Cobbinah, 2017; Owusu-Ansah, 2016).

2.15.6 Public Awareness and Education

The dissemination of information and the provision of educational initiatives are essential components in reducing the adverse effects of floods and improving the level of readiness within communities. The significance of public awareness lies in the recognition of floods as natural calamities capable of inflicting substantial harm on infrastructure, property, and human lives. It is imperative to enhance public knowledge regarding flood hazards to foster comprehension among individuals and communities regarding the inherent perils they may encounter. Through the process of enhancing awareness, individuals can acquire knowledge and understanding that enables them to make well-informed choices about their safety and afterward engage in suitable measures to safeguard both themselves and their possessions. Public awareness campaigns can disseminate pertinent information regarding regions susceptible to flooding, past occurrences of floods, and the potential ramifications associated with such inundations (Glago, 2021). These campaigns frequently employ diverse communication platforms, including television, radio, social media, and community forums, to effectively engage a broad spectrum of individuals. The primary objective of these campaigns is to improve comprehension and promote proactive actions by effectively distributing precise and timely information.

Education can focus on various sectors of society, encompassing educational institutions, professional environments, community associations, and marginalised groups (Ardoin et al., 2020). These programmes offer comprehensive instruction on multiple facets of flood preparedness, encompassing emergency planning, evacuation strategies, first aid methodologies, and the appropriate use of protective measures such as sandbags or flood barriers.

A study conducted by Smith, Brown and Dugar (2017), which revealed that communities exhibiting heightened levels of awareness regarding flood risk were more inclined to evacuate in response to warnings. Consequently, this proactive behaviour resulted in a decrease in both human casualties and property destruction. Moreover, a study conducted by Johnson and Dadson et al. (2017), emphasised the potential of educational initiatives and awareness campaigns in augmenting individuals' comprehension of flood hazards and their perception of susceptibility. The acquisition of additional knowledge can result in an enhanced inclination to embrace precautionary measures and actively participate in proactive actions.

2.15.7 Integrated Adaptation Strategies

The use of integrated adaptation techniques, which encompass a combination of structural, non-structural, and ecosystem-based measures, has been recognised as a successful approach to holistically mitigate vulnerabilities associated with flooding (Watanabe et al., 2018). These techniques acknowledge the intricate interplay among social, economic, and environmental variables that shape the susceptibility to floods. Structural measures refer to physical actions that are specifically meant to affect the natural environment or manmade infrastructure with the aim of mitigating flood hazards (Kreibich et al., 2015). These measures encompass the construction of various infrastructure such as dams, levees, flood barriers, and reservoirs, which serve the purpose of managing water flow and mitigating the risk of inundation in susceptible regions. Structural interventions have demonstrated considerable effectiveness in mitigating flood damages and safeguarding human lives and property. Nevertheless, it is important to acknowledge that these interventions potentially yield unexpected outcomes, such as the modification of natural hydrological processes or the relocation of flood hazards to downstream areas (Blöschl, 2022). Non-structural measures primarily centre on the alteration of human behaviour, policies, and institutions with the aim of diminishing susceptibility to floods (Mohit & Sellu, 2017). The measures encompassed in this category consist of land-use planning, zoning restrictions, early warning systems, emergency preparedness, and public awareness campaigns. Non-structural interventions are implemented with the objective of enhancing the capacity of society to respond effectively to flood hazards, while simultaneously minimising the level of exposure to such hazards. Community engagement and participation are frequently incorporated in order to enhance the efficacy of risk reduction endeavours. Ecosystem-based approaches acknowledge the significance of natural ecosystems in the regulation of water flow, erosion mitigation, and provision of various ecological services that contribute to the reduction of flood risk (McVittie et al., 2018). The aforementioned strategies prioritise the preservation and rehabilitation of wetlands, forests, coastal mangroves, and other ecological habitats that possess the capacity to serve as inherent safeguards against inundation events. Ecosystem-based approaches not only afford flood protection, but also yield supplementary advantages such as the preservation of biodiversity, the purification of water, and the mitigation of climate change.

2.16 Conceptual Framework

This conceptual framework presents a diagrammatic approach to illustrate how the factors causing flooding, its impacts, adaptation measures, and their effectiveness in the Tamale Metropolis. From the conceptual framework, the causal factors of flooding are climatic factors, hydrological factors, urbanization and socio-economic factors. The climatic factors consider how seasonal rainfall patterns, changes in precipitation, and extreme weather influence flooding. Also, the hydrological factors focus on drainage infrastructure, land use changes, and water influence flooding. It is also evident that urban growth leads to land development and land use changes and ultimately leads to flooding.

Furthermore, flooding leads to environmental and socio-economic vulnerabilities among residents in flood-prone areas. These environmental and socio-economic vulnerabilities include damage to ecosystems, water quality, and soil erosion, and negative impact on livelihoods, health, and social well-being. However, in the face of these environmental and socio-economic vulnerabilities, certain adaptation strategies are employed to reduce the negative impact of flooding on the lives of individuals. Mostly the commonest adaptation strategies used are flood defenses, embankments, and drainage systems and adhering to disaster preparedness measures. Finally, the success of these adaptation strategies will ultimately result in long-term sustainability and long-term resilience as shown in Figure 2.2.

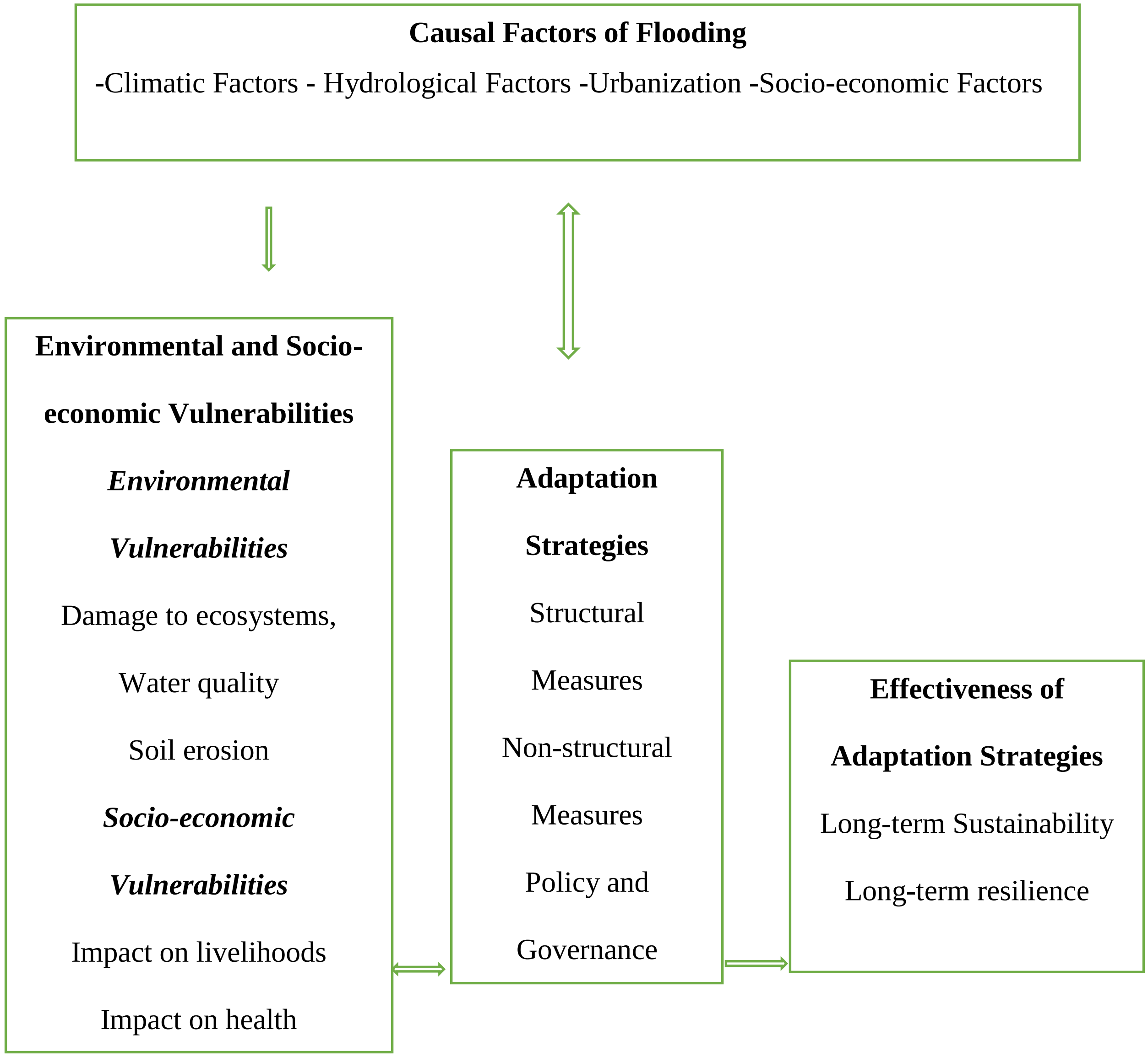

Figure 2.2: Conceptual framework showing flood vulnerability and adaptation strategies

Source: Authors own construct (2023)

CHAPTER THREE

METHODOLOGY

3.0 Introduction

The section covers the research methodology and the analytical techniques used for data collection. A brief overview of the study area is provided. It also provided details of the instruments used for data collection, study design, sampling procedure, data collection methods, pre-testing of the research questionnaire, reliability testing, and data analysis.

3.1 Profile of Study Area

The Tamale Metropolitan was officially created by the passing of a legislative instrument (L.I. 2068). Tamale functions as the Metropolitan and Regional capital of the Northern Region. The North East and Savannah regions were established as distinct entities from the Northern region following a referendum in December 2018. The Tamale Metropolis is a Metropolitan, Municipal, and District Assembly (MMDA) located in the Northern Region, one of 16 such assemblies in the area. It is situated in the central part of the Northern Region, sharing borders with the Sagnarigu Municipality to the northwest, the Mion District to the east, the East Gonja to the south, and the middle Gonja to the southwest. The Metropolis (Figure 3.1) is located at latitudes 9º16' to 9º34' North and longitudes 0º36' to 0º57' West (GSS, 2022).

The Metropolis has mostly flat and slightly rolling terrain, with an elevation between 400 and 800 feet above sea level. Water bodies are limited in the Tamale Metropolis, with only a few intermittent streams that flow during the rainy season and dry up during the arid season (GSS, 2022). The Tamale Metropolis has two distinct seasons each year: the dry season and the rainy season. The dry season usually commences in late October and extends until early May. The occurrence of dry harmattan winds from the Sahara region typically happens from November to February. December, January, and February typically have the lowest nighttime temperatures of the year, while March, April, and May are usually characterised by the warmest evenings (GSS, 2022).

In 2023, the population of the Tamale metropolitan area was 730,000, showing a 4.14% growth from the previous year. The population in 2022 was 701,000, reflecting a 4.32% growth from 2021. The population in 2021 was 672,000, showing a 4.67% growth from the previous year. Tamale is susceptible to flooding, particularly during the rainy season (GSS, 2022). The climatic conditions make metropolis prone to heavy rainfall and occasional flooding. Multiple areas in the Metropolis, such as Kobilimahagu, Jakara-yili, Kukuo, Nalung, Sawaba, Dungu, Dungu-Kukuo, Gbanbaya, Bilpela, Gumbihin South, Gumbihini North, and Lamakara, are reported susceptible to flooding (Tamale Metropolis Report, 2023).

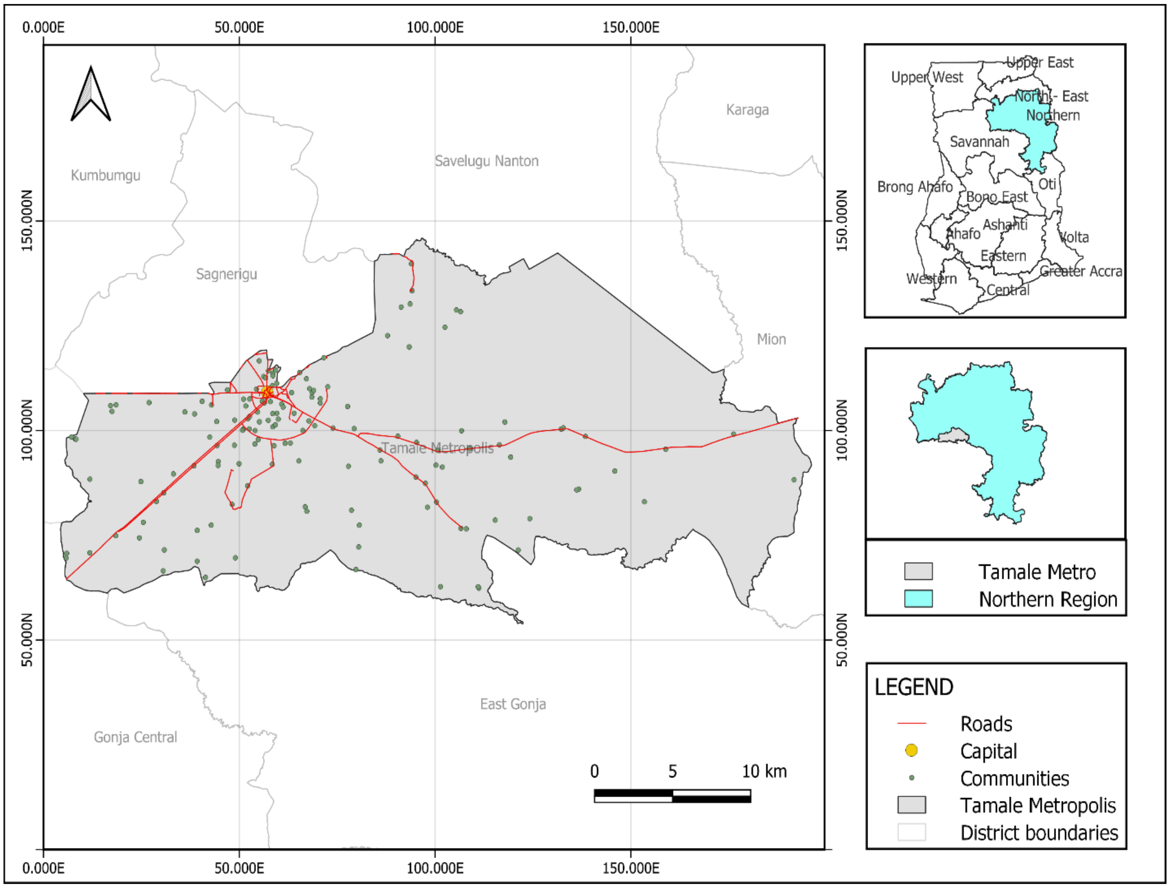

Figure 3.1: Map of Tamale Metropolis

Source: Adapted from GSS (2022)

3.2 Research Philosophy and Approach for the Research

3.2.1 Research Philosophy

Research philosophy encompasses the fundamental beliefs and assumptions regarding the nature of reality, knowledge, and the connection between the researcher and the research subject (Tamminen & Poucher, 2020). In this study, the research philosophy is categorized as either positivism or interpretivism.

Positivism is a philosophical position that prioritizes objectivity, empirical observation, and the scientific method as the means to acquire knowledge (Tekin &

Kotaman, 2013). An empirical approach to this research entailed quantifying flood vulnerability by utilizing measurable indicators such as flood frequency, severity, and their effects on infrastructure and livelihoods. The approach give priority to statistical analysis and the utilization of structured surveys to collect data on the adaptation strategies implemented by residents and authorities in the Tamale Metropolis. The objective is to establish causal connections between flood vulnerability and adaptation measures, with a focus on generating generalizable findings and predictive models.

Conversely, an interpretivist viewpoint recognizes that human experiences are subjective and emphasizes the significance of comprehending the meanings that individuals assign to their surroundings (Altheide & Johnson, 2011). This research aims to provide a comprehensive understanding of the challenges faced by the Tamale Metropolis and the effectiveness of current adaptation strategies by combining quantitative data on flood vulnerability with qualitative insights into local perceptions and adaptive behaviors.

3.2.2 Approach for the Research

Combining both quantitative and qualitative research approaches allows the researcher to gain a more comprehensive understanding of the problem. By capturing both numerical data and the lived experiences and perspectives of the affected communities, this approach provides valuable insights. The quantitative component of mixed research provides statistical data on flooding trends, frequency, and severity in Tamale's prone areas. This data is instrumental in identifying patterns, correlations, and trends related to flooding events and their impacts. It also helps quantify the extent of vulnerability. On the other hand, the qualitative research approach captures the experiences, perceptions, and adaptation strategies used by the residents, community leaders, and local authorities in mitigating the adverse effects of floods in the area. This qualitative data complements the quantitative findings and enriches our understanding of the issue.

3.3 Design for the Research

This study utilized a descriptive study design, which is a valuable method for gathering information or collecting data on important topics. According to Busetto et.al (2020), using a descriptive study design enhances a study by allowing for the examination of a large sample size in a limited timeframe, as well as enabling the identification of the causes and frequency of a phenomenon that other study designs cannot achieve. A descriptive study design is particularly suitable for providing a comprehensive overview of an event such as flood vulnerability as it allows researchers to collect detailed data on the current conditions, including the extent of vulnerability, the characteristics of vulnerable populations, and the state of adaptation measures used (Brooks et al., 2005).

3.4 Study Population

The focus of this study is on the residents of areas that are prone to flooding in the Tamale Metropolis. Specifically, the areas included in this study are Kobilimahagu, Jakara-yili, Kukuo, Nalung, Sawaba, Dungu, Dungu-Kukuo, Gbanbaya, Bilpela, Gumbihin South, Gumbihini North, and Lamakara. The entities involved in this study include the Tamale Metropolitan Disaster Management Department, the National

Disaster Management Organisation (NADMO), the Town and Country Planning department, the Meteorological Agency (Hydrological Services Department), various Non-Governmental Organizations (NGOs), and the Ghana Fire Service. According to the Ghana Statistical Services (2023), the current population of the Tamale Metropolis is 730,000, which is the population that were studied.

3.5 Sample Size and Sampling Procedure

3.5.1 Sampling Size

Sample size refers to the number of individual units (such as people, objects, observations, or data points) selected from a larger population to be included in a study (Esser & Vliegenthart, 2017). The sample size is a crucial consideration in this research, as it affects the accuracy and reliability of the study's results. A larger sample size generally provides more precise estimates and greater statistical power to detect differences or relationships (Kyriazos, 2018). Sample size is typically determined based on statistical calculations and research objectives. In this study, the sample size was taken from the overall population of Tamale Metropolis since there are no data for the number of people affected by flood in the Tamale Metropolis. According to the Ghana Statistical Services (2023), the current population of the metropolis is 730,000. This number constituted the sampling frame for this study. Cochran’s (1977) sample size determination formula was then applied in calculating the sample size. Applying Cochran (1977), sample size (n) computation formula as:

$$n = \frac{N}{1+Ne^2} \quad \ldots\ldots (1)$$

Where n = sample size

N = target population of residents of the Tamale Metropolis

e = marginal error (5%)

N = 730,000

$$n = \frac{730{,}000}{1 + 730{,}000\ (0.05)^2} = 399.56$$

To avoid decimals, the sampled size computed was round up to 400 residents and used for the study to assess the adaptation and vulnerability status of flood victims within the Tamale Metropolis.

3.5.2 Sampling Procedure

Sampling is the process of selecting a subset of individuals or items from a larger group or population (Sharma, 2017). The goal of sampling is to make inferences about the entire population based on the characteristics observed within the sample (Martínez-Mesa et al., 2016). Sampling methods include random sampling, stratified sampling, cluster sampling, convenience sampling, and more. The choice of sampling method depends on the research objectives, available resources, and the need for representativeness (Mweshi & Sakyi 2020). However, in this study, purposive, simple random sampling and convenience sampling methods were used in selecting the study respondents.

In the first stage, the Tamale Metropolis was grouped into three zones thus Tamale South, Tamale Central and Tamale North. From each zone, five communities were purposively sampled. From each selected community, respondents were randomly selected using simple random sampling and convenience sampling methods for selecting a total of 400 respondents as shown in Table 3.1.

Table 3.1: Sample zones and communities for the Study

No.	Zonal name	Community name	Number of respondents
1	Tamele North	Sogunayili	35
		Gbalo	30
		Jisonayili	20
		Gumani	30
		Fuo	15
2	Tamale Central	Kunyevila	50
		Nalung	60
		Sawaba	30
		Gumbihin South	20
		Gumbihini North	30
3	Tamale South	Kobilimahagu	20
		Jakara-yili	40
		Lamakara	60
		Dungu	30
		Nyohini,	50
Total			**400**

3.6 Types, Sources of Data and Methods of Data Collection

3.6.1 Types and Sources of Data

For this study, data were gathered from primary and secondary sources in both qualitative and quantitative formats. The study employed a perception-based survey to collect primary data from residents, assessing their insights on the causes of flooding and its impact on their lives and property. Moreover, secondary data was obtained from several Tamale institutions. This secondary data includes opinions on the causes of flooding and the necessary preventive actions to address this problem in Tamale, as well as the main responsibilities and specialized roles of government entities in flood prevention and management.

In the Tamale Metropolis, household surveys were used to collect the primary data. On the other hand, secondary data came from a variety of sources, such as Google satellite maps and records from the Ghana Meteorological Agency, Town and Country Planning, National Disaster Management Organization (NADMO), and Ghana Hydrological Service (GHS) in Tamale.

3.7 Data Collection Process

The act of data collection is a systematic approach used to get information and evidence from various sources to address specific research inquiries, facilitate decision-making, or achieve a more comprehensive comprehension of a certain subject or phenomenon (Palinkas et al., 2015). The current phase holds great importance in every research or analytical endeavour as the precision and reliability of the collected data have a substantial influence on the trustworthiness of any subsequent conclusions or findings. Using a mixed-methods approach, this study included quantitative and qualitative data gathered from primary and secondary sources. The field survey approach was employed to collect primary data, which involved conducting interviews with key informants and distributing questionnaires to residents of Tamale in flood prone areas.

3.7.1 In-depth Personal Interview

An in-depth personal interview is a qualitative research approach that helps obtain a full and detailed understanding of an individual's perception, beliefs, and behaviours (Bishop, 2015). This method involves a face-to-face dialogue between a researcher and a participant, generally lasting for a prolonged period, facilitating the participant's unrestricted and candid communication (Roller, 2020). The primary aim of conducting an in-depth personal interview is to gain a comprehensive understanding of the participant's experiences and viewpoints about study concepts. This method allows for a thorough exploration of complex study concepts that may not be effectively captured through the use of surveys or questionnaires. In this study, an in-depth interview was conducted with one (1) officer each from the Town and Country Planning, Tamale, Ghana Meteorological Agency, Tamale, National Disaster Management Organisation (NADMO), Tamale and Ghana Hydrological Service (GHS), Tamale. The study employed personal interviews, purposively selecting respondents with direct experience of flooding in the Tamale Metropolis to gather in-depth information on flood vulnerability and management.

3.7.2 Personal Questionnaire Administration Process

The technique of administering personal questionnaires is a systematic approach to conducting surveys by direct engagement with individual respondents (Gnambs & Kaspar, 2015). This approach entails the researcher or interviewer individually administering the questionnaire to each participant and gathering their replies through face-to-face interaction. Four hundred (400) respondents in the three (3) sampled zones were interviewed using closed and open-ended questionnaires. The questionnaire for respondents was grouped into five sections. The respondents' demographic information was covered in the first part. The Tamale Metropolis's flooding-related factors were covered in the second part. The Tamale Metropolis's socioeconomic and environmental risks related to flooding was also covered in the third part. The Tamale Metropolis's population use adaption techniques to lessen the consequences of flooding, which are covered in the fourth part. The final part examines how well Tamale Metropolis residents are able to reduce their vulnerability to flooding through the adoption of current adaptation strategies. Since the study involved a large number of respondents, the researcher engaged research assistants to administer the questionnaires through face-to-face interviews to ensure efficient data collection and accurate responses.

3.8 Instruments for Data Collection

The process of data collection is an essential component in the research endeavour, since it entails the acquisition of relevant information that is subsequently analysed and utilised to inform conclusions. A range of instruments are utilised for data collection, which is contingent upon the specific study aims, types of data, and the intended population (Vasileiou et al., 2018). These instruments serve an important role in guaranteeing the correctness, reliability, and validity of the acquired data (Souibgui et al., 2019). However, in this study, a questionnaire and an interview guide were used. These tools were preferred over other methods, such as FGDs and observations, because they best aligned with the study's objectives and ensured a balance between structured data collection and rich, detailed responses.

3.8.1 Questionnaire

A questionnaire was used as the primary data collection instrument to gather information from 400 respondents across selected zones and communities within the Tamale Metropolis. The questionnaire consisted of both closed- and open-ended questions and was structured into five sections. The first section covered respondents' demographic characteristics, while the second focused on flooding in the Tamale Metropolis. The third section examined socioeconomic and environmental risks associated with flooding, whereas the fourth explored adaptation strategies used by residents to mitigate flood impacts. The final section assessed the effectiveness of these adaptation measures in reducing vulnerability. The questionnaire was designed to be concise, confidential, and comprehensive, ensuring that all relevant aspects of the study were covered while encouraging honest and open responses. It included structured response options, such as binary (yes/no) questions, to facilitate analysis.

3.8.2 Interview Guide

An interview guide is a structured instrument used by researchers to facilitate and organize interviews, ensuring a comprehensive exploration of key study concepts

(Roberts, 2020). In this study, the interview guide was used to conduct in-depth personal interviews with one (1) officer each from the Town and Country Planning Department, Ghana Meteorological Agency, National Disaster Management Organisation (NADMO), and Ghana Hydrological Service (GHS) in Tamale. These participants were purposively selected due to their direct experience with flooding in the Tamale Metropolis, providing critical insights into flood vulnerability and management.

3.9 Pretesting

In general, it is commonly believed that despite conducting extensive developmental and pre-pretesting work on a questionnaire, there will still be some difficulties encountered during the main data collection process (Chasiotis, 2015). The process of field testing typically involves giving the questionnaire to respondents chosen from the target population, using the methods intended for the main study (Dikko, 2016). However, in practice, either probability or convenience sampling is employed to select respondents, and their numbers usually range from 20 to 70 (Jager, Putnick & Bornstein, 2017). To ensure the reliability and validity of the questionnaire, a pretest was conducted. In this study, 30 respondents from Sagnerigu Kuoku in the Sagnerigu Districta flood-prone area were randomly selected to complete the field questionnaire. Pretesting allowed for the identification of potential challenges in the questionnaire before the main data collection, aligning with best practices in survey research (Chasiotis, 2015; Dikko, 2016; Jager, Putnick & Bornstein, 2017).

3.10 Reliability Test

Cronbach's coefficient was employed to assess the internal reliability of the study instrument. The pre-test results yielded a Cronbach's Alpha value of 0.72, indicating acceptable reliability, as values of 0.6 or higher are considered reliable for construct measurements (Hajjar, 2018). This confirmed the instrument's consistency before proceeding with primary data collection and analysis.

3.11 Data Analysis

Research data analysis is the process of examining and interpreting data collected during a research study to derive meaningful understandings, draw conclusions, and make informed decisions (Peel, 2020). It is a critical component of the research process and helps researchers make sense of the information they have gathered. This study employed a mixed-methods approach, incorporating both quantitative and qualitative data analysis processes. Qualitative data was acquired through conducting interviews and making observations of the study area. Consequently, the data obtained through interviews were analyzed using content and thematic analyses. Content analysis is an analytical approach that involves systematically examining and interpreting the content present in various forms of media, such as text, visuals, and audio (Stemler, 2015). Its purpose is to identify and examine patterns, themes, and insights within the data. Moreover, thematic analysis is a qualitative research method used to identify, analyze, and report patterns (themes) within a dataset (Kiger & Varpio, 2020).

Once the quantitative data collected from the field underwent a thorough examination to ensure completeness and accuracy, the data were subjected to coding and subsequently entered into the Statistical Package for Social Sciences (SPSS) for analysis. Descriptive statistics, specifically frequency and percentage, were used for analysis. Additionally, time-series analysis, ordinary least squares (OLS) regression, flood vulnerability index, and Kendall's Coefficient of Concordance were used to analyze the data. However, the results were presented in tables, figures, charts, and maps.

3.11.1 Analysis of flood-vulnerable communities and the factors contributing to flooding occurrences within the Tamale Metropolis

Analysis of flood-vulnerable communities and the factors contributing to flooding occurrences within the Tamale Metropolis was achieved using historical rainfall and flood data over 20-year period and mapping the affected areas. Historical rainfall and flood data for the Tamale Metropolis spanning the past two decades (2000-2020) was used for this analysis. A correlation analysis was conducted to establish the occurrences between rainfall and flood. Also, time-series analysis was used to identify the pattern of rainfall and flooding in the Tamale Metropolis. Furthermore, once the patterns were identified, flood-prone areas within the Tamale Metropolis were mapped using Geographic Information System (GIS) software, specifically employing the Analytical Hierarchy Process (AHP) Model to create a comprehensive flood vulnerability map.

3.11.2 Analysis of the hydrological factors contributing to flooding in the Tamale Metropolis

Analysis of the factors contributing to flooding in the Tamale Metropolis was achieved using the Analytical Hierarchy Process (AHP). In AHP decision-making, the perceptions of the decision maker are organized in a multi-level hierarchy structure on a pair-wise comparison to construct a matrix. The matrix is based on established values on a normal 1 to 9 scale formulated by Saaty, (1980) as shown in Table 3.2. The scale was adopted based on a literature review of expert opinions (Castillo et al., 2022; Zghibi et al., 2020). In the context of flood vulnerability studies and mapping, the AHP hierarchy process involves identifying flood zones or localities within the study area, followed by identifying the criteria or factors that influence the floods, next is comparing the relative influence of the various factors using a pairwise matrix to determine quantitatively, thus how each contributes to the phenomenon (flood) and finally ranking the criteria.

Table 3.2: Saaty scale for pairwise comparison

Scale	*Definition*
1	*Equal importance*
3	*Moderate importance*
5	*Essential or strong importance*
7	*Very strong importance*
9	*Extreme importance*
2,4,6,8	*Intermediate values between the two adjacent judgements*

Source: Saaty (1980)

Pairwise Comparison Matrix (PCM)

PCM converts the qualitative data of the spatial map layers to quantitative scores based on the Saaty pairwise scale. The process of PCM is as follows; create a pair wise comparison matrix, X ($n \ x \ n$ matrix) of the criteria based on the expert judgement using the scales of 1 to 9. The matrix is designed with the following question in mind "How important is criteria (A) when compared to (B) in terms of scale (1-9)". The nine-point scale therefore determines the relative influence of each factor (geology, topological and hydrological) under consideration. The matrix size is equivalent to the number of criteria for the study: c_{ij} denotes the intensity scale and position in the matrix (equation

1). Also, there is a principle of reciprocity in constructing the PCM, which is expressed as c_{ij} and $\frac{1}{c_{ij}}$.

$$X = [c_{ij}] = \begin{array}{c|cccc} & A & B & \cdots & D \\ \hline A & 1 & c_{12} & \cdots & c_{1j} \\ B & \frac{1}{c_{12}} & 1 & \cdots & c_{2j} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ D & \frac{1}{c_{1j}} & \frac{1}{c_{2j}} & \cdots & 1 \end{array} \quad (1)$$

Matrix X is then normalized by dividing the sum of each column scale to generate a new matrix Y (equation 2) with normalized scales d_{ij} (equation 3).

$$Y = [d_{ij}],\ i, j = 1, 2, \ldots, n \quad (2)$$

$$d_{ij} = \frac{c_{ij}}{\sum_{i=1}^{n} c_{ij}} \quad (3)$$

The eigen vectors (W) are then calculated by averaging the normalized scale of each criteria row using equation (4). The weights should sum up to one as in equation (5).

$$W_i = \frac{\sum_{i=1}^{n} d_{ij}}{\sum_{i}^{n} \sum_{j=1}^{n} d_{ij}},\ i, j = 1, 2, \ldots, n \quad (4)$$

$$\sum_{i=1}^{n} W_i = 1 \quad (5)$$

There is a relationship between the maximum eigenvalue (λ_{max}) and the eigen vectors expressed as;

$$YW = \lambda_{max} W \quad (6)$$

To ensure consistency in the comparison between the criteria, Saaty (1987) provided the consistency ratio and index as a scientific method to validate the matrix. The consistency ensures that the comparison procedure is of sound judgment and coherent. However, hardly is perfect consistency achieved in decision-making, hence, a threshold value of less than 10% consistency ratio is considered adequate in the PCM judgment matrix. To calculate the Consistency ratio (CR), the consistency index (CI) is first estimated using λ_{max}, with the total criteria used (n) as shown in equation (7). Then the consistency ratio is finally calculated using a random index (RI) based on the matrix size and the CI following equation (8)

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \quad (7)$$

$$CR = \frac{CI}{RI} \quad (8)$$

Table 3.3: Random index (RI) for different matrix sizes

N	1	2	3	4	5	6	7	8	9	10
RI	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty, (1980)

A $CR \leq 0.1$ indicates consistency in the judgment matrix, and the weights generated are considered acceptable, otherwise, the pairwise comparison must be revised until the threshold value is achieved.

3.11.3 Investigating the effects of flooding on the environment, social, and economic dynamics within the Tamale Metropolis

Analysis of the effects of flooding on the environment, social, and economic dynamics within the Tamale Metropolis was achieved using the flood vulnerability index. A flood vulnerability index is a valuable tool used in disaster risk assessment and management to measure and assess the extent of vulnerability within a locality affected by flooding (Mavhura et al., 2017). The Flood Vulnerability Index (FVI) is a comprehensive framework that assesses the susceptibility of communities to flood hazards. The range is between 0 to 1, with 0 being very small vulnerability to floods and 1 being Very high vulnerability to floods. In this study, the vulnerability index is *Physical Factors*, *Social Factors*, *Economic Factors and Institutional Factors*.

Physical Factors: These include the topography of the area, the location of waterways and flood-prone areas, the type of land use and land cover, and the infrastructure and buildings in the area. Physical factors play a crucial role in determining the likelihood and severity of flooding. For example, areas with low-lying topography, proximity to waterways, and dense vegetation are more susceptible to flooding.

Social Factors: These include the demographic characteristics of the community, such as age, gender, income, and occupation. Social factors affect the ability of the community to prepare for and respond to floods. For example, communities with a high proportion of elderly or low-income residents may be more vulnerable to flooding due to limited mobility or resources.

Economic Factors: These include the economic activities and resources of the community, such as agriculture, industry, and tourism. Economic factors affect the resilience of the community to flooding. For example, communities that rely heavily on agriculture may be more vulnerable to flooding due to crop damage and loss.

Institutional Factors: These include the policies, regulations, and governance structures in place to manage flood risk. Institutional factors affect the ability of the community to prepare for and respond to floods. For example, communities with effective emergency management plans and adequate funding may be better equipped to respond to floods.

Flood vulnerability is a multidimensional concept influenced by various physical, social, economic, and institutional factors. To systematically assess flood vulnerability in the Tamale Metropolis, a Flood Vulnerability Index (FVI) can be developed using a composite model that integrates these key dimensions. The FVI is structured as follows:

Each sub-index represents a crucial aspect of vulnerability and is weighted accordingly to reflect its significance:

Physical Sub-Index

This accounts for geographical and infrastructural factors affecting flood risk. It is calculated as: **Topography**: Low-lying areas are more prone to flooding.

Land Use: Encroachments and poor urban planning increase vulnerability.

Infrastructure: The state of drainage systems, roads, and flood barriers determines resilience.

Social Sub-Index

This measures the demographic and societal characteristics that influence flood vulnerability:

Population density: Highly populated areas face greater flood impacts.

Housing conditions: Informal settlements are particularly vulnerable.

Community awareness: Knowledge of flood risks and preparedness levels.

Economic Sub-Index

This assesses the economic implications of flooding on livelihoods and local economies:

Employment sectors: Agriculture, trade, and services affected by floods.

Income levels: Poorer households have fewer resources for flood adaptation.

Cost of damage and recovery: Financial losses due to flooding.

Institutional Sub-Index

This evaluates governance structures, policies, and institutional preparedness for flood management:

Urban planning and zoning laws: Enforcement of flood risk reduction measures.

Disaster response mechanisms: Effectiveness of early warning systems and relief efforts.

Government and stakeholder coordination: Policy implementation and community engagement.

By integrating these factors, the **FVI provides a comprehensive measure of flood vulnerability**, enabling targeted interventions to reduce flood risk and enhance resilience in the Tamale Metropolis.

Would you like to include specific weighting criteria or real-world data applications for this model?

Model for Flood Vulnerability Index (FVI)

Flood Vulnerability Index (FVI) = Physical Sub-Index + Social Sub-Index + Economic Sub-Index + Institutional Sub-Index …………………………………… (1)

Physical Sub-Index = Weight_Physical * (Topography + Land use + Infrastructure) ………………………………………..…………………………………… (2)

Social Sub-Index = Weight_Social * (Demographic factors) ………………… (3)

Economic Sub-Index = Weight_Economic * (Economic activities) ………..… (4)

Institutional Sub-Index = Weight_Institutional * (Policies + Governance) …… (5)

Based on each vulnerability index variable, a flood vulnerability index range will be adopted from Balica et al. (2012), to determine the extent of flood vulnerability among communities within Tamale Metropolis as shown in the Table 3.4.

Table 3.4: Interpretation of flood vulnerability index

Index value	Description
Less than 0.1	Very small vulnerability to floods
0.1 to 0.25	Small vulnerability to floods
0.26 to 0.50	Vulnerability to floods
0.51 to 0.75	High vulnerability to floods
0.76 to 1	Very high vulnerability to floods

Source: Balica et al. (2012).

3.11.4 Analysis of the adaptation strategies employed by residents of the Tamale Metropolis to mitigate the effects of flooding

Adaptation techniques are any tactics used by flood-affected persons to get past the difficulties brought on by these natural disasters. To help respondents score the adaptation strategies according to severity, a collection of these strategies was gathered from pertinent literature. Kendall's coefficient of concordance was used to assess the degree of agreement between the ranked ratings that the respondents awarded to the various adaption strategies. According to Legendre (2005), as cited in Awal (2009), Kendall's coefficient of concordance (W) serves as a measure of agreement among multiple judges (p) who are assessing a given set of objects (n).

The ratio of the observed variance of the sum of ranks to the maximum variance of the ranks is quantified by the index W. Finding the sum of ranks for each ranked adaption approach is the fundamental concept. In the event of perfect agreement in the ranking, the variability among these sums is at its maximum (Mattson, 1986). Thus, the Kendall's concordance coefficient (W) is expressed by the following equation:

$W = 12S/p^2 (n^3 - n) - pT$ …………………………………………………… (7)

Where W denotes Kendall’s Concordance Coefficient, p denotes the number of adaptation strategies, n denotes the number of respondents (sample size), T denotes correlation factor for tied ranks and S denotes the sum of square statistics. The sum of a square statistic (S) is given as:

$S = \sum (R_i - R)^2$ ……………………………………………………………… (8)

Where: R_i = rows sums of ranks

R = the mean of R_i

The correlation factor for tied ranks (T) is also given as:

$T = \sum (t_k^3 - t^k)$……………………………………………………………… (8)

Where: t_k = the number of ranks in each (k) of m groups of ties.

$X^2 = p (n - 1) W$……………………………………………………………….. (9)

p = number of adaptation strategies

W = Kendall’s coefficients of concordance

However, analysis of the effectiveness of existing adaptation strategies used by residents of the Tamale Metropolis in reducing flood-related vulnerabilities was achieved using descriptive statistics, particularly frequency, percentage and means. Furthermore, a five-point Likert scale measurement (Strongly Disagree, Disagree, Moderate, Agree and Strongly Agree) was used to measure the degree of effectiveness of adaptation strategies used by residents of the Tamale Metropolis in reducing flood-related vulnerabilities. However, various adaptation strategies statements such as "The adaptation strategies have significantly reduced flood damage", "Residents feel safer due to the adaptation strategies", "Adaptation strategies have improved community preparedness for flooding" and "Residents believe that the strategies are sustainable", were incorporated into the main questionnaire for the respondents to ranking This enabled each respondent to rate their agreement with the statements on a scale of 1 to 5, with 1 indicating strong disagreement and 5 indicating strong agreement.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents the results and discussion of a study that was conducted to evaluate the vulnerability to floods and assess the effectiveness of existing adaptation strategies in mitigating the adverse impacts of flooding in the Tamale Metropolis. The chapter is structured into five sections. The first section provides an analysis and discussion of the socio-demographic characteristics of the respondents. Section two identifies the communities that are most vulnerable to flooding and examines the factors contributing to the occurrence of floods in the area. Section three focuses on the findings regarding the environmental, social, and economic consequences of flooding in the metropolis. Section four presents the flood mitigation strategies that have proven to be effective among the residents. Lastly, section five presents a comprehensive Flood Vulnerability Index (FVI) for the Tamale Metropolis.

4.1 Demographics Characteristics of Respondents

The results of selected demographic factors from the sampled population are shown in this section. The chosen demographic features are those that the existing literature on the topics under investigation has determined to be significant to the goal of this investigation. These consist of age, marital status, sex, and level of education.

4.1.1 Sex of Respondents

The findings presented in Table 4.1 reveal the distribution of respondents in flood-prone areas of the Tamale Metropolis based on their sex. The data indicates that 73.0% of the respondents were male, whereas 27.0% were female. Understanding the sex distribution of respondents in flood-prone areas is crucial for comprehending the differential impacts experienced by men and women in relation to flooding. Extensive research has demonstrated that sex dynamics play a significant role in shaping vulnerability, adaptive capacity, and decision-making processes concerning disaster risk reduction and response (Cohen et al., 2016). Azad and Pritchard (2023) have further highlighted that women and men have distinct patterns of mobility, varying levels of resource access, and differing responsibilities within households, all of which influence their ability to cope with and adapt to flood events. However, it is worth noting that the majority of the respondents (73.0%) are male, implying that men may be more likely to overcome the adverse effects of flood occurrences in flood-prone areas compared to their female counterparts.

4.1.2 Age of Respondents

The results presented in Table 4.1 reveal that a majority of the respondents fall within the age range of 29 to 38, representing 48.0% of the total respondents. The age bracket of 18 to 28 constitutes 15.0% of the respondents, while the age groups of 39 to 48 and 49 and above account for 23.0% and 14.0% of the respondents, respectively. The age composition of respondents residing in flood-prone areas proves to be a crucial determinant in their decision to remain in these regions.

Younger individuals are more prone to taking risks and prioritize affordability over safety, while older individuals tend to prioritize safety and stability over affordability (Bentley et al., 2022). The findings of this study suggest that the majority (48.0%) of the respondents were aged between 29 and 38, implying that this age group is more inclined towards prioritizing affordability over safety. This preference can be attributed to the fact that many young individuals may not possess the financial stability required to afford housing in prime areas, leading them to prioritize affordability over safety (Jones, 2019). Therefore, it implies that the age distribution of respondents in flood-prone areas plays a significant role in shaping their housing decisions.

4.1.3 Marital Status of Respondents

The marital status of respondents provides valuable information on the dynamics of flooding. The results in Table 4.1 indicate that the majority of respondents (67.8%) are married, while a significant proportion (17.8%) are single, 6.8% are divorced/separated, and 7.8% are widowed. According to research by Christian et al. (2021), marital status is an important factor in understanding the differential impacts of flooding on households. Also, households with married couples or other close family members mostly have access to additional resources and support during flood events, whereas single individuals or those with unstable marital statuses face greater challenges in coping with flood-related disruptions (Chacowry, McEwen & Lynch, 2018). This suggests that the marital status of household members can influence their ability to prepare for, respond to, and recover from floods. Furthermore, the marital status of respondents in flood-prone areas also affects their financial well-being and access to resources, because, households with married couples have a higher combined income and assets, which provide them with greater resilience to flood-related losses (Nguyen & James, 2013). In contrast, single individuals or those with unstable marital statuses may struggle financially and have fewer resources to invest in flood preparedness and recovery (Salignac et al., 2019). In addition, the marital status of respondents may also influence their social networks and support systems. Married couples and other close family members may have stronger social connections and a larger support network, which can be critical during times of crisis such as floods (Aldrich & Meyer, 2015).

4.1.4 Educational Level of Respondents

The educational status of respondents in flood-prone areas of the Tamale Metropolis shows notable variations. A majority (55.0%) have completed Senior High School, while a smaller proportion (6.0%) have received non-formal education. Additionally, a considerable share (20.0%) hold university degrees, reflecting a mix of educational backgrounds among residents (Table 4.1). These statistics indicate that a considerable portion of the population in flood-prone areas possesses a high level of education, which can potentially enhance their capacity to cope with flood-related disruptions. Extensive research has demonstrated that education levels significantly shape vulnerability, adaptive capacity, and decision-making processes concerning disaster risk reduction and response (Adger et al., 2011; Boehm et al., 2017; Cannon et al., 2017). Individuals with higher levels of education are likely to enjoy better access to resources, information, and coping strategies during flood events, while those with lower levels of education may encounter greater challenges in dealing with flood-related disruptions. As such, it is imperative to take into account the educational status of the population when formulating disaster risk reduction and response strategies in flood-prone areas. This entails implementing targeted interventions to enhance educational access for individuals with lower levels of education, as well as creating information and resources that cater to the specific needs and capacities of different educational groups.

4.1.5 Duration of respondents staying in the flood prone areas

The results on the duration of respondents living in flood-prone areas in the Tamale Metropolis show that the majority (57.8%) have resided in these areas for 6 to 10 years, while a smaller proportion (4.0%) have lived there for 16 to 20 years. This indicates that most residents have relatively long-term exposure to flood risks, with fewer respondents having lived there for extended periods beyond two decades (Table 4.1). The duration of resident residing in an area is an important factor in understanding their vulnerability to disaster. According to Seebauer and Winkler (2020), long-term residents in flood-prone areas have a better understanding of flood risks and adaptive strategies, while newcomers might face greater challenges in coping with flood events. Additionally, the duration of resident influences the level of investment in properties, community engagement, and access to local resources, which shape vulnerability and resilience during flood events (Keating et al., 2017). However, this study revealed that most of the respondents had leaved in these flood-prone areas for between 6 to 10 years. This implies that these residents are more equipped to cope with the adverse effects of flooding in the study area.

Table 4.1: Demographics Characteristics of Respondents (N=400)

Attributes	Frequency	Percentage
Sex of Respondents:		
Male	292	73.0
Female	108	27.0
Age of respondents:		
18 – 28	60	15.0
29 – 38	192	48.0
39 – 48	92	23.0
49 and above	56	14.0
Marital status of respondents:		
Married	271	67.8
Single	71	17.8
Divorced/separated	27	6.8
Widowed	31	7.8
Education status of respondents:		
Non-formal education	24	6.0
Primary	14	3.5
Junior High School	11	2.8
Senior High School	220	55.0
Teacher/Nursing Training College	51	12.8
University education	80	20.0

Duration of respondents stay:		
0 – 5 years	26	6.5
6 – 10 years	231	57.8
11 – 15 years	4	1.0
16 – 20 years	88	22.0
Above 20 years	51	12.8

Source: Field Survey Data, 2023

4.1.6 Respondents' source of information on flooding

The result in Table 4.2, indicates that community leaders or elders and local media are the most accessed sources of information, with 89.3% and 100.0% of respondents accessing them, respectively. The influence of these sources of information on individual preparation for flooding in the Tamale metropolis is significant as access to information from community leaders or elders and local media play a crucial role in shaping individual preparedness and response to flood events. Community leaders and elders often possess local knowledge and experience, which inform residents about flood risks and appropriate preparedness measures (Marfai, Sekaranom & Ward, 2015). Local media, including TV and radio, serve as important channels for disseminating flood-related information, warnings, and preparedness guidelines to the public.

The study revealed that Non-governmental organizations (NGOs) are also a main source of information for respondents as 37.0% of respondents revealed accessing information from NGOs. These NGOs contribute to flood risk awareness and preparedness through their community engagement, awareness-building training, and dissemination of relevant information. Their role in providing information and support for disaster preparedness influences individual and community-level responses to flooding.

Furthermore, the district assemblies and Ghana meteorological agencies are accessed by 6.0% and 11.3% of respondents, respectively. While district assemblies and Ghana meteorological agencies are accessed by a smaller percentage of respondents, their role in providing official information, flood forecasts, and early warnings is essential for enhancing preparedness and response to flood events. These sources all contribute to the dissemination of actionable information, flood risk awareness, and long-term planning for individuals and communities.

Table 4.2: Respondents source of information on flooding

Source of information	Frequency		Percentage (%)	
	Yes	No	Yes	No
District assembles	24	376	6.0	94.0
Ghana meteorological agencies	45	355	11.3	88.8
Non-governmental organizations (NGOs)	148	252	37.0	63.0
Community leaders or elders	357	43	89.3	10.7
Local media (TV, radio, newspapers)	400	0	100.0	0.0
Total	**400**		**100.0**	

Source: Field Survey Data, 2023

4.1.7 Frequency of respondents accessing information on flooding

The result in Table 4.3 on the frequency of respondents accessing information in the Tamale metropolis indicates that 54.3% of respondents access information occasionally (once a year or less), while 19.5% access information rarely, and 16.0% never access information. Only 10.3% of respondents access information frequently (multiple times a year). The result implies that there is a need to improve the frequency and accessibility of information on flooding in the Tamale metropolis to enhance individual and community preparedness since most of the respondents' access information on flooding once a year or less. Access to timely and accurate information is important for effective flood risk communication, awareness-building, and preparedness efforts. Because, effective communication, collaboration, and engagement with various stakeholders are essential for promoting population health research for disaster recovery and enhancing preparedness and response to flood events. This finding aligns with broader trends observed in areas with limited infrastructure and resources for information dissemination (Mohanty & Karmakar, 2021). Also, in this study, most 54.3% of respondents access information occasionally (once a year or less). This occasionally information access among respondents might affect effective preparation in dealing with flood-related vulnerabilities.

Table 4.3: Frequency of respondents accessing information on flooding

Frequency of information accessed	Frequency	Percentage (%)
Frequently (Multiple times a year)	41	10.3
Occasionally (Once a year or less)	217	54.3
Rarely	78	19.5
Never	64	16.0
Total	**400**	**100**

Source: Field Survey Data, 2023

4.2 Identify flood-vulnerable communities and the factors contributing to flooding occurrences within the Tamale Metropolis

This section identifies the various communities in the Tamale Metropolis that are highly prone to flood. The areas prone to flooding within the Tamale Metropolis are shown using maps and satellite images.

The Tamale Metropolis, located in the northern region of Ghana, is a rapidly urbanizing area that has experienced perennial flood issues. Flooding in this area has a significant impact on social services, infrastructure, and the local population. Thus identification of flood-prone areas in Tamale Metropolis is very important to this study as it serves for the development of fold risk maps and early warning systems for the people of the Tamale Metropolis. Generally, in the Tamale Metropolis areas that are highly prone to flooding are ***Sakasaka, Taha, Kanvilla, Norrip village, Chogu, Nyohni, Kunyilla, Zujung, Kaakpayili, Shishegu, Jekeriyili, Lamashegu, Kalpohin estate and Fuo*** (GSS, 2022). These areas are vulnerable to flooding due to their low-lying nature and the heavy downpours that occur in these areas. In accessing the flood-prone areas in the Tamale Metropolis, topography, geology and hydrological variables were considered. In this study, the variables considered are geology (soil type), topography (slope, elevation, and land use land cover) and hydrology (drainage density, flow accumulation, rainfall and topographic wetness index).

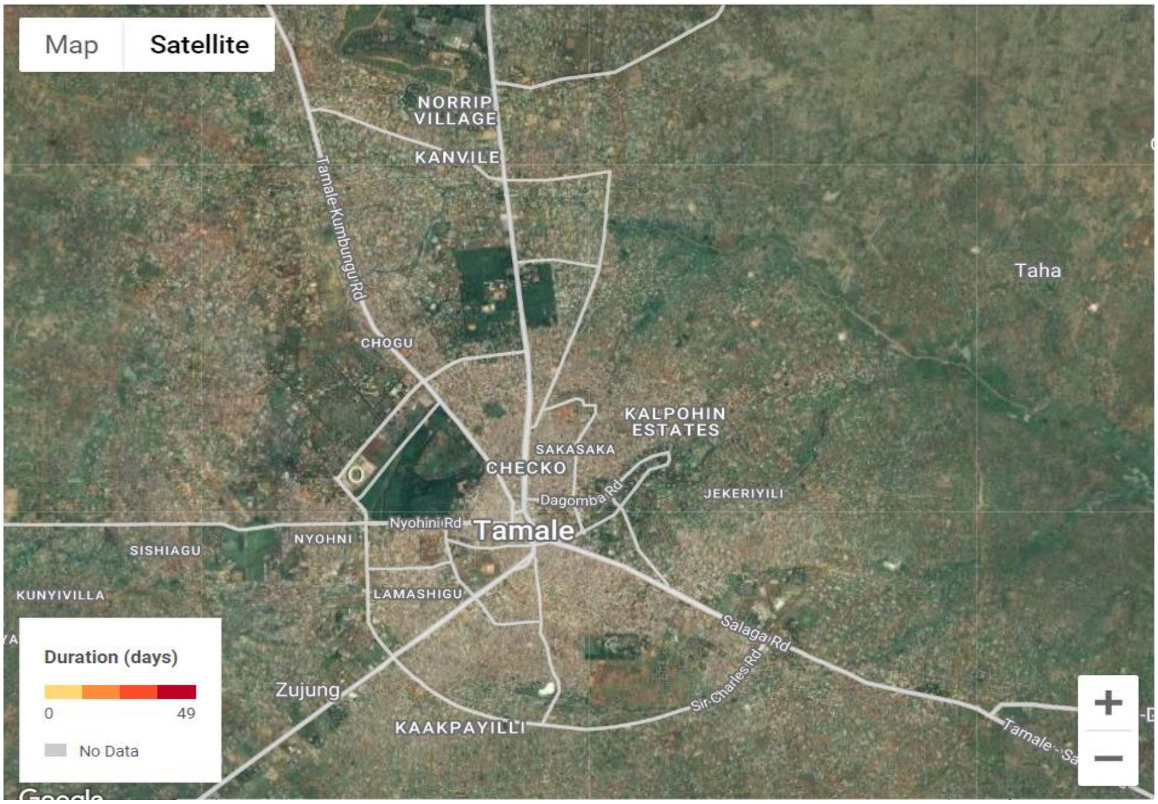

Figure 4.1: Satellite image of flood prone areas in Tamale Metropolis

Source: Authors own construct from www.earthmap.net, (2023)

4.2.1 Mean annual rainfall pattern of Tamale Metropolis

Analyzing the data on mean annual rainfall for the Tamale Metropolis, as presented in Figure 4.2, reveals distinct trends and variations over the years. Generally, higher rainfall levels are associated with increased flood risks, as supported by Olanrewaju et al. (2017). Figure 4.3 categorizes mean annual rainfall into different levels very low, low, medium, high, and very high. However, the classification of these categories requires a clear justification based on defined breakpoints. It is important to critically assess whether the thresholds for each category accurately reflect the observed rainfall distribution, especially if the majority of years fall within the same category. The data indicates that mean annual rainfall in the Tamale Metropolis has shown fluctuations, with an overall increasing trend over the past twenty-seven years. The highest recorded rainfall occurred in 2018, reaching 298 mm, while the lowest was observed in 2013 at 152 mm. The increasing rainfall trend has significant implications, particularly for flood-prone zones in the metropolis. The existing drainage systems are not adequately designed to handle high water volumes, leading to water accumulation and flooding. Additionally, higher rainfall, combined with rising temperatures, contributes to increased surface runoff and flood risks.

Beyond flooding, the variability in rainfall has broader implications for agricultural livelihoods, water supply, and local ecosystems. Higher rainfall levels can enhance agricultural productivity by improving soil moisture availability, yet excessive rainfall may lead to crop damage, soil erosion, and waterlogging. Conversely, periods of lower rainfall, such as in 2013, may reduce flood risks but can also lead to water shortages, affecting both domestic water supply and agricultural activities. Understanding these trends is crucial for developing adaptive strategies to mitigate the adverse impacts of rainfall variability in the Tamale Metropolis.

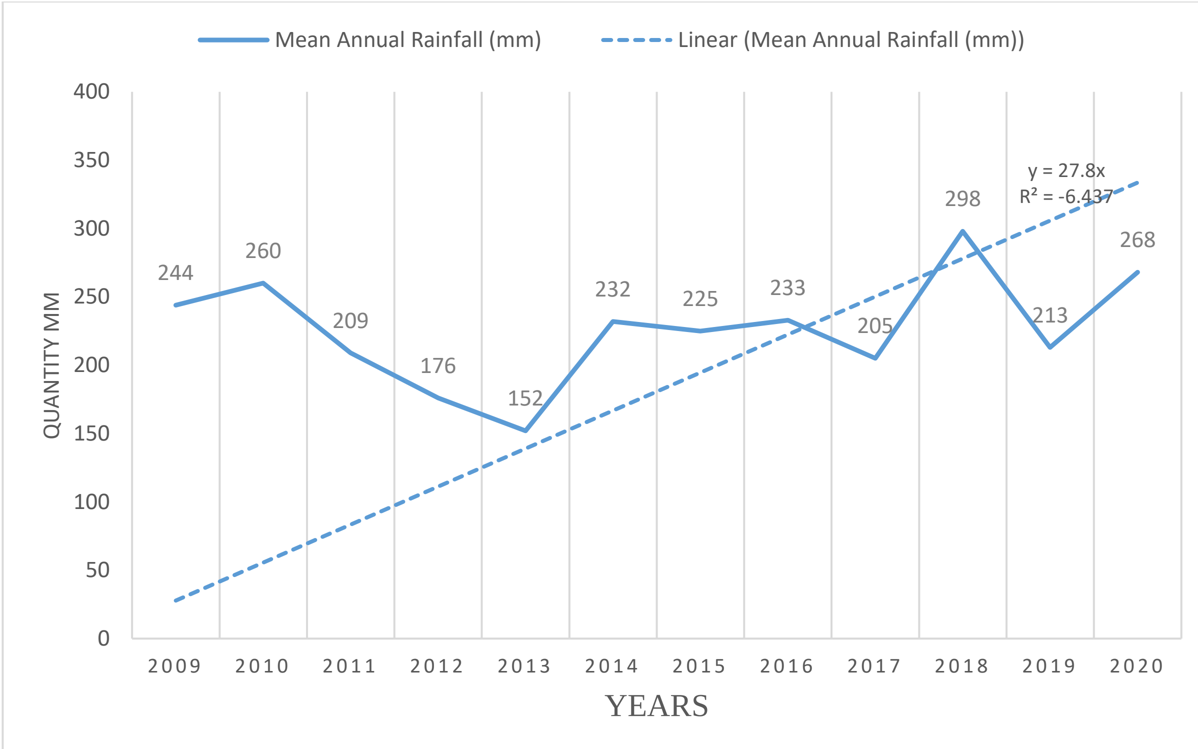

Figure 4.2: Mean annual rainfall

Source: www.climate-data.org (2023)

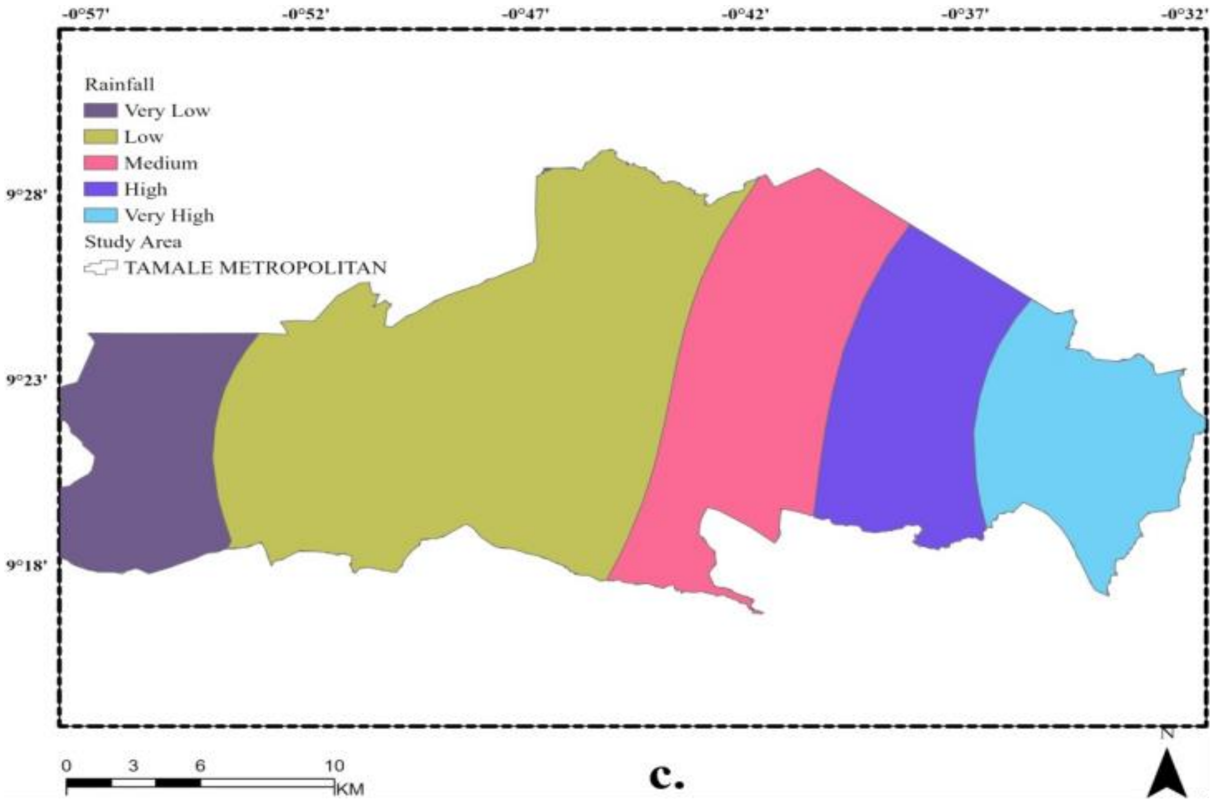

Figure 4.3: Mean annual rainfall

4.2.2 Soil type of Tamale Metropolis

The soil map of the Tamale Metropolis is presented in Figure 4.4 which indicates two main soil types in the metropolis. There included Ferric Luvisols and Plinthic Luvisols, covering 162.65 km^2 and 406 km^2 of land area, respectively (Figure 4.4 and Table 4.13). Ferric Luvisols has a high clay nature and low infiltration rate, making it prone to flooding (Ružičić et al., 2019). The predominant soil types in the Metropolis include sandstone-derived soils, gravelly soils, mudstone-derived soils, and shale-based soils, which have weathered into various soil grades. The presence of these soil types and their properties directly lead to flooding in the area. Ferric Ferric Luvisols, the predominant soil type in the Tamale Metropolis, contribute significantly to flooding due to their high clay content and low infiltration rate. As a result, rainwater is not easily absorbed, leading to surface runoff and water accumulation. This excess water flows downhill, saturating the soil and causing flooding in low-lying areas (Zapata & Nabhan, 2003). The clay particles in Ferric Luvisols with a weight of 2.74, signifying a higher importance in influencing flooding, because it swell when wet, which further reduces the soil's permeability. This means that even after the rain has stopped, the soil remains saturated, and it takes longer for the water to drain away. Consequently, the risk of flooding remains high during and after rainfall.

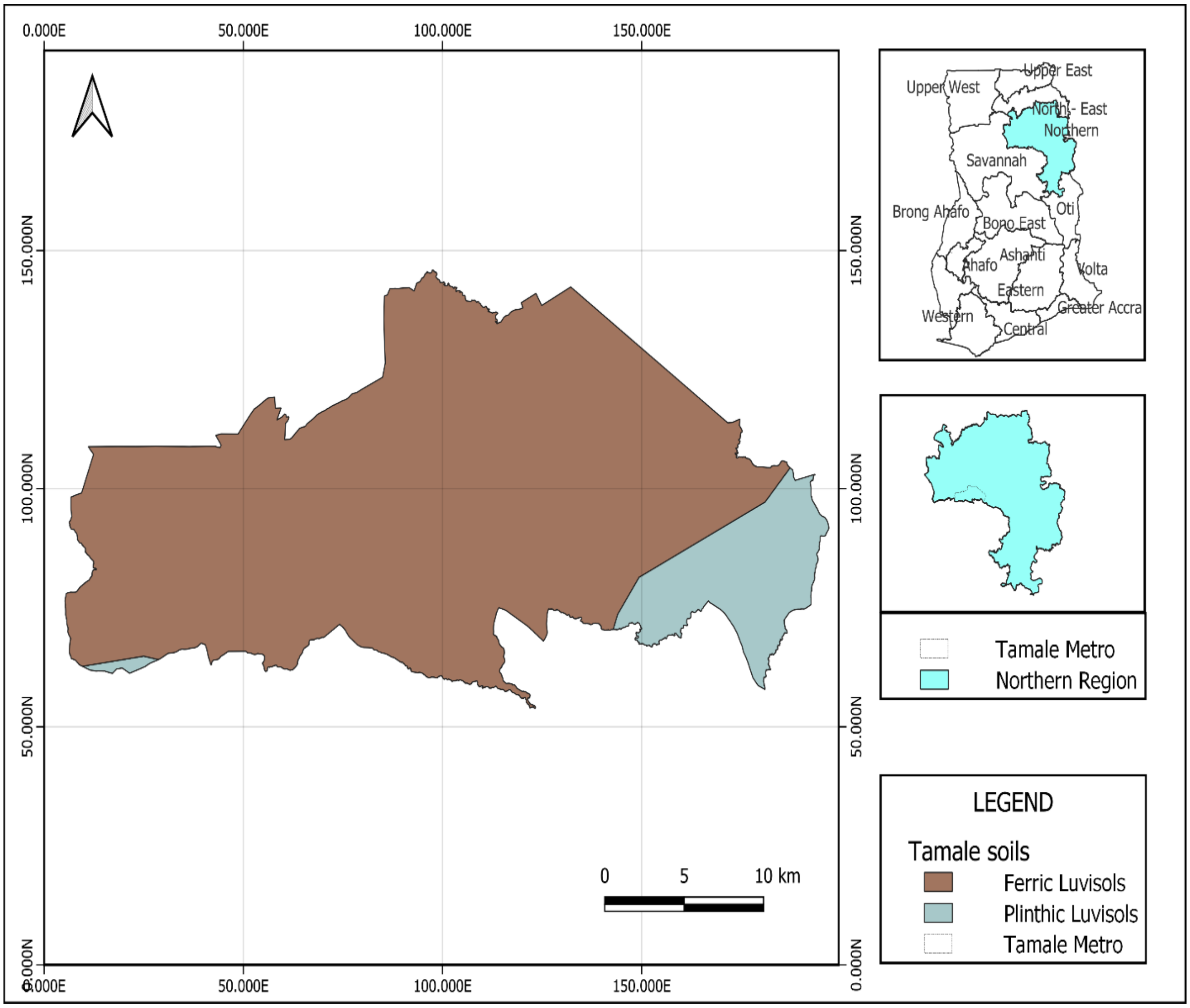

Figure 4.4: Soil types in the Tamale Metropolis

4.2.3 Elevation of Tamale Metropolis

The elevation of the area is one of the indicators leading to flooding in flood-prone areas (Zaharia et al., 2017). From Table 4.13, the elevation in the area ranges from a minimum of 100 meters to a maximum of 200 meters. The lowest elevation areas, which cover 42.94 km², are classified as highly flood-prone, whereas the highest elevation areas, covering 184.45 km², are classified as low flood-prone zones. From Figure 4.5, it is evident that lower elevation areas are dominant in the study area which makes it more prone to flooding. In the Tamale Metropolis, several areas are identified as prone to flooding due to their low elevation. These areas include Sakasaka, Taha, Kanvilla, Norrip village, Chogu, Nyohni, Kunyilla, Zujung, Kaakpayili, Shishegu, Jekeriyili, Lamashegu, Kalpohin estate and Fuo. This finding is consistent with the general understanding that lower elevations are more prone to flooding, as flood disasters often occur in areas with low topographic elevations or downstream areas (Mohanty et al., 2020; Klemas, 2015).

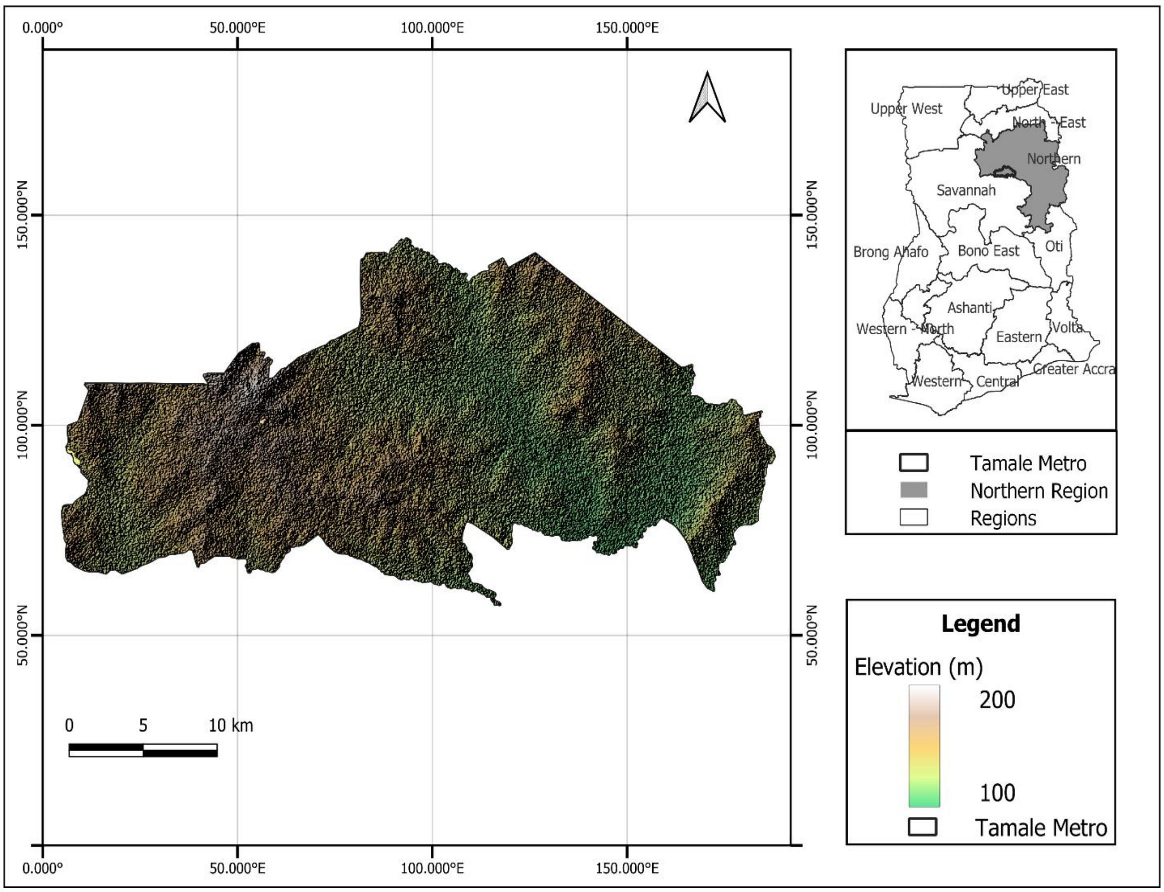

Figure 4.5: Elevation in the Tamale Metropolis

4.2.4 Slope of Tamale Metropolis

The inundation of an area by water depends on the length and steepness of its slope (Abubakari & Twum, 2019). Areas with low slope length and angle are more likely to experience inundation compared to areas with high slope length and angle (Acharya & Chettri, 2012). Areas with low slopes generally have a lower risk of rapid surface runoff, allowing for better water absorption and reducing the likelihood of flash floods (Afriyie et al., 2018). However, these areas may still be susceptible to flooding if there is prolonged rainfall or if the soil has limited drainage capacity. As the slope increases, there is a higher potential for surface runoff, resulting in faster movement of water over the land surface and contributing to increased flood risk (Wenger, 2015). Steeper slopes can enhance the speed of runoff, potentially leading to higher flood risk. Areas with slopes greater than 5% are generally more prone to rapid runoff and increased flood risk, making them susceptible to flash floods, especially during heavy rainfall (Abdelkareem, 2017).

Figure 4.6 presents the slope map of the Tamale Metropolis, highlighting variations in elevation across the study area. The highest slope recorded is 5.97, while the lowest ranges between 0 and 1.51. The color gradient on the map suggests that most of the Tamale Metropolis has a relatively gentle slope, as indicated by the dominance of lighter shades. This implies that the area is predominantly flat, with only a few sections exhibiting steeper inclines. The highest slopes, represented by darker shades, are concentrated in certain parts of the metropolis, possibly in areas with minor hills or elevated landforms. The relatively flat topography is characteristic of many parts of northern Ghana, which are known for their expansive plains and gradual elevation changes. These variations influence the area's susceptibility to flooding, with lower-lying regions being more prone to inundation. Despite Tamale Metropolis generally being characterized by a relatively flat and low-lying terrain, the city has experienced recurrent severe flooding over the years, leading to significant loss of lives and property (Kasei, Kalanda-Joshua & Benefor, 2019).

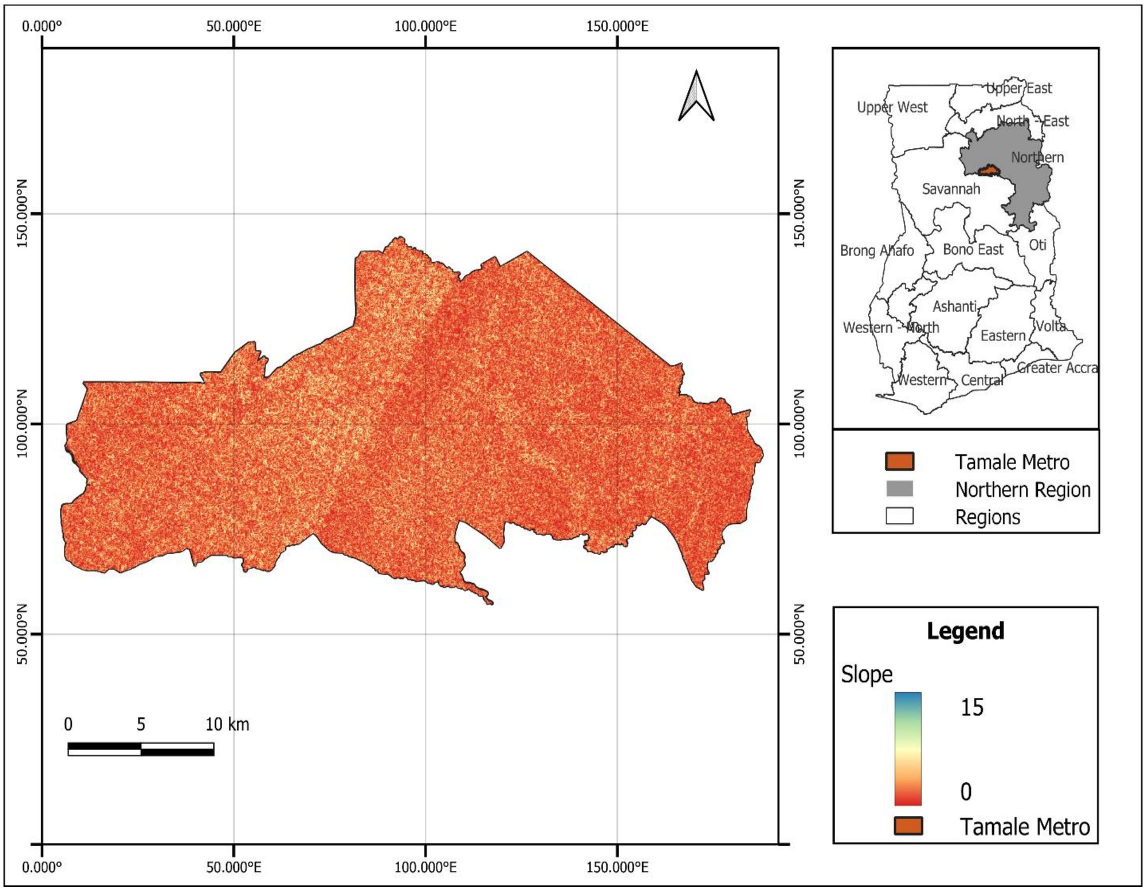

Figure 4.6: Slope in the Tamale Metropolis

4.2.5 Drainage Density of Tamale Metropolis

A high drainage density indicates a significant generation of surface runoff, consequently increasing the likelihood of flooding, and vice versa (Prokešová, Horáčková & Snopková, 2022). Urban areas with road networks and agricultural lands commonly exhibit high drainage densities. This is primarily due to the prevalence of impervious surfaces such as roads, buildings, and paved surfaces, which impede water infiltration into the soil. As a result, water flow is accelerated, leading to higher drainage densities. Conversely, areas devoid of vegetation, such as barren lands, typically exhibit very low drainage densities (Radwan, Alazba & Mossad, 2019). The absence of plant roots, which aid in soil particle cohesion and increased infiltration, contributes to the low water flow rates in such regions. Furthermore, the lack of vegetation promotes a higher proportion of surface runoff, thereby contributing to the reduced drainage density. Figure 4.7 shows the drainage density map of the Tamale Metropolis. The drainage density map is categorized into five classes: ≤2.2, 2.3–4.5, 4.6–6.7, 6.8–9.0, and >9.0 (Figure 4.7). The area covered by each drainage density class is as follows: very high drainage density covers 125.398 km², high drainage density covers 126.544 km², medium drainage density covers 92.300 km², low drainage density covers 204.92 km², and very low drainage density covers 227.36 km² (Table 4.13).

Areas classified as having very high drainage density (125.398 km²) are likely to have a dense network of streams and channels, indicating a high potential for rapid runoff and increased susceptibility to flash flooding during heavy rainfall events. High drainage density values reflect a high runoff volume and a greater potential for flash flooding (Karmokar & De, 2020). This is because a high drainage density is associated with a dense network of streams and channels, which can lead to rapid runoff and an increased risk of flash flooding, especially during heavy rainfall events. Similar to very high-density areas, those with high drainage density (126.544 km^2) also exhibit significant stream channel networks. These areas may experience heightened flood risk due to the efficient conveyance of water through the drainage system. In addition, the moderate drainage density which covered an area of 92.300 km^2, suggests a less extensive network of streams compared to the high or very high-density areas. While these areas may still be prone to localized flooding, the overall flood risk may be lower compared to higher-density areas. Furthermore, areas with low drainage density (204.92 km^2) have fewer natural channels, resulting in slower runoff and reduced flood risk under normal conditions. Low drainage density is associated with less efficient water conveyance through the landscape, as water moves more slowly over hillslopes. Finally, the lowest drainage density class covering an area of 227.36 km^2, indicates areas with minimal natural stream networks. Here, these areas with very low drainage density have minimal stream channels, ultimately resulting in slower runoff and reduced flood risk under normal conditions.

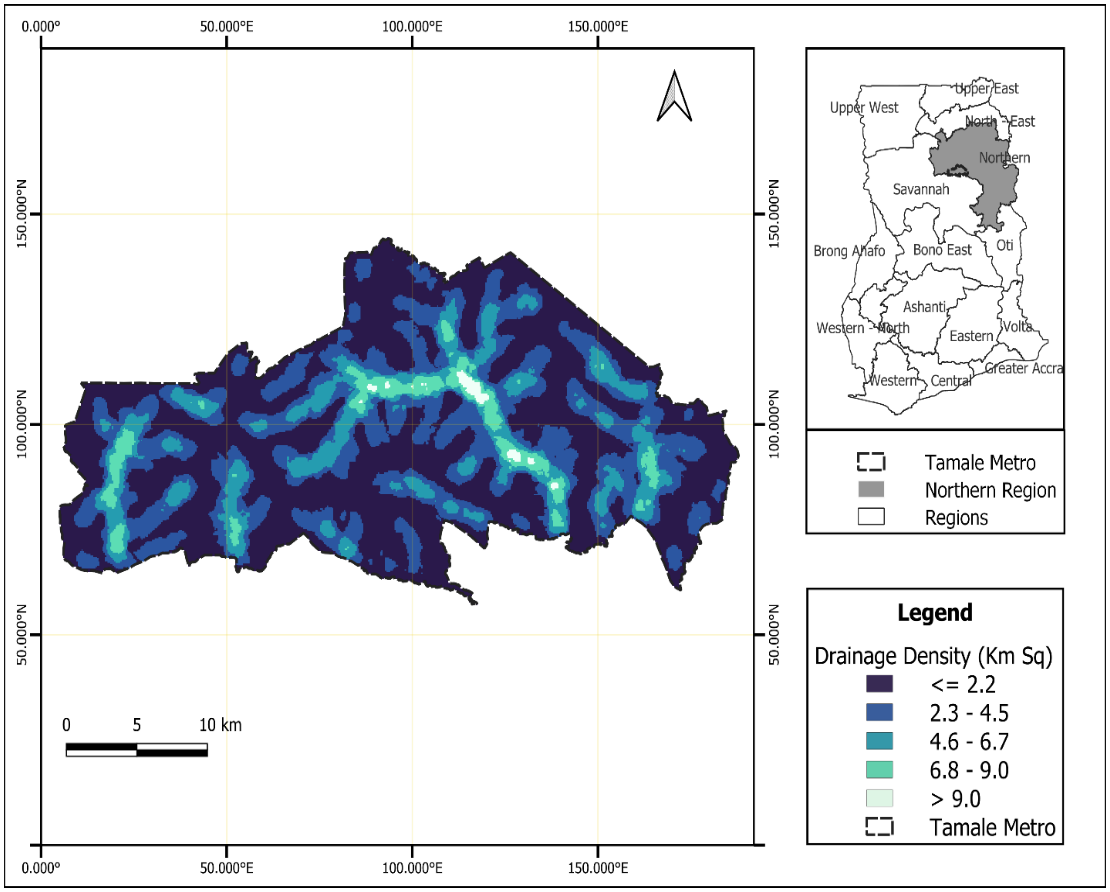

Figure 4.7: Drainage Density in the Tamale Metropolis

4.2.6 Flow Accumulation of Tamale Metropolis

The flow accumulation is considered a significant factor in assessing flood risk within the Tamale Metropolis. A high flow accumulation level indicates a higher likelihood of flooding (Oppong, 2011). This is supported by research conducted by Bannari et al. (2016), which demonstrates that areas with high flow accumulation tend to have larger runoff volumes and greater potential for flash floods. Figure 4.8 visually the map indicating a legend that categorizes stream orders into different levels: very low, low, medium, high, and very high. First-order streams are the smallest and originate from source areas, such as springs or runoff channels. Also, the second-order streams form when two first-order streams converge. While, higher-order streams (e.g., third, fourth, or higher) result from successive merging of lower-order streams, growing larger and carrying more water. The stream network in Tamale Metropolis, as represented in the map, highlights a dense network of lower-order streams (depicted in light colors) feeding into higher-order streams (darker colors), which eventually contribute to larger drainage systems.

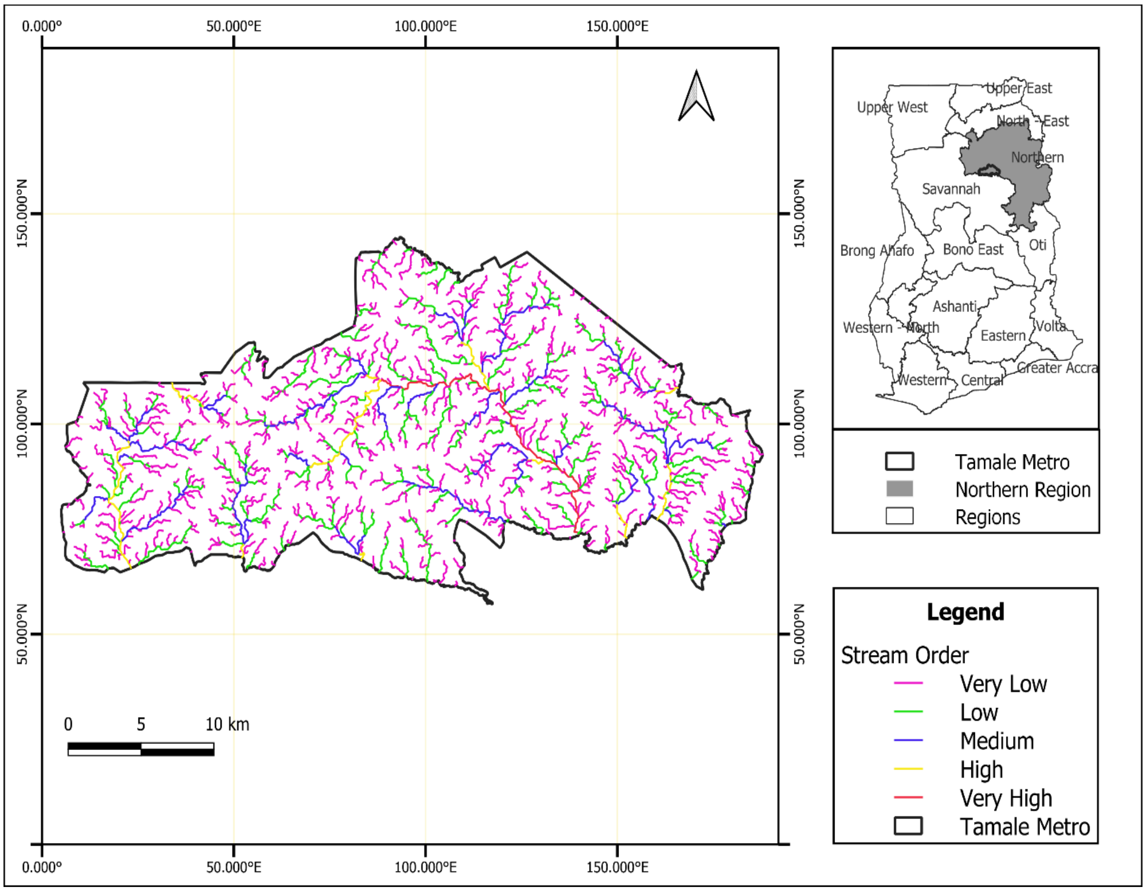

Figure 4.8: Stream Order in the Tamale Metropolis

4.2.7 Land use dynamics of the Tamale Metropolis

The land use and land cover (LULC) classification of the Tamale Metropolis highlights the spatial distribution of different land types, including water bodies, developed/urban areas, bare land, vegetation, and agricultural/cultivated land. These land cover types play a crucial role in influencing flood risk and inundation. However, as the analysis is based on a single LULC map, it represents a static snapshot rather than a dynamic assessment of land use changes over time. Therefore, the focus is on land cover rather than land use dynamics.

In the study area, water bodies cover 29.98 km², this water includes rivers and ponds which act as natural drainage channels, aiding in the absorption and conveyance of excess water during rainfall events (Figure 4.9). However, extensive water bodies also pose a risk of overflow, potentially leading to localized flooding. Therefore, while water bodies help manage water flow, their extensive presence also contributes to flood risk, especially during heavy rainfall or storm events (Ward et al., 2020). In addition, the developed/urban areas in the study area cover 136.45 km². As a result of development, impervious surfaces like roads and buildings, reduce natural infiltration and increase surface runoff during heavy rainfall, potentially causing urban flooding.

In the Tamale metropolis, the built-up area has increased from 12% to 24% from 2009 to 2020, due to considerable urban expansion (Abubakari, Anaman & Ahene-Codjoe, 2022). Additionally, the increased impermeable surfaces in urban areas lead to a higher risk of flooding, as there is less space for water to absorb into the ground (Amoateng et al., 2018).

Furthermore, bare land in the study area covers 251.07 km², which can potentially reduce surface runoff during rainfall. Also, vegetation covers 135.88 km², which plays a major role in mitigating flooding by promoting infiltration, reducing surface runoff, and stabilizing soil. However, changes in land use that reduce vegetation cover, such as deforestation or urban expansion, may increase the risk of flooding. Finally, agricultural/cultivated land covered only 52.89 km², of the study area. The impact of agricultural areas on flooding in Northern Ghana varies depending on the specific cultivation practices used. Common agricultural practices in the region include rain-fed farming, slash-and-burn cultivation, monocropping, and small-scale irrigation. Poor land management, deforestation for farming, and inadequate soil conservation measures often exacerbate flooding by reducing soil infiltration and increasing surface runoff. . Well-managed agricultural lands with effective drainage systems help reduce flood risk. However, improper land management, such as inadequate soil conservation practices, leads to soil erosion and increased runoff, potentially contributing to flooding.

Generally, the transformation from vegetation-covered land to urban structures has led to increased surface temperature and the potential for higher levels of runoff and flooding (Dibaba, 2023). The vegetation in the area helps to regulate the water cycle by absorbing and storing water, and urbanization has reduced the amount of vegetation, leading to an imbalance in the water cycle. This imbalance causes flooding, as there is more water than the area can absorb, leading to a higher risk of flooding during rainfall.

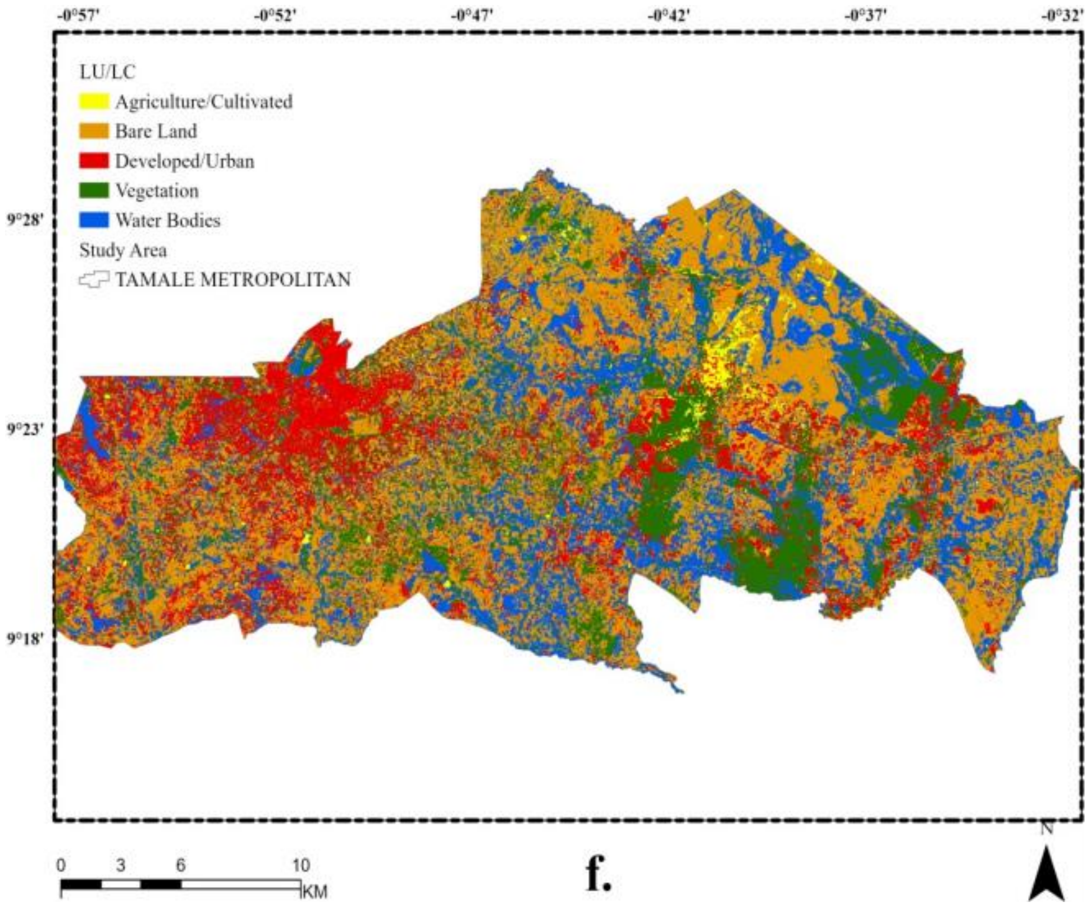

Figure 4.9: Land Use and Land Cover for the Tamale Metropolis for 2024

4.2.8 Distance to Stream of the Tamale Metropolis

The spatial distribution of buffer zones around streams in Tamale Metropolis plays a crucial role in understanding accessibility to water resources and assessing flood risks. The map of the metropolis categorizes these zones using a color-coded system that represents varying distances from water bodies. These classifications include areas within 250 meters (dark blue), 500 meters (light blue), 750 meters (green), 1000 meters (yellow), and beyond 1000 meters (orange). Each of these zones exhibits distinct characteristics in terms of exposure to flooding, water availability, and interactions with human settlements. The areas closest to the streams, represented by dark blue

(250 meters) and light blue (500 meters), are the most vulnerable to flooding and erosion. These regions experience a higher probability of waterlogging and stream overflow, particularly during intense rainfall events. The increased presence of surface water in these zones can also contribute to soil degradation and infrastructure damage. In contrast, the green (750 meters) and yellow (1000 meters) zones represent intermediate distances, striking a balance between accessibility to water resources and reduced flood risks. These areas benefit from relatively lower exposure to direct stream overflow while still maintaining proximity to water sources. On the other hand, the orange zone, which extends beyond 1000 meters from the streams, is the farthest from these water bodies. While these areas are less prone to flooding, they may face challenges related to water scarcity, especially during dry seasons when reliance on surface water is critical.

The distance to streams is a key factor in flood risk assessment, as it directly influences the likelihood of flash floods and other water-related hazards. Streams are part of a broader drainage system, with each stream playing a role in channeling runoff within a specific drainage basin (Leibowitz et al., 2018). Areas situated close to streams are particularly susceptible to flooding, given the higher probability of stream overflow during heavy rainfall (Korichi, Hazzab & Atallah, 2016). Additionally, land topography and the presence of impermeable surfaces, such as roads and buildings, can intensify flooding in these regions by limiting natural water infiltration and increasing surface runoff (Kaur et al., 2019). The capacity of the drainage system to manage large volumes of water is also influenced by proximity to streams, further affecting the severity of flooding, particularly in urbanized and densely populated areas.

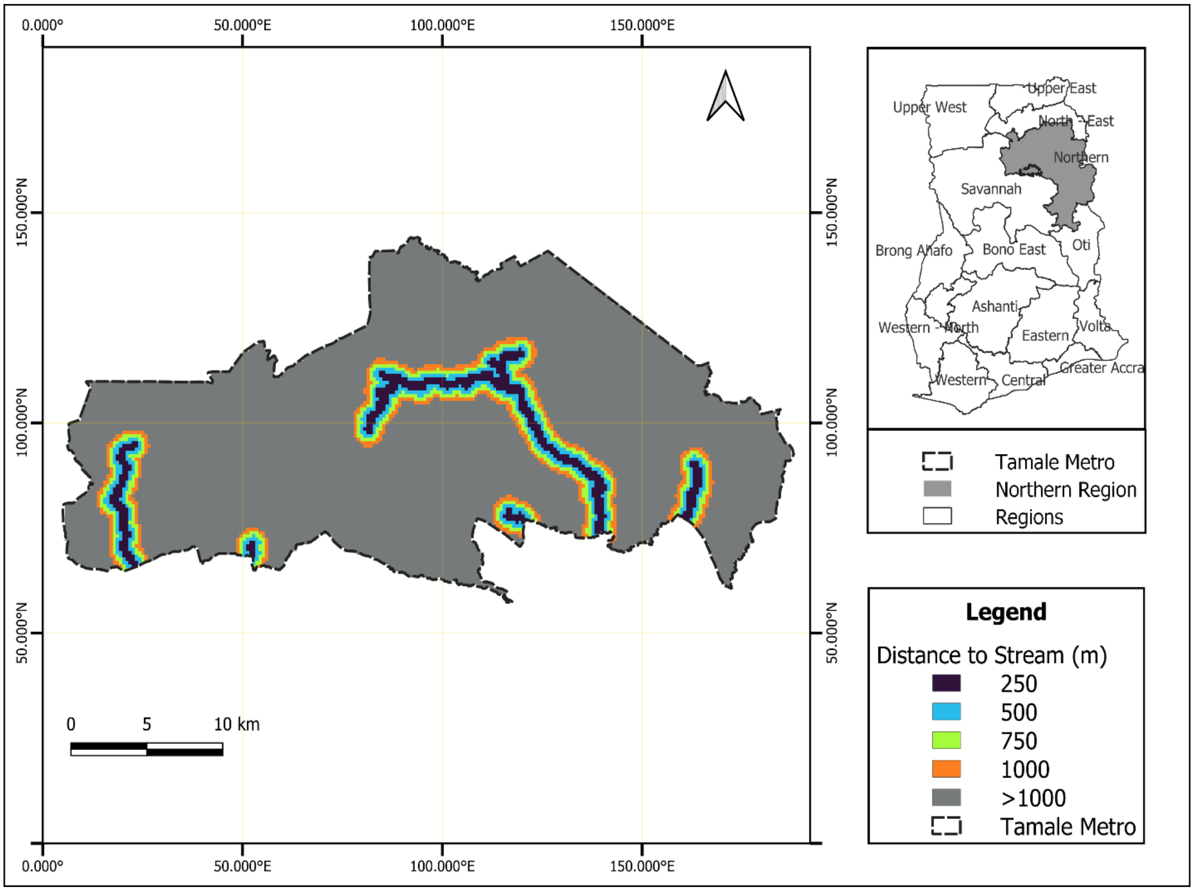

Figure 4.10: Distance to Stream for the Tamale Metropolis

4.2.9 Topographic Wetness Index (TWI) for the Tamale Metropolis

The Topographic Wetness Index (TWI) is a key measure of moisture distribution in the Tamale Metropolis, influencing precipitation patterns and flood risks (Oswald et al., 2023). In this study, the TWI ranges from 8 to -16, with higher values indicating greater moisture accumulation, which can contribute to heavy rainfall and increased flood risk. To ensure accuracy, the map may need adjustments to reflect these ranges properly. Areas with high TWI values, often found in low-lying zones, valleys, and riverbanks, tend to retain more moisture and are more prone to flooding. In Tamale, such flood-prone areas include Nabagla, Dohanayili, and Gburimani. Conversely, regions with low TWI values are typically elevated or well-drained, experiencing drier conditions and lower flood risks. In Tamale, these include Kukuo, Vittin, and parts of Lamashegu, which sit on higher ground. This interpretation aligns with the existing literature, which highlights the influence of climatological factors on flood vulnerability and the necessity for proactive measures to prevent and mitigate the destructive effects of flooding, especially in rapidly urbanizing regions (Martinez, Bakheet & Akib, 2020; Idris & Dharmasiri, 2015) such as the Tamale Metropolis.

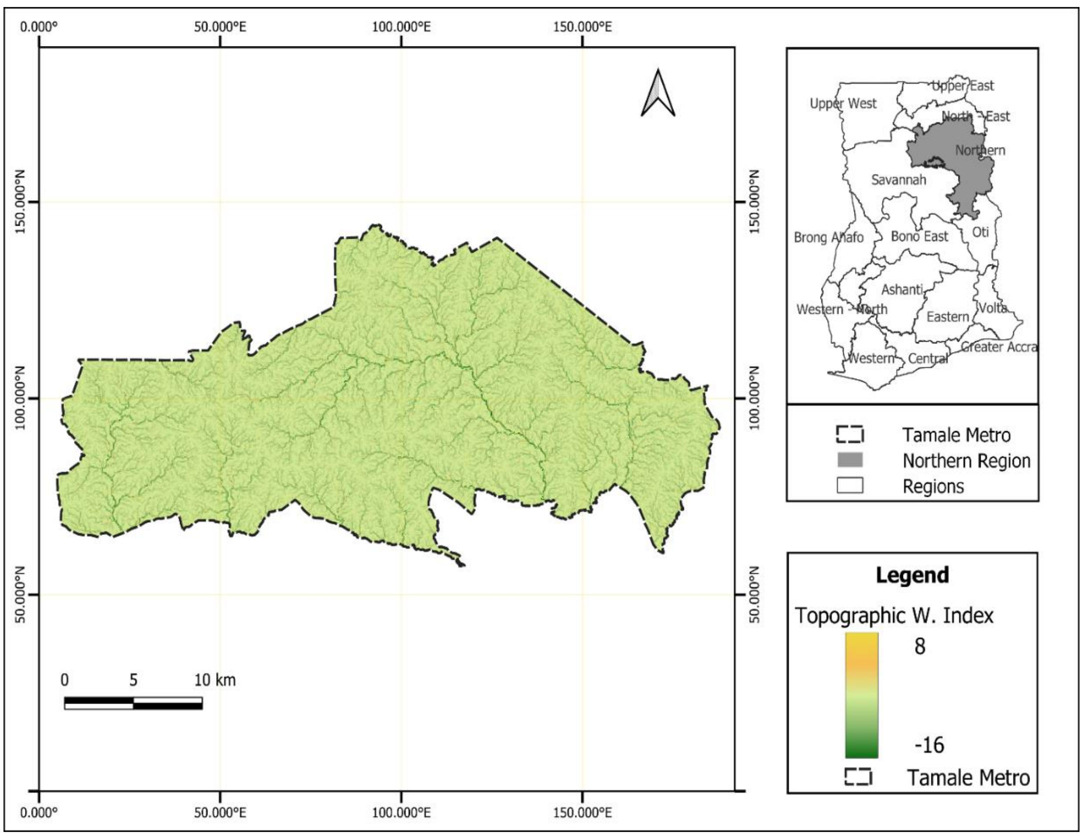

Figure 4.11: Topographic Wetness Index (TWI) for the Tamale Metropolis

4.3 Effects of flooding on the environment, social, and economic dynamics within the Tamale Metropolis

This objective aims to investigate the impact of flooding on the environment, as well as the social and economic dynamics within the Tamale Metropolis. The study assesses the socio-economic vulnerability to floods by analyzing the social, economic, and environmental factors that contribute to the susceptibility of individuals residing in flood-prone areas of the Tamale Metropolis. Additionally, the study examines hydrological vulnerabilities by taking into account various factors such as soil type, slope, elevation, land use and land cover, drainage density, flow accumulation, rainfall, and the topographic wetness index of the area.

4.3.1 Socio-economic flood vulnerabilities indicators

In this study, the socio-economic flood vulnerabilities aspect, is measured based on the weight of social, economic and environmental indexes on victims within the flood-prone areas of the Tamale Metropolis.

4.3.1.1 Social Flood Vulnerability Index

The Social Sub-Index for the Tamale Metropolis is 1.6, indicating a moderate level of awareness and preparedness for flood risks within the community (Table 4.4). This suggests that although there are ongoing flood-related awareness campaigns and educational programs, there is still room for improvement in terms of community-led initiatives and resources for income, employment, and education. The score of two (2) for the Social Sub-Index component in the Tamale Metropolis indicates the presence of flood awareness and preparedness initiatives in the community, but their effectiveness varies. This implies that while efforts are being made to address flood risks, there are inconsistencies in the impact of these initiatives. These initiatives include resilient design and construction in the Tamale Metropolis, continuous awareness creation about the consequences of flooding, promotion of education on disaster preparedness, and the implementation of traditional and local knowledge practices, such as building mud flood barriers around farms and creating water channels and flood retardation ponds, to mitigate the impacts of floods (Macnight-Ngwese et al., 2018). Therefore, the varying effectiveness of flood awareness and preparedness initiatives in the Tamale Metropolis highlights the need for a more cohesive and integrated approach to ensure consistent and impactful outcomes in addressing flood risks within the Tamale Metropolis.

The significance of continuous improvement and effective resource management in addressing flood risks within the Tamale Metropolis is underscored by the need to enhance community awareness and preparedness. Research on flood risk management in Ghana highlights the importance of creating awareness about the consequences of flooding and promoting education on disaster preparedness (Tasantab et al., 2020). Furthermore, the evaluation of current flood risk management practices in Ghana calls for an integrated approach involving the active participation of all relevant stakeholders to address flooding problems (Atanga, 2020). Therefore, continuous improvement and effective resource management are crucial for enhancing the community's resilience and reducing the impact of flood risks in the Tamale Metropolis.

Table 4.4: Social Vulnerability Index

Social Sub-Index Components	Weight	Score	Contribution
Flood-related awareness campaigns or educational programs	0.4	2	0.8
Level of awareness regarding flood risks and preparedness	0.3	3	0.9
Community-led initiatives or organizations for flood risk awareness and preparedness	0.2	2	0.4
Community resources or organizations providing support related to income, employment, or education	0.1	2	0.2
Total			**1.6**

Source: Field Survey Data (2023)

4.3.1.2 Economic Vulnerability Index

The Economic Sub-Index for the Tamale Metropolis is 1.95, indicating a moderate level of economic development and accessibility within the community (Table 4.5). The Tamale Metropolis has an Economic Sub-Index score of 1.95, signifying a moderate level of economic development and accessibility within the community. This moderate level implies that the existing economic activities and resources in the area are not sufficient to meet the needs of the people, particularly in terms of employment, education, healthcare, and transportation. Despite being strategically located in the Northern Region of Ghana and having the potential to attract both population and economic development, the Tamale Metropolis still requires improvements to meet the demands of its residents. Efforts to enhance flood resilience through resilient design and construction would be crucial in reducing the risk of floods in the area, considering its vulnerability during such events.

Table 4.5: Economic Vulnerability Index

Economic Sub-Index Components	**Weight**	**Score**	**Contribution**
Economic activities	0.2	3	0.6
Accessibility of employment	0.15	2	0.3
Accessibility of educational institutions	0.1	2	0.2
Economic development initiatives	0.15	1	0.15
Accessibility of healthcare facilities	0.1	2	0.2
Transportation network and services	0.15	2	0.3
Land use pattern and zoning regulations	0.1	2	0.2
Development projects impact	0.05	1	0.05
Total			**1.95**

Source: Field Survey Data (2023)

4.3.1.3 Environmental Vulnerability Index

The Environmental Sub-Index for the Tamale Metropolis, which has a score of 1.5, indicates a moderate level of physical vulnerability to flooding (Table 4.6). This suggests that the Metropolis is confronted with significant challenges in terms of its environmental resilience, specifically regarding flood risks. The score highlights the necessity for implementing measures aimed at addressing the area's environmental vulnerability to flooding. A study conducted by Owusu (2014) on minimizing the risk of floods through resilient design and construction in the Tamale Metropolis discusses the socioeconomic implications of recurrent floods and emphasizes the importance of resilient designs capable of withstanding the impact of floods. The study identifies key design features that provide adequate resilience against floods, including appropriate provisions in facility design, ample vegetative cover, and strict adherence to zoning laws.

The causes of flooding in the Tamale Metropolis are both natural, such as climate change, and man-made, such as improper land use and unplanned development of settlements (Asiedu, 2020). Consequently, the contamination of water sources during floods poses health risks to the affected population. The environmental vulnerability to flooding results in the loss of lives and damage to infrastructure such as roads, bridges, and utilities, thereby affecting the accessibility and functionality of essential services. Therefore, the moderate level of vulnerability implies that the population in the Tamale Metropolis is at an elevated risk of harm during floods.

Table 4.6: Environmental Vulnerability Index

Environmental Sub-Index Components	Weight	Score	Contribution
Access to a reliable and safe water supply system	0.2	1	0.2
Quality of the water supply in terms of safety and cleanliness	0.15	2	0.3
Availability of proper sanitation facilities to residents (toilets, waste disposal)	0.15	2	0.3
Located in a low-lying area or valley where water tends to accumulate during heavy rains or floods	0.2	1	0.2
Proximity to the nearest major water body	0.1	3	0.3
Proximity to drainage systems or streams that could affect water flow during heavy rains or floods	0.2	2	0.4
Total			**1.5**

Source: Field Survey Data (2023)

4.3.1.4 Overall Vulnerability Index

The Tamale Metropolis, situated in the northern region of Ghana, exhibits a moderate level of vulnerability to flooding, with an overall index of 4.02 (Table 4.7). This suggests that although the area is not highly vulnerable, it still faces significant risks associated with flooding events.

The environmental sub-index accounts for 45% of the overall index, indicating its notable impact on the area's vulnerability. This sub-index considers factors such as land use, topography, and climate patterns, which influence the probability and severity of flooding events (Table 4.7). In the Tamale Metropolis, rapid urbanization, deforestation, and poor waste management contribute to increased vulnerability to flooding (Shokri, Sabzevari & Hashemi, 2020). Additionally, the economic sub-index contributes 57% to the overall index, emphasizing its role in shaping vulnerability. This sub-index takes into account factors such as infrastructure, economic activities, and investments that either exacerbate or mitigate the risks associated with flooding events. In the Tamale Metropolis, the expansion of informal settlements, inadequate infrastructure, and limited access to financial resources contribute to the area's vulnerability (Rufat et al., 2015). Lastly, the social sub-index contributes 64% to the overall index, highlighting its substantial influence on vulnerability. This sub-index considers factors such as demographics, social cohesion, and access to information that affect communities' ability to prepare for, respond to, and recover from flooding events. In the Tamale Metropolis, high population growth, limited access to education, and poor access to information contribute to vulnerability. Consequently, the high percentage of this vulnerability makes the people of Tamale more susceptible to flooding, particularly those residing in flood-prone areas within the Tamale Metropolis.

Table 4.7: Overall Vulnerability Index

Overall Vulnerability Index	Weight	Score	Contribution
Social Flood Vulnerability Index	0.4	1.6	0.64
Economic Vulnerability Index	0.3	1.9	0.57
Environmental Vulnerability Index	0.3	1.5	0.45
Total			**4.02**

Source: Field Survey Data (2023)

4.4 Effective Flood Adaptation Strategies used by residents in the Tamale Metropolis

This objective examine the effective flood mitigation strategies used by residents in the Tamale Metropolis.

4.4.1 Flood Mitigation Strategies used by residents in the Tamale Metropolis

The residents of Tamale Metropolis use the flood control techniques shown in this section. The findings of Kendall's coefficients of concordance show that there is a highly substantial level of agreement between respondents' rank scores on the adaptation strategies they have employed to lessen the negative effects of floods in urban areas. According to Table 4.8, there is a significant agreement among respondents' rank scores at a 1% level of significance, as indicated by the Chi-Square (df = 9) = 1060.809 and asymptotic Significance = 0.000. Additionally, Kendall's coefficient of concordance (W) = 0.795 indicates that 79.5% of respondents' ranking scores agree.

According to the results in Table 4.8, the most common adaptation option used to lessen the effects of floods in Tamale is the use of sandbags and flood barriers. This tactic involves erecting physical barriers, including flood barriers and sandbags, to stop or lessen the effects of floods. These precautions are essential for protecting infrastructure and properties from flooding when there is heavy rainfall or rising water levels.

The Tamale metropolis uses sandbags and flood barriers as their main adaptation method to counteract the consequences of floods, according to the findings of the qualitative interviews. The participants described this method as a realistic reaction to lessen the harmful impact of floods, emphasizing its confined nature and practicality. It was constantly believed that the community's deployment of these physical barriers was a proactive step toward strengthening its resistance against flooding. According to respondents, this adaptation plan emphasizes teamwork in defending inhabitants and infrastructure, which is in line with the overarching objective of efficiently managing and reducing the negative impacts of seasonal floods in Tamale.

Both natural and artificial factors contribute to the yearly floods experienced by flood-prone zones in Tamale; throughout the past 27 years, rising average temperatures and more rainfall have been brought on by climate change. In addition, improper land use, uncontrolled settlement growth, and careless trash disposal into and along riverbanks are recognized as man-made factors contributing to urban floods. Given these difficulties, the use of sandbags and flood barriers is an essential adaptation technique to lessen the effects of flooding in Tamale. These physical barriers lessen the economical effects of floods in flood-prone areas, safeguard life and property, and stop flooding. In addition, using sandbags as flood barriers is an affordable and useful way to keep different places safe from flooding. Sandbags are useful for blocking the outer crevices of homes and containing rainfall in low-elevation terrain (Atufu & Holt, 2018), making them a valuable tool for flood protection.

Furthermore, the second most widely used adaptation approach for reducing the negative consequences of flooding is the deployment of early warning systems. By quickly alerting people to impending floods, early warning systems are essential in reducing the vulnerabilities associated with flooding. This reduces the number of fatalities and property damage by facilitating early evacuation and preparation. Early warning systems provide people and officials in Tamale with crucial information that allows for prompt evacuation and preparation in the event of approaching flooding. As a result, the effects of flooding on infrastructure and communities are greatly reduced. Furthermore, early warning system implementation is critical to catastrophe risk reduction and improving community flood resistance. By increasing awareness of flood hazards and assisting in the adoption of essential actions to lessen the effects of floods, these systems empower communities.

Community evacuation plans are developed as the third adaptation approach used to lessen the effects of flooding. As a result, community evacuation strategies are ranked third. As part of these plans, protocols for safely evacuating citizens from flood-prone areas to designated shelters or safe locations must be established. Having well-thought-out community evacuation strategies is crucial to protecting locals during flooding incidents. According to Kuusaana and Eledi (2015), residents of flood-prone regions in the Tamale Metropolis typically relocate to higher ground or even temporarily stay with their loved ones until the rainy season ends before returning to their homes.

Furthermore, the fourth-ranked adaptation option used to lessen the consequences of flooding is the construction of higher structures. Homes, public buildings, and infrastructure are far less vulnerable to flooding when they are elevated above possible flood levels. During flood occurrences, this adaption technique helps to reduce property damage and guarantees the continued operation of critical services. Residents in flood-prone areas elevate the foundations of their homes to reduce the risk of floodwater intrusion and property damage.

Furthermore, the fifth-ranked adaptation method used to lessen the effects of floods is the purchase of flood insurance. Flood insurance offers monetary security to people and communities impacted by flooding, making it an essential adaptation tactic. Flood insurance is considered a mitigation technique because it doesn't reduce damage but compensates the affected individuals or societies for their losses (Mishra & Sinha, 2020). It lessens the financial strain on impacted homes and companies by helping to pay for the costs of rebuilding or repairing structures damaged by floods. Generally speaking, businesses in flood-prone locations are more likely than individuals to use flood insurance. This is due to the fact that businesses are frequently more susceptible to the financial effects of flood damage since they have more property and assets to safeguard.

Using sustainable landscaping is the sixth adaptation approach that is used to lessen the impact of floods. Sustainable landscaping is a strategy that involves using techniques to promote natural water absorption and drainage, thereby reducing surface runoff and the risk of localized flooding (Collentine & Futter, 2018). This strategy also strengthens the Tamale metropolis' flood-prone districts' resistance to severe weather. When it comes to flooding, homes with rain gardens are less likely to be severely impacted than those with concrete flooring. Additionally, specific landscaping designs, such as laying mulch, choosing native plants with high water tolerance, and building rain gardens, help prevent flood damage (Sharath & Peter, 2019).

Managing stormwater effectively was classified as the eighth adaptation approach used to prevent the effects of floods to support local flood control measures. This entails supporting and funding infrastructure initiatives like the enlargement of drainage systems in flood-prone areas that are meant to prevent floods locally. According to the Norizan, Hassan and Yusoff (2021), local flood control measures are essential for reducing the impact of floods and building more resilient communities. Over the years, NADMO has created initiatives targeted at reducing the amount of money lost to floods and other natural catastrophes.

Despite being the least effective adaptation technique for reducing the effects of floods, using emergency supplies is nevertheless an essential part of being prepared for flooding. Emergency supplies, including food, water, and medical supplies, are essential to the survival of individuals and communities during and after flooding incidents. Philpott and Casavant (2016), recommend having emergency supplies such as sandbags, shovels, and sump pumps assist individuals in overcoming the challenges of flooding.

Table 4.8: Adaptation strategies in reducing flood-related vulnerabilities

Types of adaptation strategies used	**Mean Rank**	**Ranking**
Obtaining flood insurance coverage	5.84	5th
Using flood barriers and sandbags	2.09	1st
Utilizing early warning systems	3.81	2nd
Developing community evacuation plans	4.26	3rd
Building elevated structures	5.31	4th
Implementing sustainable landscaping	6.19	6th
Managing stormwater effectively	6.83	8th
Stocking emergency supplies	7.00	10th
Participating in community flood preparedness programs	6.89	9th
Supporting local flood control measures	6.80	7th
N	400	
Kendall's W	0.795	
Chi-Square	1060.809	
df	9	
Asymp. Sig.	.000	

Source: Field Data (2023)

4.4.2 Effectiveness of existing adaptation strategies used by residents of the Tamale Metropolis in reducing flood-related vulnerabilities

The residents of Tamale Metropolis assessments of the adaptation measures' efficacy in lowering flood-related vulnerabilities are presented in this section. Community outreach and involvement initiatives, investing in better drainage systems, educating the public about flood hazards and adaptation methods, zoning regulations and land-use planning are some of the strategies.

Table 4.9A indicates that 18% of participants strongly agreed and 71% agreed that community outreach and engagement initiatives increased community resilience to flooding. This suggests that raising community awareness and involving the community has a high perceived efficacy in minimizing flood-related vulnerabilities. Additionally, the community's investment in financial support programs and flood insurance helped residents recover from flooding incidents, as acknowledged by 29.8% of respondents and strongly agreed by 70.3% of respondents. This suggests that financial interventions are thought to be successful in lessening the effects of floods on those who are impacted. Furthermore, the results showed that a sizable majority of respondents—69.3% strongly agreed and 29.8% agreed, that financial assistance programs and flood insurance provided by the community were essential in aiding citizens in their recovery following flooding incidents. Investments in infrastructure, early warning systems, and community-based disaster risk reduction strategies are commonly cited as essential components for effective flood management (Perera et al., 2020).

Over half of the respondents representing 52.5% believed that investing in better drainage systems has effectively reduced the risk of floods, while 41.8% of respondents strongly agreed. This suggests that improving infrastructure can effectively mitigate flood vulnerability to a comparatively high degree. The significance and influence of such infrastructure expenditures are highlighted by the large percentage of respondents who agreed that better drainage systems reduce the likelihood of flooding. This sentiment is supported by a study on the positive outcomes associated with well-designed and maintained drainage systems (McClymont et al., 2020).

A study by Davis and Naumann (2017), claimed that effective drainage systems can significantly reduce the likelihood and severity of flooding events, thereby safeguarding communities, infrastructure, and natural environments from the detrimental effects of excessive water accumulation. Through the effective transportation and handling of stormwater, these systems enhance the overall ability to withstand flood-related risks.

Regarding the measures pertaining to education on flood hazards and adaptation strategies, 37% strongly agreed, 41.5 percent agreed, and 13.5 percent were unsure about their effectiveness in reducing the risk of flooding occurrence. According to the study's findings, a sizeable section of the populace understands the value of education regarding flood hazards and mitigation strategies. It is clear that the majority of respondents recognize the value of such educational activities in lowering the likelihood of floods occurring, with 37% strongly agreeing and 41.5% agreeing. It's also noteworthy that 13.5% of respondents were unsure of its efficacy, suggesting a need for more information to be disseminated and clarification to be provided.

Furthermore, the findings indicated that 40% of respondents strongly agreed, 43.8% agreed, and 8.5% were unsure about the effectiveness of zoning regulations and land-use planning in lowering the risk of floods. Land-use planning and zoning regulations are essential for controlling flood risk and lessening the effects of flooding incidents. A significant consideration is how effective they are perceived to be in lowering the likelihood of flooding occurring. On the other hand, regarding the efficacy of zoning regulations and land-use planning in mitigating the risk of floods, 40% strongly agreed, 43.8% agreed, and 8.5% were unsure. The degree to which land-use planning and zoning regulations are perceived as effective in lowering the likelihood of flooding is a crucial determinant of stakeholder and public sentiment toward these policies. This finding suggests a high degree of consensus regarding their efficacy, with a minority expressing skepticism.

Finally, building flood barriers and levees is likewise thought to be an effective strategy in lowering the likelihood of flooding, albeit with a somewhat lesser degree of consensus overall when compared to early warning systems and flood predictions. The view of residents of Tamale metropolis on the efficacy of flood barriers and levees is positive, indicating that these physical infrastructure measures have helped to mitigate flood-related vulnerabilities. By providing a physical barrier against rising water levels, flood barriers and levees protect communities, infrastructure, and agricultural land from inundation during periods of heavy rainfall or river overflow (Wenger, 2015).

Table 4.9A: Perceived effectiveness of adaptation strategies in reducing flood-related vulnerabilities

Types of adaptation strategies used	Perceived effectiveness level of adaptation strategies *f (%)*				
	SA	**A**	**NS**	**D**	**SD**
Community outreach and engagement efforts improved community flooding resilience	72 (18.0)	284 (71.0)	44 (11.0)	0 (0.0)	0 (0.0)
Community investment in flood insurance and financial assistance programme helped residents recover from flooding event	281 (70.3)	119 (29.8)	0 (0.0)	0 (0.0)	0 (0.0)
Investment in improved drainage system has effectively reduced the risk of flooding occurrence	167 (41.8)	210 (52.5)	23 (5.8)	0 (0.0)	0 (0.0)
Education on flood risks and adaptation measures has effectively reduced the risk of flooding occurrence	148 (37.0)	166 (41.5)	32 (8.0)	54 (13.5)	0 (0.0)
Zoning regulation and land-use planning has effectively reduced the risk of flooding occurrence	160 (40.0)	175 (43.8)	34 (8.5)	17 (4.3)	14 (3.5)
Early warning systems and flood forecasting has effectively reduced the risk of flooding occurrence	153 (38.3)	204 (51.0)	23 (5.8)	16 (4.0)	4 (1.0)
Construction of flood barriers and levees has effectively reduced the risk of flooding occurrence	128 (32.0)	170 (42.5)	19 (4.8)	46 (11.5)	37 (9.3)

Source: Field Data (2023) Note: {SA= Strongly Agreed, A= Agreed, NS= Not Sure, D= Disagreed and SD = Strongly Disagreed}

4.4.3 Preferred Adaptation Strategies for Reducing Flood-Related Vulnerabilities

Table 4.9B, presents results of analysis of the preferred adaptation strategies for mitigating flood-related vulnerabilities as perceived by the respondents. The various strategies, ranging from community engagement efforts to infrastructural investments, provide an overview of the level of agreement (SA + A) among the respondents on the effectiveness of these strategies. The percentages represent the proportion of respondents who either strongly agreed (SA) or agreed (A) that each strategy is effective in reducing the risks associated with flooding.

Community Outreach and Engagement Efforts

The strategy of community outreach and engagement is widely recognized in the literature as a crucial component of effective flood resilience efforts. In this study, 89% of respondents agreed on its effectiveness, highlighting the significance of involving local communities in disaster preparedness and mitigation. Several Ghanaian studies support this finding. For instance, Osei and Ampomah (2020) emphasize that community-driven flood awareness programs in Accra have led to improved preparedness and reduced vulnerability among residents. Similarly, Asante et al. (2018) found that in flood-prone areas of northern Ghana, community participation in early warning systems and flood management initiatives significantly enhanced resilience and reduced losses. Additionally, Mensah and Adjei (2019) highlight that participatory flood risk communication strategies in Kumasi have strengthened collective action and encouraged proactive responses to flood threats. The strong preference for this approach in the present study aligns with these findings, reaffirming the role of communication, collaboration, and local participation in strengthening resilience against flooding in Ghana.

Community Investment in Flood Insurance and Financial Assistance

The unanimous support for community investment in flood insurance and financial assistance, with 100% of respondents in agreement, highlights the critical role of financial security in post-disaster recovery. Flood insurance and financial assistance programs provide residents with the necessary resources to rebuild and recover after a flooding event. This finding reflects a widespread recognition that economic resilience is integral to overall flood resilience (Olanrewaju et al., 2017). It also indicates that respondents perceive financial mechanisms as vital tools for mitigating the long-term impacts of flooding.

Investment in Improved Drainage Systems

The investment in improved drainage systems is another highly favored strategy, with 94.3% of respondents agreeing on its effectiveness. Effective drainage systems are crucial in managing floodwaters and preventing inundation, particularly in urban areas (Mavhura et al., 2017). The high level of support for this strategy indicates that respondents prioritize infrastructural solutions that directly address the physical causes of flooding. This preference suggests that people see tangible improvements in infrastructure as a key component of flood risk reduction.

Education on Flood Risks and Adaptation Measures

Education on flood risks and adaptation measures, with 78.5% of respondents in agreement, highlights the importance of knowledge dissemination in flood risk management. While this strategy received slightly lower support compared to others, it still reflects a significant majority who believe in the power of education to reduce flood vulnerabilities. Education initiatives help communities understand the risks they face and the actions they can take to protect themselves. The moderate preference for this strategy indicates that while education is recognized as important, it may not be viewed as a standalone solution but rather as a supportive measure alongside other more immediate strategies.

Zoning Regulation and Land-Use Planning

Zoning regulation and land-use planning received 83.8% agreement from respondents, indicating strong support for regulatory approaches to flood risk management. Zoning regulations and land-use planning are essential for preventing construction in flood-prone areas and ensuring that development is sustainable and resilient. The substantial preference for this strategy reflects a recognition of the importance of long-term planning in mitigating flood risks. Respondents likely appreciate that such regulations can reduce the likelihood of flooding by controlling how land is used and developed.

Early Warning Systems and Flood Forecasting

Early warning systems and flood forecasting, with 89.3% of respondents in agreement, are highly valued for their ability to provide timely information and alerts about impending flood events. This strategy allows communities to prepare and respond more effectively, potentially saving lives and reducing damage. The high level of support indicates that respondents place great importance on having reliable systems in place to anticipate and react to flood risks. It also suggests that early warning systems are seen as a critical component of a comprehensive flood risk management strategy.

Construction of Flood Barriers and Levees

Finally, the construction of flood barriers and levees received the lowest level of agreement at 74.5%. While still a majority, this strategy appears to be less favored compared to others. Flood barriers and levees are physical structures designed to prevent floodwaters from reaching vulnerable areas. The relatively lower preference for this strategy could be due to concerns about the cost, maintenance, or potential environmental impact of such structures. It may also reflect a belief that while barriers and levees are important, they should be part of a broader, integrated approach to flood risk management rather than standalone solutions (Kiedrzyńska et al., 2015)

Table 4.9B: Preferred Adaptation Strategies

Types of Adaptation Strategy	Total SA + A	Percentage of SA + A (%)
Community outreach and engagement efforts	356	89.0
Community investment in flood insurance and financial assistance	400	100.0
Investment in improved drainage system	377	94.3
Education on flood risks and adaptation measures	314	78.5
Zoning regulation and land-use planning	335	83.8
Early warning systems and flood forecasting	357	89.3
Construction of flood barriers and levees	298	74.5

Source: Field Data (2023)

4.5 Flood Vulnerability Index (FVI) for Tamale Metropolis

This section presents the computation of the Flood Vulnerability Index (FVI) for Tamale Metropolis, incorporating a structured analytical approach. The process began with Weight Assignment using the Analytical Hierarchy Process (AHP), which allowed for the systematic comparison of various flood vulnerability factors. AHP facilitated objective weight allocation, ensuring a data-driven assessment of flood susceptibility. Using the assigned weights, Flood Vulnerability Mapping was conducted by integrating spatial data and key vulnerability indicators. The process involved overlaying thematic layers to visualize flood-prone areas within the metropolis. This resulted in the development of a Flood Vulnerability Map, which categorized different regions based on their susceptibility levels, providing a clear representation of flood risk distribution. To ensure the accuracy and reliability of the vulnerability map, a Validation of the Flood Vulnerability Map was carried out by comparing the mapped vulnerability zones with historical flood occurrence data and ground truth observations. Finally, a Validation Map for the Tamale Metropolis was generated to illustrate the correlation between predicted flood-prone areas and actual flood events, enhancing the credibility of the model and supporting effective flood risk management strategies.

4.5.1 Weight Assignment using AHP

The AHP method was used to assign weight to all nine flood vulnerability factors. The weights were created from a pairwise comparison using Saaty's scale. The scale was selected based on a literature review of expert opinions (Castillo et al., 2020; Zghibi et al., 2020) on the relative importance of the pair comparison in vulnerability studies. A matrix was then created from the comparison (Table 4.10), which was then normalized in Table 4.11 to create a new matrix.

The pairwise matrix analysis revealed that land use and land cover (LULC) and topographic wetness index (TWI) were identified as highly important, contributing 30.46% and 25.65% to flood risk, respectively. Additionally, drainage density, elevation, and distance to the stream were found to have considerable importance in influencing flood dynamics. The normalized principal eigenvector values further emphasized the significant impact of LULC, and TWI on flood susceptibility, with LULC emerging as the most influential factor.

Table 4.10: Pairwise matrix of flood factors

Matrix	Rainfall	TWI	Slope	Drainage Density	LULC	Distance to Stream	Soil	Elevation	Flow Accumulation	**Normalized principal Eigenvector**
ainfall	1	1/5	2	4	1/6	3	3	4	2	**12.28%**
TWI	5	1	7	3	1	4	4	5	7	**25.65%**
Slope	1/2	1/7	1	1/6	1/9	1/3	1	½	½	**2.67%**
rainage Density	1/4	1/3	6	1	1/3	3	4	5	2	**10.72%**
LULC	6	1	9	3	1	5	7	8	8	**30.46%**
stance to Stream	1/3	¼	3	1/3	1/5	1	3	2	4	**6.94%**
Soil	1/3	¼	1	¼	1/7	1/3	1	1/3	¼	**2.74%**
evation	1/4	1/5	2	1/5	1/8	½	3	1	½	**3.69%**
Flow umulation	1/2	1/7	2	½	1/8	¼	4	2	1	**4.87%**
ol. Sum	**14.17**	**3.52**	**33**	**12.45**	**3.204**	**17.42**	**30**	**27.83**	**25.25**	

Source: (Based on Experts' and residents interview, 2023 and literature review, 2023)

Table 4.11: Normalized matrix of Flood Factors

Matrix	Rainfall	TWI	Slope	Drainage Density	LULC	Distance to Stream	Soil	Elevation	Flow Accumulation	**Normalization Eigenvector**
Rainfall	0.07	0.06	0.06	0.32	0.05	0.17	0.10	0.14	0.08	**0.1154**
TWI	0.35	0.28	0.21	0.24	0.31	0.23	0.13	0.18	0.28	**0.2204**
Slope	0.04	0.04	0.03	0.01	0.03	0.02	0.03	0.02	0.02	**0.0253**
Drainage density	0.02	0.09	0.18	0.08	0.10	0.17	0.13	0.18	0.08	**0.1306**
LULC	0.42	0.28	0.27	0.24	0.31	0.29	0.23	0.29	0.32	**0.2860**
Distance to stream	0.02	0.07	0.09	0.03	0.06	0.06	0.10	0.07	0.16	**0.0841**
Soil	0.02	0.07	0.03	0.02	0.04	0.02	0.03	0.01	0.01	**0.0232**
Elevation	0.02	0.06	0.06	0.02	0.04	0.03	0.10	0.04	0.02	**0.0463**
Flow Accumulation	0.04	0.04	0.06	0.04	0.04	0.01	0.13	0.07	0.04	**0.0627**
Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Source: (Based on Experts' and residents interview, 2023 and literature review, 2023)

Table 4.12 presents the estimation of the principal eigenvalue and consistency ratio (CR) for assessing flood vulnerability. The ranking of factors shows the sum values derived from the pairwise comparison matrix (Table 4.10) and the corresponding eigenvectors (Table 4.11), which were multiplied to obtain weighted contributions. The calculated principal eigenvalue (λmax) was 10.81, and the consistency index (CI) was 0.12. The consistency ratio (CR) was estimated at 0.08, which is below the acceptable threshold of 0.1. This indicates that the pairwise comparisons were consistent, validating the expert judgments used in weighting the flood vulnerability factors.

Table 4.12: Estimating the principal Eigenvalue and consistency ratio (CR)

Ranking of factors	Sum values from Table 4.10 (1)	Eigen vector from Table 4.11 (2)	(1) x (2)
Rainfall	14.17	0.115	1.63
TWI	3.52	0.220	0.77
Slope	33	0.025	0.83
Drainage Density	12.45	0.131	1.63
LULC	3.204	0.286	0.92
Distance to Stream	17.45	0.084	1.47
Soil	30	0.023	0.69
Elevation	27.83	0.046	1.28
Flow Accumulation	25.25	0.063	1.59
Principal Eigenvalue (λ_{max})			**10.81**
Consistency Index (CI)			**0.12**
Consistency Ratio (CR)			**0.08**

Source: (Based on Experts' and residents interview, 2023 and literature review, 2023)

4.5.2 Flood vulnerability mapping

Flood vulnerability mapping under the GIS environment meant that all the nine flood vulnerability layer maps must be of the same scale and unit and aggregated into a single map in ArcGIS. Hence the need to reclassify the individual maps into a defined range of scale, thus, 1 (very low), 2 (low), 3 (medium), 4 (high) and 5 (very high). Table 4.13 details the relative weights of the map layers in addition to their reclassification scale as well the area occupied in the study area in kilometer square. Land use/land cover was assigned the highest weight (30.46%), followed by Topographic Wetness Index (25.65), Rainfall (12.28) and drainage density (10.72).

Elevation, Geology and Slope were assigned the lowest weight (soil) of 3.69%, 2.74% and 2.67% respectively (Table 4.13).

Table 4.13: AHP ranking of the flood factors with corresponding reclassification scale

Map layer	Classification	Area (km^2)	AHP Weights (%)	Scale (1 – 5)
Soil	Ferric Luvisols	162.65	2.74	1
	Plinthic Luvisols	406		2
Slope (%)	0-2	163.48	2.67	1
	2-3	206.80		2
	3-4	158.8		3
	4-5	75.7		4
	>5	17.2		5
Topographic Wetness index	Very Low	203.75	25.65	5
	Low	254.68		4
	Medium	127.15		3
	High	32.8		2
	Very High	5.05		1
Drainage Density (km/km^2)	Very High	125.398	10.72	4
	High	126.544		3
	Medium	92.300		3
	Low	204.92		2
	Very Low	227.36		1
Elevation	Very Low	130.17	3.69	1
	Low	184.45		2
	Medium	160.03		3
	High	103.29		4
	Very High	42.94		5
LULC	Water Bodies	29.98	30.46	5
	Developed/Urban	136.45		1
	Bare land	251.07		3
	Vegetation	135.88	***Unclassified areas**	5
	Agric/Cultivated	52.89	**(15.73)**	4
Flow Accumulation	Land	611.73	4.87	3
	Stream	10.228		1
Rainfall	Very High	*	12.28	1
	High	*		2
	Medium	*		3
	Low	*		4
	Very low	*		5
Distance to Stream	Very Low	*	6.9	1
	Low	*		2
	Medium	*		3
	High	*		4
	Very High	*		5

**** (1) = highest, (2) =High, (3) =moderate, (4) =low, (5) =lowest likelihood of vulnerability***

Source: (Based on Experts' and residents interview, 2023 and literature review, 2023)

4.4.2.3 Flood Vulnerability Map

The final vulnerability map for the Tamale Metropolis categorizes different areas based on their vulnerability to flooding, providing a spatial representation of flood vulnerability levels across the study area.

Figure 4.12 shows four areas of flood vulnerability classes ranging from High Flood Vulnerability, Low Flood Vulnerability, Medium Flood Vulnerability and No/Very low Flood Vulnerability. The high flood vulnerability class in the Tamale Metropolis, covering 14.413 km^2, is characterized by urban built-up and bare soil land use, high population, and very poor road network systems. Specific areas such as Gumani, Gumbihini, Kanvili Tuunaayili, Wurishe, Koblimahigu, and Fuo have been identified as having high flood vulnerability. On the other hand, the medium flood vulnerability class, spanning 227.56 km^2, exhibits an intermediate range of susceptibility and is spatially distributed across Sogunayili, Gbalo, and Jisonayili. The causes of flooding in the metropolis are attributed to both natural and human factors, such as the dumping of refuse into drains and water bodies, construction in environmentally sensitive areas, and the opening of dams upstream. The widespread and complex nature of flooding in urban areas has led to significant challenges, including the lack of a systematic forecasting system to warn residents of impending floods and the absence of well-organized evacuation and psychological support for potential victims.

In addition, the areas with low and no/very low flood vulnerability classes cover 64.019 km^2 and 309.58 km^2 of the study area respectively. This implies that these areas are relatively safe from significant flooding events, due to favorable geographical and environmental conditions in the Tamale Metropolis. This finding alien with Kasei et al. (2019), on the reduction of flooding in the Tamale Metropolis such as construction drains and water bodies, and construction in environmentally sensitive areas.

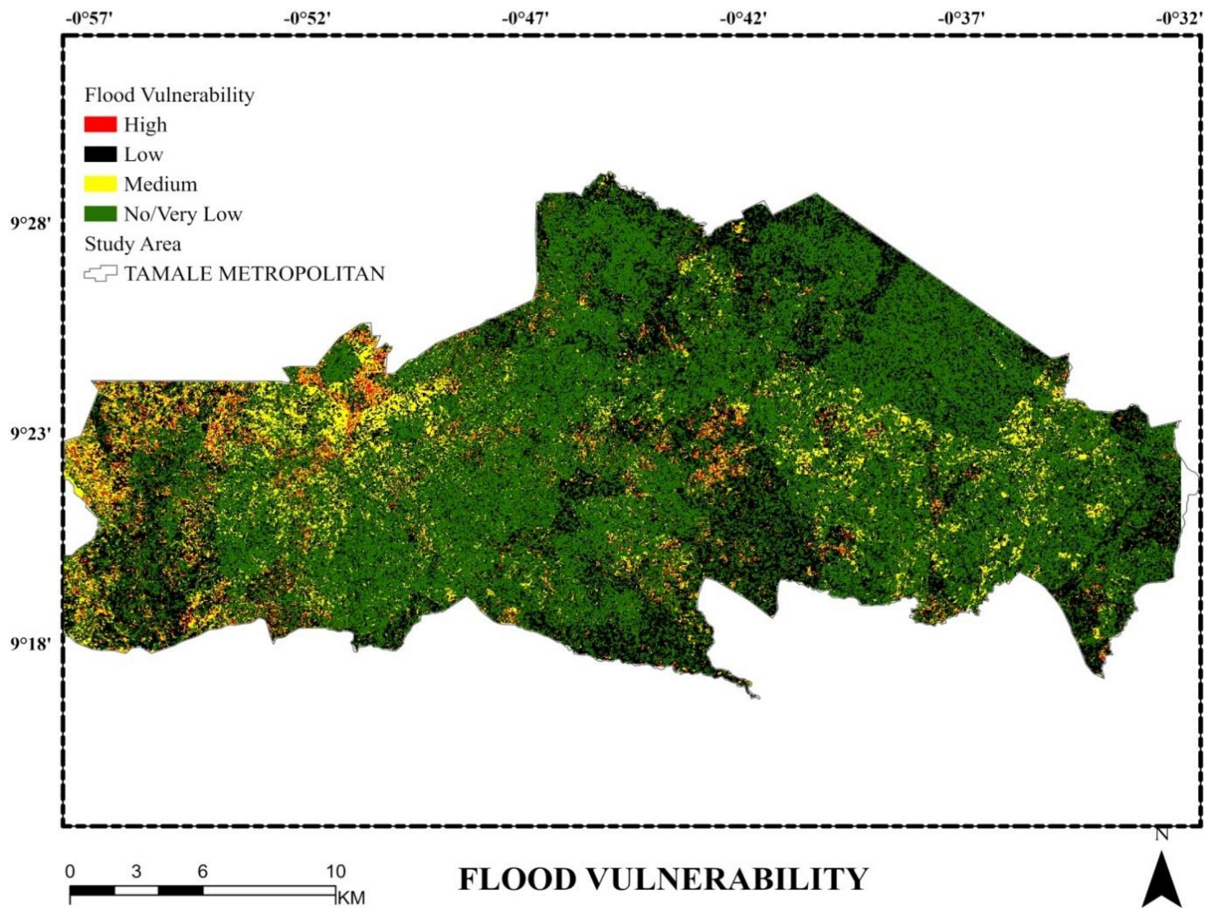

Figure 4.12: Final vulnerability map for the Tamale Metropolis

4.5.3 Validation of flood vulnerability map

The flood vulnerability map of the Tamale Metropolis is presented in Figure 4.13. The result of the verification revealed a perfect agreement between flood maps and historical and expert flood records. This implied that this model is appropriate and can be used for similar studies on flood vulnerability studies as it is flexible and easy to use with a high accuracy level.

The results from the map indicate that areas with high and very high flood incidence are concentrated in specific parts of the metropolis with a history of flooding. These areas include Tamale Central, Gumbihini, Kakpayili, Vittin, and Lamashegu, while, areas with moderate, low and very low flood incidence are located within the Tamale central. An example is the flood event which July 25, 2017, where two were confirmed dead following floods that affected some communities in the Tamale Metropolis and also led to some thatch houses in the affected communities being submerged while containers, livestock and other valuables were carried away (Myjoyonline, 2023).

However, from the map, it is evident that areas with moderate flood incidence recorded about six (6) historical flood incidence. Whereas, areas with low flood incidence recorded only one historical flood incidence. This disparity in historical flood occurrences aligns with the varying flood vulnerability levels observed in different parts of the country such as Accra, Kumasi and Sekondi-Takoradi (Mensah et al., 2018). Hence, this shows that the adopted methodology is the best fit to predict areas that are likely to experience flooding in the future.

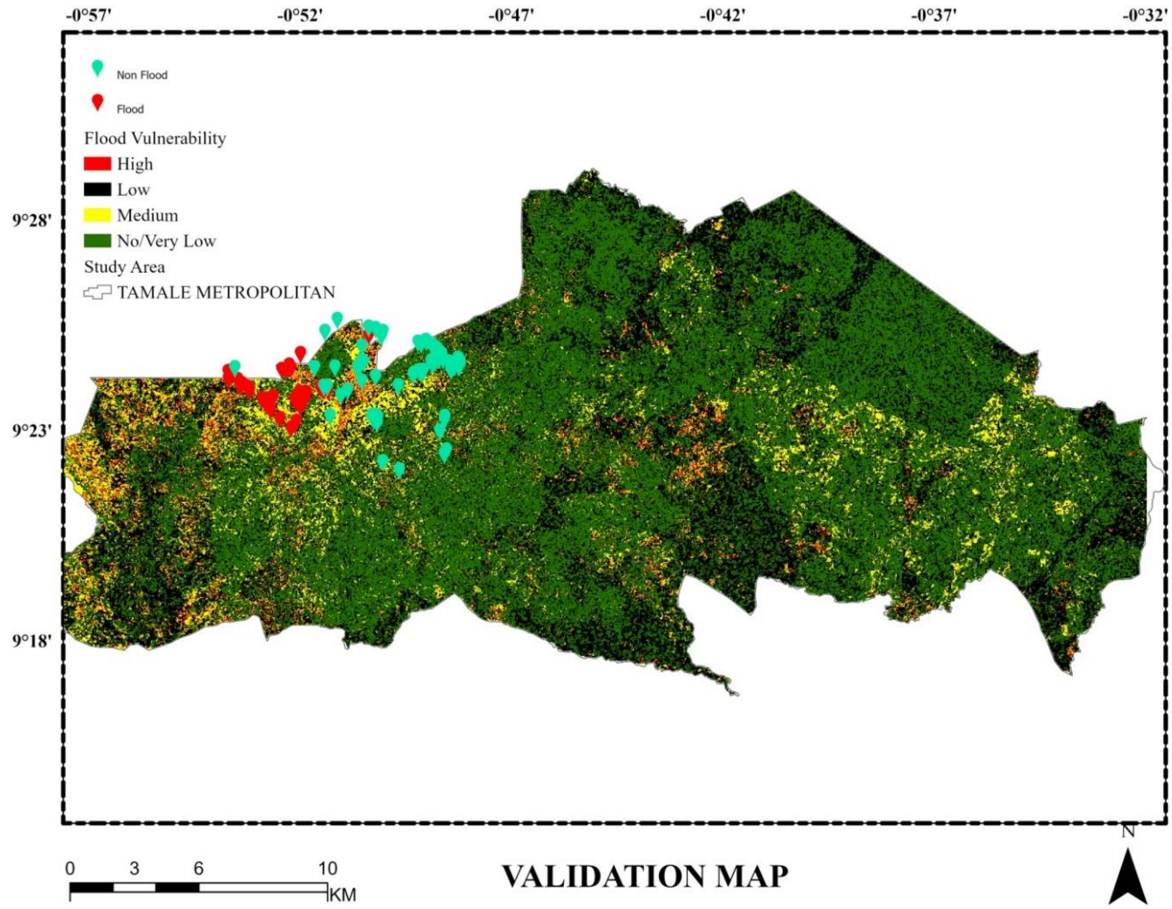

Figure 4.13: Validation Map for the Tamale Metropolis

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter presents the summary of the findings of the study, conclusions and recommendations which when implemented could reduce flooding in the Tamale Metropolis.

5.2 Summary of findings

The study was undertaken to assess the susceptibility of communities to flooding and the adaptation strategies employed in the Tamale Metropolis. Specifically, it

1. To identify the communities within the Tamale Metropolis that are most vulnerable to flooding.
2. To examine the primary factors contributing to flood occurrences in the Tamale Metropolis.
3. To assess the effects of flooding on the environment, social structures, and economic dynamics within the Tamale Metropolis.
4. Examine the flood mitigation strategies utilized by residents in the Tamale Metropolis.
5. To identify and analyze the key factors that should be considered in developing a Flood Vulnerability Index (FVI) for the Tamale Metropolis.

The study used a descriptive study design with a mixed research approach. Furthermore, 400 respondents were interviewed using questionnaire on the study concepts. Also, expert opinion on flood-related issues was assessed using an interview guide and semi-structured questionnaire. Both primary and secondary data were used. The data were processed using both SPSS Version 22.0 and ArcGIS. The results were analysed in frequency, percentage, time-series analysis, ordinary least squares (OLS) regression, Chi-Square, flood vulnerability index and Kendall's Coefficient of Concordance and presented in the form of chart, tables and maps.

5.2.1 Socio-demographic characteristics of respondents

In the flood-prone areas of the Tamale Metropolis, the majority of respondents were male (73.0%), with females constituting 27.0%. Most respondents (48.0%) were between 29 and 38 years old, while a smaller proportion (15.0%) fell within the 18 to 28 age group. Marital status data indicated that over two-thirds (67.8%) were married, with lower proportions being single (17.8%), divorced/separated (6.8%), or widowed (7.8%). Educational attainment varied, with a significant portion (55.0%) having completed Senior High School, while 20.0% held university degrees and 12.8% had teacher or nursing training. A minority had Junior High School (2.8%), primary (3.5%), or non-formal education (6.0%). Residency patterns showed that more than half (57.8%) had lived in flood-prone areas for 6 to 10 years, while only 6.5% had resided there for over 20 years.

5.2.2 Identification of flood-vulnerable communities and the factors contributing to flooding occurrences within the Tamale Metropolis

The Tamale Metropolis in northern Ghana is experiencing rapid urbanization and recurring flood issues, significantly impacting social services, infrastructure, and the local population. However, based on satellite data, it was evident that the areas that are highly prone to flooding are Sakasaka, Taha, Kanvilla, Norrip village, Chogu, Nyohni, Kunyilla, Zujung, Kaakpayili, Shishegu, Jekeriyili, Lamashegu, and Kalpohin estate. These are being vulnerable to flood due to their low-lying nature and heavy downpours. The study indicated that the hydrological factors influencing flooding are annual rainfall fluctuations, soil types, drainage density, flow accumulation, water bodies, land cover, and distance to streams all contributed to flooding. From the study, it was observed that annual rainfall fluctuates, with 2018 recording the highest and 2013 the lowest. Soil types in the study area are Ferric Luvisols and Plinthic Luvisols, and the area exhibits diverse land cover, with water bodies and vegetation.

5.2.3 Effects of flooding on the environment, social, and economic dynamics within the Tamale Metropolis

In this study, socio-economic flood vulnerabilities aspect, it was observed that the Tamale Metropolis exhibits a moderate level of awareness and preparedness for flood risks, with a Social Sub-Index score of 1.6. The Economic Sub-Index, scoring 1.95, indicates a moderate level of economic development and accessibility, but insufficient resources and opportunities, exposing residents to vulnerability during flooding. The Environmental Sub-Index, with a score of 1.5, reveals a moderate physical vulnerability to flooding, contributing 45% to the overall vulnerability index of 4.02. While not highly vulnerable, the Tamale Metropolis still faces significant risks associated with flooding events, influenced by hydrological factors.

5.2.4 Effective flood mitigation strategies used by residents in the Tamale Metropolis

Kendall's coefficients of concordance demonstrated a highly significant agreement among respondents on adaptation strategies for mitigating flooding in the Tamale metropolis. The Chi-Square test further confirmed significant agreement, with a p-value of 0.000. The Kendall's coefficient (W) of 0.795 indicated 79.5% agreement in ranked scores. Flood barriers and sandbags were identified as the top adaptation strategies, crucial for addressing annual flooding in flood-prone zones. Other strategies include early warning systems, community evacuation plans, building elevated structures, flood insurance coverage, sustainable landscaping, and support for local flood control measures. Emergency supplies, while ranked least, remain a crucial aspect of flood preparedness in the area.

Community investment in flood insurance and financial assistance programs, improvement of drainage systems, education on flood risks and adaptation measures, zoning regulations, and land-use planning are among the adaptation strategies that residents of the Tamale Metropolis believe to be effective in reducing flood-related vulnerabilities.

5.2.5 Flood Vulnerability Index (FVI) for Tamale Metropolis

Based on the study results, it further observed that Land use/land cover (LULC) and topographic wetness index (TWI) emerged as highly important factors, contributing 30.46% and 25.65% to flood risk, respectively. However, the flood vulnerability map revealed that high vulnerability areas, covering 14.413 km^2, include urban built-up areas with poor road networks. Medium vulnerability spans 227.56 km^2, while low and no/very low vulnerability areas cover 64.019 km^2 and 309.58 km^2, respectively.

5.3 Conclusions for the Study

Based on study findings, the following conclusions were made:

- Areas prone to flood in the Tamale Metropolis included Sakasaka, Taha, Kanvilla, Norrip village, Chogu, Nyohni, Kunyilla, Zujung, Kaakpayili, Shishegu, Jekeriyili, Lamashegu, and Kalpohin which are low lying areas.
- The Tamale Metropolis exhibits a moderate level of awareness and preparedness for flood risks, along with moderate economic development and accessibility; however, limited resources and opportunities heighten residents' vulnerability during flooding, resulting in an overall moderate level of flood vulnerability across the study area.
- Sandbags and flood barriers were the most effective flood mitigation measures. Other strategies included flood insurance, raised structures, community evacuation plans, early warning systems, and sustainable landscaping. Although emergency supplies were the least utilized, they remain crucial for flood preparedness.
- Investments in improved drainage systems, community engagement initiatives, and financial support programs were seen as effective in reducing vulnerability. While zoning laws, land-use planning, and flood risk education were considered beneficial, their effectiveness faced some skepticism. Levees and flood barriers also played a key role in flood risk reduction.

- Respondents preferred a combination of financial, infrastructural, and community-based strategies. Flood insurance and financial assistance were the most widely supported, emphasizing economic resilience. Infrastructure improvements, such as drainage systems and early warning systems, were highly valued. A comprehensive approach integrating immediate interventions with long-term planning and education was favored for enhancing community resilience.
- Flood risk in the Tamale Metropolis is influenced by factors such as annual rainfall fluctuations, soil types, drainage density, flow accumulation, water bodies, land cover, distance to streams, land use/land cover (LULC), and the topographic wetness index (TWI), with findings indicating that urban built-up areas and inadequate road networks contribute significantly to vulnerability, resulting in 14.413 sq km being classified as high-vulnerability zones.

5.4 Study Contribution

The study puts theoretical, practical and policy implications to contribute to literature on flood vulnerability.

5.4.1 Theoretical Contribution

The theoretical contribution of the study on flood-prone areas in the Tamale Metropolis lies in its comprehensive understanding of the hydrological and socio-economic factors influencing flooding. The study's theoretical contribution places significant emphasis on the complex relationship between socio-economic and hydrological factors. It emphasises the significance of socioeconomic status, infrastructure, land use, annual precipitation fluctuations, soil varieties, and drainage density. Based on the study variables, the researcher derives a ***theory of integrated flood risk management*** and recognise the significance of incorporating geophysical and socio-economic factors when evaluating and mitigating flood vulnerability from this. The study findings indicate that flood vulnerability is determined by a confluence of socio-economic and hydrological determinants. The importance of ***integrated flood risk management***, community engagement, and targeted interventions in mitigating vulnerabilities and bolstering resilience is emphasised. This implies a theoretical framework for understanding flood vulnerability that takes into account the interaction between socio-economic and geophysical elements, emphasising the significance of implementing comprehensive and integrated strategies for managing flood risks.

5.4.2 Practical/Policy Implication

The study practically contributes to the prospective advantages or ramifications of the study findings in the real world. The study demonstrates a practical implementation of the results or the ways in which they will benefit particular groups or society as a whole. The practical implications of the study on flood vulnerability in the Tamale Metropolis include the implementation of efficient adaptation measures, including flood barriers, early warning systems, and evacuation plans for the community. The implications guide policy, practice, and future research by highlighting the criticality of infrastructure investments, community engagement, and targeted interventions in mitigating flood-related vulnerabilities and boosting resilience in light of the findings.

5.5 Recommendation

Based on the study findings, the following recommendations are made for research and policy consideration.

1. The study recommends that the Tamale Metropolitan Assembly should invest in infrastructure projects that reduce flood vulnerability, such as the construction of bridges, roads, and other transportation networks that can withstand flooding during the raining season. Also, the assembly should implement socio-economic interventions to reduce the vulnerability of low-income communities to flooding. This may involve providing financial assistance to help residents rebuild after floods, offering training programs to help residents develop flood-resistant livelihoods, and promoting the use of flood-resistant building materials.

2. Furthermore, the government of Ghana through town and country planning department should develop and implement land use and zoning regulations that take into account the identified hydrological and socio-economic factors to reduce the risk of flooding in the Tamale Metropolis. Also, the Tamale Metropolitan Assembly should include measures to control unplanned development, illegal settlements on flood prone areas, improve drainage systems, and preserve natural water bodies within the metropolis.The study recommends that the Tamale Metropolitan Assembly should implement public awareness and education programmes to increase awareness of flood risks and the importance of preparedness. This may involve training on evacuation

procedures, flood-resistant building techniques, and the importance of maintaining clean drainage systems.

3. According to the report, the Ghana Metrological Service should enhance its early warning systems to notify communities of approaching floods. This will enable the populace to make the appropriate preparations and move to safer areas during the rainy season. In addition, the Tamale Metropolitan Assembly ought to put into effect a thorough policy for managing flood risks, giving special attention to the usage of sandbags and flood barriers as the main methods of adaptation in flood-prone areas in Tamale. The adoption of such a strategy would have a major positive influence on the resilience of the community and lessen the detrimental effects of flooding in the affected areas during flooding disasters.

4. The study further recommends that the government in collaboration with civic education services should embark on community outreach and engagement in flood preparedness. These community outreach and engagement should be tailored to the specific needs of the residents in flood areas within the Tamale Metropolis. Finally, the study recommends that Tamale Metropolitan Assembly should improve infrastructure, such as drainage systems, water supply systems, and transportation networks particularly in areas most affected by flooding during heavy downpours.

5. The identified high vulnerability zones in urban built-up areas with inadequate road networks in the Tamale Metropolis call for comprehensive

urban planning strategies by the Metropolitan Assembly. This should involve the integration of resilient infrastructure development, such as improved drainage systems and road networks, along with sustainable land use management practices. Also, central government commitment to addressing drainage challenges and flood risk management further emphasizes the importance of prioritizing resilient infrastructure and urban planning strategies in the face of increasing flood vulnerability.

5.6 Direction for Future Research

Future research should be conducted on the socio-economic and financial impact of flooding in the Tamale Metropolis.

Given the unanimous support for community investment in flood insurance and financial assistance, further research should focus on the economic impact of these programs on households and communities. Investigating the long-term benefits and potential challenges of flood insurance, including affordability, accessibility, and the adequacy of coverage, would provide policymakers with critical information to design more effective and equitable insurance schemes.

5.7 Limitation of the Study

To accurately interpret findings and make informed decisions, it is important to understand the limitations of the Tamale Metropolis flood vulnerability and adaptation strategy study. The study's scope is limited to the Tamale Metropolis, which means that its findings may not be applicable to other regions or cities with different characteristics. This should be taken into consideration when extrapolating the results beyond the study area. Data constraints also affect the accuracy and reliability of the FVI and flood vulnerability mapping. Incomplete or outdated data may invalidate the study's conclusions. Furthermore, the use of Kendall's coefficients of concordance and the Chi-Square test as validation techniques may have limitations. Considering other statistical methods or validation techniques could provide additional insights. The study's temporal constraints may overlook long-term trends and flood risk projections, reducing the analysis's predictive power. Resource constraints, such as time, budget, and manpower, may have limited the study's scope and overlooked socio-economic analysis and community engagement. Assumptions about the uniform implementation and effectiveness of adaptation strategies across communities and socioeconomic groups should be considered, as resource availability and community resilience may affect their implementation and effectiveness. Lastly, subjectivity in perceptions and interpretations may bias the analysis, distorting flood risk and adaptation needs.

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APPENDIX

APPENDIX A: QUESTIONNAIRE FOR HOUSEHOLDS

ASSESSMENT OF FLOOD VULNERABILITY AND ADAPTATION STRATEGIES IN THE TAMALE METROPOLIS

This study is purely for academic purposes toward the award of a ***Doctor of Philosophy degree in Environmental Management and Sustainability***. You will be contributing to success if you answer the items as frankly and honestly as possible. You are assured of confidentiality and anonymity.

Name of Enumerator ……………………………

Community…………………………

Please Tick [√] or Answer where Applicable

Section A: Demographic characteristics of respondent

1. Sex: Male [ ] Female [ ]
2. Age: 18 – 28 [ ] 29 – 38 [ ] 39 – 48 [ ] 49 and above [ ]
3. Marital Status: Married [ ] Single [ ] Divorced/separated [ ] Widowed [ ]
4. Level of Education: Primary [ ] Secondary [ ] Teacher/Nursing Training College [ ] University [ ] Others specify…………………………………
5. Occupation: Farmer [ ] Trader [ ] Student [ ] Civil/Public Servant [ ] Artisan [ ] Others specify……………………………………
6. For how long have you stayed in this area? 0 – 5 years [ ] 6 – 10 years [ ]

11 – 15 years [ ] 16 – 20 years [ ] Above 20 years [ ]

7. What is your annual household income? (In GH₵…………………………..)
8. Are there noticeable income disparities within your neighborhood, where some households have significantly higher incomes than others? 1= Yes [ ] 2= No [ ]

Section B: Determine the factors contributing to flooding in the Tamale Metropolis

9. Have you experienced any water-related issues, such as flooding or drainage problems, in your area during past rainfall events? 1= Yes [ ] 2= No [ ]
10. If yes, what how would you describe the typical severity of floods in Tamale over the past years? 1= Mild [ ] 2= Moderate [ ] 3= Severe [ ] 4= Extremely Severe [ ]
11. In your opinion, what are the most common impacts of floods in Tamale? (Select all that apply)
    a. Damage to infrastructure [ ]
    b. Displacement of communities [ ]
    c. Loss of life [ ]
    d. Economic losses [ ]
    e. Environmental damage [ ]
12. Do you think urbanization and increased impervious surfaces contribute to flooding? 1= Yes [ ] 2= No [ ]

13. Do you think climate change influences the frequency and severity of flooding? 1= Yes [ ] 2= No [ ]
14. Is inadequate drainage infrastructure a key factor in causing flooding? 1= Yes [ ] 2= No [ ]
15. Do you think deforestation and land use changes play a role in increased flood risk? 1= Yes [ ] 2= No [ ]
16. Are river and drains overflows a major cause of flooding in your area? 1= Yes [ ] 2= No [ ]
17. Do you think poor land management practices such as overdevelopment in flood prone areas are causes of flooding? 1= Yes [ ] 2= No [ ]
18. Are improper waste disposal and clogged stormwater drains a factor of flooding in your area? 1= Yes [ ] 2= No [ ]

Section C: Assess the environmental and socio-economic vulnerabilities associated with flooding in the Tamale Metropolis

19. Have there been any recent flood-related awareness campaigns or educational programs conducted in your community? 1= Yes [ ] 2= No [ ]
20. How would you rate the level of awareness within your community regarding flood risks and preparedness? 1= Very High Awareness [ ] 2= High Awareness [ ] 3= Moderate Awareness [ ] 4= Low Awareness [ ] 5= Very Low Awareness [ ]
21. Are there community-led initiatives or organizations dedicated to flood risk awareness and preparedness in your area? 1= Yes [ ] 2= No [ ]

22. Are there sufficient employment opportunities available within your neighborhood or community? 1= Yes [ ] 2= No [ ]
23. Are there educational institutions, such as schools and training centers, easily accessible within your neighborhood? 1= Yes [ ] 2= No [ ]
24. Are there any specific economic development initiatives or businesses that have contributed to economic growth in your neighborhood? 1= Yes [ ] 2= No [ ]
25. Are there community resources or organizations in your neighborhood that provide support or assistance related to income, employment, or education? 1= Yes [ ] 2= No [ ]
26. Do you have access to a reliable and safe water supply system? 1= Yes [ ] 2= No [ ]
27. How would you rate the quality of the water supply in terms of safety and cleanliness? 1= Excellent [ ] 2= Good [ ] 3= Fair [ ] 4= Poor [ ] 5= Not sure [ ]
28. Are there proper sanitation facilities available to residents in the area, such as toilets and waste disposal systems? 1= Yes [ ] 2= No [ ]
29. How would you rate the overall sanitation conditions in the area? 1= Excellent [ ] 2= Good [ ] 3= Fair [ ] 4= Poor [ ] 5= Not sure [ ]
30. Are healthcare facilities, such as clinics or hospitals, accessible to residents in the area? 1= Yes [ ] 2= No [ ]

31. How would you rate the availability and quality of healthcare services in the area? 1= Excellent [ ] 2= Good [ ] 3= Fair [ ] 4= Poor [ ] 5= Not sure [ ]
32. Is there a reliable transportation network, including roads and public transportation, in the area? 1= Yes [ ] 2= No [ ]
33. How would you rate the accessibility and reliability of transportation services in the area? 1= Excellent [ ] 2= Good [ ] 3= Fair [ ] 4= Poor [ ] 5= Not sure [ ]
34. Are you located in a low-lying area or valley where water tends to accumulate during heavy rains or floods? 1= Yes [ ] 2= No [ ]
35. How close is your location to the nearest major water body? 1= Less than 100 meters [ ] 2= 100 - 500 meters [ ] 3= 500 meters - 1 kilometer [ ] 4= 1 - 5 kilometers [ ] 5= More than 5 kilometers [ ]
36. Is your location within the proximity of any drainage systems or streams that could affect water flow during heavy rains or floods? 1= Yes [ ] 2= No [ ]
37. How would you describe the predominant land use pattern in your neighborhood?1= Residential [ ] 2= Commercial [ ] 3= Mixed-use (combination of residential and commercial) [ ]
38. Are there zoning regulations or land-use planning policies in place in your area? 1= Yes [ ] 2=
39. Are there any planned or ongoing development projects in your area that could impact land use, housing availability, or zoning regulations? 1= Yes [ ] 2= No [ ]

40. Are there existing policies or regulations in your community related to flood risk management? 1= Yes [ ] 2= No [ ]

41. If yes, please specify the main policies or regulations related to flood risk management in your community. (Please list or describe them)

    A: ……………………………………………..

    B: . ……………………………………………

    C: ……………………………………………..

42. Are there specific government agencies or departments responsible for implementing and overseeing flood risk management policies in your area? 1= Yes [ ] 2= No [ ]

43. If yes, please provide the names of these agencies or departments.

    A: ……………………………………………..

    B: . ……………………………………………

    C: ……………………………………………..

44. How would you rate the effectiveness of existing policies in reducing flood risk and protecting the community? 1= Very Effective [ ] 2= Somewhat Effective [ ] 3= Ineffective [ ] 4= I'm not sure [ ]

45. Please describe the main challenges or obstacles faced in implementing these policies.

A: ……………………………………………..

B: . ……………………………………………

C: ……………………………………………..

Section D: Established the adaptation strategies employed by residents of the Tamale Metropolis to mitigate the effects of flooding

46. Kindly rank the various coping strategies you used in managing flood in this area?

Coping Strategies	**Rank (1 = Most Preferred, 10 = Least Preferred)**
Building elevated structures	
Using flood barriers and sandbags	
Utilizing early warning systems	
Developing community evacuation plans	

Obtaining flood insurance coverage	
Implementing sustainable landscaping	
Managing stormwater effectively	
Stocking emergency supplies	
Participating in community flood preparedness programs	
Supporting local flood control measures	

Section E: Evaluate the effectiveness of existing adaptation strategies used by residents of the Tamale Metropolis in reducing flood-related vulnerabilities

47. How frequently does your community receive information or warnings about potential flood events? 1= Frequently (Multiple times a year) [ ] 2= Occasionally (Once a year or less) [ ] 3= Rarely (Very infrequently) [ ] 4= Never [ ]
48. What are the primary sources of flood-related information in your community? (Select all that apply)
    a. District assembles [ ]
    b. Ghana meteorological agencies [ ]
    c. Non-governmental organizations (NGOs) [ ]

d. Community leaders or elders [ ]

e. Local media (TV, radio, newspapers) [ ]

f. Social media and online sources [ ]

49. In your opinion, how effective are the current awareness efforts in preparing the community for flood events? 1= Very Effective [ ] 2= Effective [ ] 3= Neutral [ ] 4= Ineffective [ ] 5= Very Ineffective [ ]

50. Community outreach and engagement efforts improved community flooding resilience? 1= Strongly Agree [ ] 2= Agree [ ] 3= Not Sure [ ] 4= Disagree [ ] 5= Strongly Disagree [ ]

51. Community investment in flood insurance and financial assistance programme helped residents recover from flooding event? 1= Strongly Agree [ ] 2= Agree [ ] 3= Not Sure [ ] 4= Disagree [ ] 5= Strongly Disagree [ ]

52. Investment in improved drainage system has effectively reduced the risk of flooding occurrence? 1= Strongly Agree [ ] 2= Agree [ ] 3= Not Sure [ ] 4= Disagree [ ] 5= Strongly Disagree [ ]

53. Education on flood risks and adaptation measures has effectively reduced the risk of flooding occurrence? 1= Strongly Agree [ ] 2= Agree [ ] 3= Not Sure [ ] 4= Disagree [ ] 5= Strongly Disagree [ ]

54. Zoning regulation and land-use planning has effectively reduced the risk of flooding occurrence? 1= Strongly Agree [ ] 2= Agree [ ] 3= Not Sure [ ] 4= Disagree [ ] 5= Strongly Disagree [ ]

55. Early warning systems and flood forecasting has effectively reduced the risk of flooding occurrence? 1= Strongly Agree [ ] 2= Agree [ ] 3= Not Sure [ ] 4= Disagree [ ] 5= Strongly Disagree [ ]
56. Construction of flood barriers and levees has effectively reduced the risk of flooding occurrence? 1= Strongly Agree [ ] 2= Agree [ ] 3= Not Sure [ ] 4= Disagree [ ] 5= Strongly Disagree [ ]
57. How confident are you that the adaptation strategies in place are sustainable in the long term for reducing flood vulnerability? 1= Strongly Agree [ ] 2= Agree [ ] 3= Not Sure [ ] 4= Disagree [ ] 5= Strongly Disagree [ ]
58. The adaptation strategies have significantly reduced flood damage? 1= Strongly Agree [ ] 2= Agree [ ] 3= Not Sure [ ] 4= Disagree [ ] 5= Strongly Disagree [ ]
59. Adaptation strategies have improved community preparedness for flooding? 1= Strongly Agree [ ] 2= Agree [ ] 3= Not Sure [ ] 4= Disagree [ ] 5= Strongly Disagree [ ]

Thank you

APPENDIX B: INTERVIEW GUIDE FOR INSTITUTIONS

ASSESSMENT OF FLOOD VULNERABILITY AND ADAPTATION STRATEGIES IN THE TAMALE METROPOLIS

Informed Consent:

Hello, ***JUSTICE AGYEI AMPOFO*** is my name. I am a Ph.D. candidate at UDS and am researching "*Flood Vulnerability Situation and Adaptation Strategies in Tamale's Prone Areas in The Northern Region of Ghana"*. I am conducting an interview and would be grateful for your participation. The questionnaire generally takes 20 minutes to complete. Your answers to the questions will be kept confidential and will solely be used for the intended purpose. Please note that participation and withdrawal along the process are without a cost.

1. Name of Institutions: ………………………………………………………………
2. What methods or data sources have organization used over the years in identifying floods in Tamale?
3. Can you describe the criteria or indicators used to classify an area as flood-prone?
4. Can you describe any recent flooding event in the Tamale Metropolis?
5. In your opinion, what are the main natural factors contributing to flooding vulnerability in the Tamale Metropolis?
6. What role does human activity and urbanization play in increasing the vulnerability to flooding

7. Are there on going initiatives or adaptation strategies in place to address flooding vulnerability in the Tamale Metropolis?
8. What policies or regulations exist in Tamale that either encourage or discourage settlement in flood-prone areas, and how effective are they (**probe**)?
9. Can you describe the demographic characteristics of the population living in flood-prone areas in Tamale?
10. What are the key social and economic vulnerabilities faced by residents in during flooding in the Tamale Metropolis?
11. Have you identified any specific groups or communities within these areas that are particularly vulnerable to the impacts of flooding?
12. How do residents in flood-prone areas access essential services, and what challenges do they face in doing so?
13. What adaptation strategies have residents in flood-prone areas developed to mitigate the impacts of flooding?
14. How effective have these adaptation strategies been in reducing the vulnerability of the community during flood events?
15. Are there any community-based initiatives or interventions aimed at enhancing resilience to flooding in the Tamale Metropolis?
16. How can external support, such as government agencies or NGOs, assist residents in improving their coping strategies and resilience to flooding.

Thank you