

**ASSESSING SEASONAL FLOOD HAZARDS AND ITS MITIGATION
STRATEGIES: THE CASE OF ADAMA CITY**



Ayinaddis Alemu Bekele

**A thesis proposal submitted to the department of Architecture
School of Civil Engineering and Architecture**

**Office of Graduate Studies
Adama Science and Technology University**

November, 2024

Adama, Ethiopia

**ASSESSING SEASONAL FLOOD HAZARDS AND ITS MITIGATION
STRATEGIES: THE CASE OF ADAMA CITY**

Ayinaddis Alemu Bekele

Advisor: Sileshi Azagew (PHD)

**A thesis proposal submitted to the department of Architecture
School of Civil Engineering and Architecture**

**Office of Graduate Studies
Adama Science and Technology University**

November, 2024

Adama, Ethiopia

Declaration

I declare that this “Assessing Seasonal Flood Hazards and Its Mitigation Strategies: The Case of Adama City is my work and has not been submitted to any university for a similar purpose. The references used in this Thesis are duly recognized by proper citations.

Ayinaddis Alemu Bekele

Name of student

Signature

Date

Recommendation of Advisors/ Supervisors

I, the major advisor of this research Thesis, hereby certify that I have closely advised the student while developing this Thesis and read the draft thesis entitled "Assessing Seasonal Flood Hazards and Its Mitigation Strategies: The Case of Adama City" prepared under my guidance by Ayinaddis Alemu. Therefore, I recommend the submission of the Thesis to the department for further review and evaluation.

DR SILESHI AZAGEW

Major Advisor/Supervisor

Signature

Date

Approval Page Thesis

I hereby certify that the recommendations and suggestions given by the Thesis review the committees are appropriately incorporated into the final thesis entitled "Assessing Seasonal Flood Hazards and Its Mitigation Strategies: The Case of Adama City “prepared under my guidance by Ayinaddis Alemu. Therefore, I recommend the submission of the thesis to the department for further review and evaluation.

DR SILESHI AZAGEW

Major Advisor/Supervisor

Signature

Date

Co-advisor/ Co-supervisor

Signature

Date

Approval Board of Reviewers

We, the undersigned, members of the Board of Reviewers of the Thesis open defense **Ayinaddis Alemu Bekele** have read and evaluated the thesis "Assessing Seasonal Flood Hazards and Its Mitigation Strategies: The Case of Adama City" and assessed the understanding of the candidate about the Thesis research. This is, therefore, to certify that the thesis is accepted and we recommend the implementation of the Thesis. -----
-----.

_____	_____	_____
Chairperson	Signature	Date

_____	_____	_____
Reviewer 1	Signature	Date

_____	_____	_____
Reviewer 2	Signature	Date

Finally, approval and acceptance of the thesis/dissertation proposal is contingent upon Submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

_____	_____	_____
Department Head	Signature	Date

_____	_____	_____
School Dean	Signature	Date

_____	_____	_____
Office of Postgraduate Studies,	Dean Signature	Date

ACKNOWLEDGMENT

First and foremost, I would like to thank my adviser, Dr. Sileshi Azagew, from the Department of Architecture at Adama Science and Technology University's School of Civil Engineering and Architecture. His advice, intelligent feedback, and constant support have been critical to the successful completion of this thesis.

I would also like to express my heartfelt gratitude to Adama Science and Technology University's Department of Architecture faculty and staff, whose knowledge, encouragement, and intellectual contributions have significantly increased my academic experience.

I am grateful like to thank the local community members of Irrcha or 09 kebele for their assistance and insights during the data collection procedure, as their firsthand knowledge and viewpoints have been critical in determining the impact of seasonal floods on the community.

Finally, I want to convey my heartfelt gratitude to my family and friends for their constant support, understanding, and encouragement during the duration of this research project.

TABLE OF CONTENTS

ACKNOWLEDGMENT.....	iv
LIST OF TABLES.....	viii
LIST OF FIGURES	x
LIST OF ABBREVIATIONS AND ACRONYMS.....	xi
ABSTRACT.....	xii
CHAPTER ONE	1
INTRODUCTION	1
1.1. Background of the study	1
1.2. Statement of the Problem.....	2
1.3. Objective of the Research	3
1.3.1. General Objective:	3
1.3.2. Specific objective.....	4
1.4 Research Questions.....	4
1.5 Significance of the study.....	4
1.6. Scope of the study.....	5
1.7. Limitations and Challenges of the Research.....	5
1.8. Operational Definitions of key terms and concepts	6
1.9. Organization of the Research.....	7
CHAPTER TWO	9
LITERATURE REVIEW	9
2.1. Theoretical literature.....	9
2.1.1 Introduction.....	9
2.1.2 Flooding.....	10
2.1.3 Historical background.....	10
2.1.4 Factors can influence flood risk.....	11
2.1.4 Type of Flood Impacts.....	14
2.1.5 Measuring the Impact of Flood.....	16
2.1.6 Challenges in Measuring and Mitigating Flood Threats.....	17
2.2. Empirical Literature Review	19
2.2.1. Urbanization and Flood Risk	19
2.2.2. Flood Mitigation Approaches	19
2.3 International, legal, and institutional Frameworks.....	26
2.4. Theoretical and empirical gaps of different literature.....	27

CHAPTER THREE	31
MATERIALS AND METHODS.....	31
3.1. Introduction.....	31
3.2. Description of the study area	31
3.3. Research Design.....	33
3.4. Study approaches	34
3.5. Data Type and Sources	35
3.6 Research population.....	36
3.7. Sampling Techniquep	37
3.7.1. Sample size	37
3.8 Data Analysis Techniques.....	39
3.9. Study instruments (Data collection tools)	42
3.9.1 Software's and Tools	43
3.10 Methods of data analysis.....	44
3.11. Ethical Consideration.....	45
3.12. Validity and Reliability of the Data	45
CHAPTER FOUR.....	46
RESULTS AND DISCUSSIONS.....	46
4.1 Description of Flood Conditioning Factors	46
4.2 Flood susceptibility mapping through the GIS-AHP technique	56
4.2.1 Flood Susceptibility Criteria and Sub-criteria and their weight based on GIS-AHP technique	57
4.2.2 Topographic Wetness Index (TWI)	60
4.2.3 Slope	61
4.2.4 Elevation	62
4.2.5 Rainfall.....	63
4.2.6 Distance to River.....	64
4.2.7 Distance to Road.....	65
4.2.8 Land Use/Land Cover	66
4.2.9 Drainage Density	67
4.2.10 NDVI (Normalized difference vegetation index)	68
4.3. Inundation modeling areas thematic area.....	74
4.3.1 Flood plain level analysis (Impact level assessment around residence)	75
4.3.2 Impact level analysis.....	76

4.4. Background of the Respondents	79
4.4.1. Gender Composition	79
4.4.2 Age of the household	79
4.4.3. Educational Background	80
4.4.4 Family Size of the Respondent	80
4.4.5. Duration of Residency	81
4.4.6. Employment situation	81
4.4.7. Source of Income	82
4.4.8. Monthly Household Income	82
4.5. Filed Observation	83
4.6 Discussions	87
4.6.1 Interpretation of Findings	87
4.6.2 Comparison with Existing Literature	88
4.6.3 Implications for Flood Management	89
4.6.4 Community Perspectives	89
4.6.5 Recommendations for Future Research	90
CHAPTER FIVE	91
CONCLUSION AND RECOMMENDATION	91
5.1 Conclusion	91
5.2 General Recommendations:	92
5.2.1 Site-specific Recommendations and Designs	93
5.2.2 Limitations of the Study	103
Reference	104
Annex-1 House-to-house visits	111
Annex-2 Key Informant Interview	118
Annex-3 Expert respondents on the AHP Analytical Hierarchy Process	120

LIST OF TABLES

Table 1 Hydrologic groups of soils and their properties.....	12
Table 2 Factor infiltration of soil Percent on a slope (USDA Natural Resources Conservation Service (NRCS)	13
Table 3 Different journal's theoretical and empirical gaps source (revised by the author)	28
Table 4 Method of the study	34
Table 5 Study Approach of the study	35
Table 6 Data Type and Sources (by author)	36
Table 7 The purposive sample size of expert respondents.....	38
Table 8 Sample size of from the thematic area respondents.....	38
Table 9 Software and tools and data use.....	43
Table 10 Specifications of Satellite Imagery	43
Table 19 Lulc 1991 class coverage.....	49
Table 20 Lulc 2007 class coverage.....	50
Table 21 Lulc 2024 class coverage.....	51
Table 22 Thematic area irrcha (09) kebel.....	54
Table 23 Flood Susceptibility Criteria and Sub-criteria for Adama City	58
Table 24 Topographic Witness Index	60
Table 25 Slope of Adama City.....	61
Table 26 Elevation data	62
Table 27 Rainfall data.....	63
Table 28. Distance to River	64
Table 29 Distance to Road.....	65
Table 30 Land Use/Land Cover.....	66
Table 31 Drainage Density data.....	67
Table 32 Normalized difference vegetation index	68
Table 33 Soil type and characteristics	69
Table 34 Flood Risk coverage area in Adama City	72
Table 35 The data The statistics revealed that the flood level in the sub-city of Adama City.....	73
Table 36 Thematic area risk.....	73

Table 37 Flood Inundation Level.....	74
Table 38 Flood impact on land use level of the thematic area.....	76
Table 11 Gender distribution	79
Table 12 Age Distribution	79
Table 13 Educational Qualifications.....	80
Table 14 Number of Family Members.....	80
Table 15 Duration of Living in the Study Area.....	81
Table 16 Socio-Economic Data Analysis	81
Table 17 Source of Income	82
Table 18 Monthly Household Income	82
Table 39 Before and after the design of solid wastes and other filtering fences.....	96
Table 40 Before and after runoff reduction measures for sample 01.....	99
Table 41 Before and after runoff reduction measures for sample 02.....	101

LIST OF FIGURES

Figure 1 uses a low embankment as a buffer zone along rivers (Source: Study team.).....	20
Figure 2. Damage assessment of residences a without the mitigation structure and b after its construction with a 200-year return time. The color legend is the same for both panels.	21
Figure 3 Location Map of the Study Area: Adama City (Source: Author).....	32
Figure 4 Research Design (Source: Author).....	33
Figure 5 Watershed analysis of the study area (Source: Author).....	47
Figure 6 Lulc 1991 of Adama city (Source: Author).....	49
Figure 7 Lulc 2007 of Adama city (Source: Author).....	50
Figure 8 Lulc 2024 of Adama city (Source: Author).....	51
Figure 9 Lulc coverage of thematic area (Source: Author).....	54
Figure 10 Result from the analysis matrix weight based on GIS-AHP technique (Source: Author)	57
Figure 11 Topographic witness index map (TWI) (Source: Author).....	60
Figure 12 Slope map of Adama (Source: Author)	61
Figure 13 Elevation map (Source: Author).....	62
Figure 14 Annual rainfall map (Source: Author).....	63
Figure 15 Distance to the river map of Adama (Source: Author).....	64
Figure 16 Distance to the road map (Source: Author)	65
Figure 17 Land use the land cover of Adama city map (Source: Author)	66
Figure 18 Drainage Density map (Source: Author)	67
Figure 19 NDVI (Normalized difference vegetation index) (Source: Author).....	68
Figure 20 Soil type and characteristics (Source: Author)	69
Figure 21 Flood risk map Adama City (Source: Author)	71
Figure 22 Thematic area risk Map (Source: Author).....	73
Figure 23 Flood inundation map (Source: Author).....	74
Figure 24 Flood plain level analysis (Impact level assessment around residence) using Google Earth (Source: Author).....	75
Figure 25 Impact level analysis auto cad (Source: Author).....	76
Figure 26 Interview hot spot using GPS (Source: Author)	77
Figure 27 Natural drainage of the thematic area (Source: Author).....	83
Figure 28 Impact on structure and residences 01 (Source: Author).....	84
Figure 29 Impact on structure and residences 02 (Source: Author).....	85
Figure 30 Proposed drainage line	95
Figure 31 Before and after the drainage layout.....	95
Figure 32 Before-after design drainage	95
Figure 33 Before and after the design of solid wastes and other filtering fences	96
Figure 34 Proposed design of the Drainage components.....	97
Figure 35 Land use land cover proposal in the sample on a residential area.....	98
Figure 36 Land use land cover proposal in the sample on factory (store area).....	100

LIST OF ABBREVIATIONS AND ACRONYMS

AHP: Analytic Hierarchy Process

CAD: Computer-Aided Design

ESRI: Environmental Systems Research Institute

FEMA: Federal Emergency Management Agency

GIS: Geographic Information System

IPCC: Intergovernmental Panel on Climate Change

LULC: Land Use Land Cover

NDVI: Normalized Difference Vegetation Index

SWMM: Storm Water Management Model

TWI: Topographic Wetness Index

UNEP: United Nations Environment Program

WSE: Water Surface Elevation

SETS: Social-Ecological-Technological Systems

MCDM: Multi-Criteria Decision-Making

ABSTRACT

Understanding the repercussions of floods is critical for effective disaster risk management, particularly in urban settings where they pose significant threats to public health and safety. This study investigates flood hazards in Adama City, Ethiopia, employing a mixed-methods approach that integrates primary data from field surveys, interviews, and focus group discussions with secondary data from historical records, climate data, and Geographic Information System (GIS) analyses. Key findings reveal that 41% of the studied area is classified as having very high or high flood risk, underscoring the urgent need for targeted mitigation efforts. Notably, 94% of respondents expressed concerns about drainage, yet few had received flood preparedness training, indicating a significant gap in community awareness. Residents in flood-prone areas face severe consequences, including home destruction and disruptions to education and local businesses, with observations showing that the natural drainage system in densely populated areas exacerbates soil erosion and flooding. To address these challenges, the study recommends improving drainage infrastructure, implementing sustainable urban design practices, creating a comprehensive flood emergency plan, enhancing community engagement, and improving data management. While Adama City has taken steps to tackle flooding—such as constructing new drainage systems and conducting community workshops—there are limitations, including inadequate long-term strategies, insufficient outreach and education on flood preparedness, project delays, and a lack of ongoing maintenance for drainage systems. By addressing these limitations, Adama City can strengthen its flood management strategies, ultimately fostering a safer and more resilient urban environment.

Keywords: Flood hazards, mitigation strategies, Adama city

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Although flood investigations and flood protection policy have been dominated by a technical worldview since their inception, the social and socio-economic aspects have grown in importance in recent decades as a result of expanded and intensified land use, rising damage potentials in floodplain areas, and thus increasing disputes between socio-economic land use and flood protection policy (Schwerdtle et al. 2018). Floods are a significant natural hazard in Africa and have resulted in more than 27,000 fatalities between 1950 and 2019. Despite their importance, our understanding of changes in flood hazard across the continent is limited. This is primarily due to the lack of long-term, high-quality stream flow records necessary for comprehensive analysis (Tramblay et al., 2020).

Understanding the changing hazards to human health caused by seasonal variations in environmental circumstances is critical, especially in light of climate change and its impact on low-income nations. (Few, R., et al. 2009) underline the importance of a multidisciplinary approach to improve knowledge, particularly when data resources are low but the environmental health implications of seasonal hazards are important. Seasonal ecological dangers such as floods, droughts, and landslides pose major issues in many African towns IPCC (Intergovernmental Panel on Climate Change). (2014) Climate change, deforestation, inappropriate land use practices, and insufficient water management infrastructure impact these hazards (Kempen et al., 2021)) the city's vulnerability to such risks is exacerbated by erratic rainfall patterns and intense weather events.

Flooding has grown to be one of the most prevalent, frequent, and severe natural disasters in nations such as Ethiopia in recent years. According to (Jalayer et al., 2014),

floods hit Pakistan in August 2022, killing over 1,700 people and displacing nearly 8 million.

(Wodnimu, M. A., et al. 2022) Given the increasing frequency and severity of such catastrophes, a full analysis of flood hazards in Adama City, particularly in the region of 09 (Irrecha) Kebele, is required.

Various techniques and methodologies, such as GIS modeling, meteorological data, and primary and secondary data sources, will be used in the proposed analysis. The study intends to examine and comprehend the specific flood hazard threats faced by Adama City, notably in the vicinity of 09 (Irrecha) Kebele, by combining various resources. According to Wodnimu et al., (2022), the area of Irrecha (09) Kebele in Adama City is identified as one of the 14 locations with high flood vulnerability. This designation is based on their flood vulnerability assessment. Additionally, the Kebele is intersected by the main natural drainage line, which serves as a key criterion for determining flood-prone areas in the city. The analysis will provide useful insights into flood hazard patterns and risk effects on residents, allowing policymakers, urban planners, and stakeholders to build effective disaster risk management and sustainable development strategies.

However, there is limited research on this specific problem, emphasizing the importance of this study. This research intends to address a knowledge gap and contribute to a better understanding of the impact of seasonal flood risks in Adama City by undertaking a complete analysis. The findings will be used to help the development of targeted interventions and policies to alleviate the negative effects of flood risks and increase the well-being of the local people.

1.2. Statement of the Problem

The regular flood hazard endangers the health and safety of Adama City people, particularly those living near 09 (Irrecha) Kebele. Flooding in residential areas occurs due to of inadequate management of the natural drainage system during the winter months, causing property damage and jeopardizing public safety. These concerns

underscore the city's larger challenges in safeguarding its natural resources while maintaining a sustainable and habitable environment. (Portney et al., 2013).

Ethiopia's institutional frameworks do not fully integrate urban planning and design techniques to address flood risks, leaving a significant gap in efficiently mitigating flood hazards and improving long-term resilience in urban areas. This gap is particularly obvious in highly populated areas, where increased construction, poor infrastructure, and unsustainable land use practices make it difficult to assess flood risks and impacts.

The poorly managed natural drainage system in 09 (Irrecha) Kebele exacerbates problems during the winter season, failing to handle extra water and causing flooding. This inefficiency is caused by poor drainage management and insufficient infrastructure. Furthermore, existing institutional frameworks do not completely embrace urban planning strategies that address flood hazards, leaving a gap in effective flood risk reduction.

Addressing the identified flood risk is essential for the health and safety of the Kebele community. This study aims to contribute to establishing a sustainable and habitable environment in Adama City by examining the specific effects of flood hazards and proposing appropriate mitigation strategies. By investigating flood management strategies, this study seeks to bridge the gap between theoretical understanding and empirical data, providing valuable insights into the efficacy of proposed mitigation measures and aiding in the development of evidence-based plans for long-term flood management in the region.

1.3. Objective of the Research

1.3.1. General Objective:

The general objective of this study is to examine the flood risks facing Adama City to inform effective mitigation and adaptation strategies.

1.3.2. Specific objective

1. Identify key factors contributing to flood impacts in Adama City
2. Create a detailed flood hazard map for Adama City using the Analytical Hierarchy Process (AHP) to visualize and prioritize flood risk areas.
3. To assess the socio-economic and environmental impact of flood risks.
4. Develop comprehensive strategies to mitigate flood risks in Adama City.

1.4 Research Questions

1. What are the key factors contributing to the impacts of flooding in Adama City?
2. How can the Analytical Hierarchy Process (AHP) be utilized to create a detailed flood hazard map that visualizes and prioritizes flood risk areas in Adama City?
3. What are the socio-economic and environmental impacts of flood risks in Adama City?
4. What comprehensive strategies can be developed to mitigate flood risks in Adama City?

1.5 Significance of the study

The study's value stems from its ability to refine, update, or extend existing knowledge on the subject of seasonal environmental dangers and their impact on residents, specifically in Adama City's 09 (Irrecha) Kebele. The work has substantive, theoretical, methodological, and practical value because it conducted a complete investigation and provided useful insights into the impact of natural drainage on houses. Substantively, it expands our awareness of the specific impacts of seasonal environmental dangers on Adama City residents, contributing to the area's unique issues. Theoretically, it contributes to our understanding of the interactions between natural drainage systems, residential areas, and flood threats by refining and expanding on current theories. Methodologically, it gives a foundation for future research in similar circumstances, expanding researchers' methodological toolkit. In practice, the study's recommendations

and mitigation measures feed evidence-based decision-making, allowing stakeholders to build focused actions and strategies to improve Adama City's resilience and serve as a valuable resource for practitioners.

1.6. Scope of the study

Thematic Scope

The study's thematic scope focuses on seasonal environmental risks, specifically the impact of flood threats on Adama City's 09 (Irrecha) Kebele residents. It contains an examination of the reasons and elements that contribute to the impact of flooding living side of the natural drainage line, as well as recommendations and mitigation techniques to address these concerns. The study's goal is to improve our understanding of the unique effects of flood threats on residences and to contribute to the body of knowledge on urban flood management, resilience, and sustainable development.

Spatial Scope

The study's spatial scope is Adama City, with a specific focus on the city's 09 (Irrecha) Kebele. The geographical area of interest for the examination is Adama City, and the precise neighborhood or administrative division within the city where the research will be conducted is the 09 (Irrecha) Kebele.

1.7. Limitations and Challenges of the Research

The study has various limitations that hampered its completion. Due to a scarcity of historical flood data, primary data through surveys and interviews were used. Engaging the community proved difficult owing to various degrees of awareness, however focus group talks increased involvement. Due to resource constraints, the study's scope was limited, forcing a mixed-methods approach to optimize findings. Institutional constraints hampered coordination with local officials; however, collaboration with non-governmental organizations (NGOs) increased support. Flood evaluations were problematic due to the unique topography, which was handled utilizing Geographic Information System (GIS) methodologies. Time restrictions caused by yearly flooding needed speedy assessments, while a lack of information about mitigating methods was

addressed through educational outreach. These adaptive tactics sought to greatly improve Adama City's understanding of flood hazards and proposed viable mitigation techniques.

1.8. Operational Definitions of key terms and concepts

Flood Resilience: Flood resilience is the ability of metropolitan areas to withstand and recover from the effects of flooding. This includes managing physical damage and socioeconomic disturbances to avoid casualties and protect the community's social, economic, and environmental fabric. It includes numerous components of urban morphology, such as roadway networks, building configurations, and drainage systems, which together improve a city's ability to reduce flood damage (Folke, 2006).

Urban Flood Vulnerability: Urban flood susceptibility is defined as the degree to which urban regions are prone to flooding due to factors such as population density, infrastructural quality, and land use. It is evaluated using three primary criteria: exposure (the extent to which a region is at risk), sensitivity (the extent to which a community is impacted by flooding), and adaptive capability (the ability to respond and adapt to flood threats) (IPCC, 2014).

Social-Ecological-Technological Systems (SETS) Framework: The SETS framework is a comprehensive approach to assessing urban flood vulnerability that incorporates social, ecological, and technological components. It uses a variety of indicators, including population demographics, land use, and infrastructure quality, to assess how these elements interact and contribute to flood risk (Klein et al., 2003).

Geographic Information Systems (GIS): GIS is a technology tool for mapping and analyzing spatial data about flood threats. It allows researchers to view flood-prone locations, measure vulnerability, and create flood susceptibility maps, which are critical for successful flood management and planning (Goodchild, 2007).

Multi-Criteria Decision-Making (MCDM): MCDM is a systematic approach for evaluating and prioritizing many elements that influence flood susceptibility. It entails

evaluating several variables to make informed decisions about flood risk management and mitigation techniques (Triantaphyllou, 2000).

Inundation Modeling: Inundation modeling is the simulation of flood occurrences to determine the extent and depth of flooding in specified areas. This modeling aids in understanding flood dynamics and developing appropriate response methods (Bates et al., 2008).

Flood Susceptibility Mapping: Flood susceptibility mapping is the process of detecting flood-prone locations using a variety of environmental and socioeconomic criteria. This mapping is critical for urban planning and disaster preparedness, as it allows for targeted interventions in vulnerable areas (Van Der Meulen et al., 2016).

Socio-Economic Impacts of Flooding: Flooding has a variety of socioeconomic effects, including displacement and housing loss, economic disruption, health concerns, educational interruption, and social injustice. Flooding can cause house loss, damage to local businesses, higher health risks from watery infections, disruptions in education, and exacerbate existing social inequities, particularly among disadvantaged groups (Aldrich & Meyer, 2015; Kousky, 2012).

Environmental Impacts of Flooding: Flooding has a variety of environmental consequences, including ecosystem destruction, soil erosion, worsening of water quality, altered hydrological patterns, and feedback on climate change. Floods can harm habitats, degrade soil and agricultural land, taint water supplies, disturb natural water flows, and contribute to overall climate change dynamics (Zhang et al., 2018; IPCC, 2014)

1.9. Organization of the Research

This research is organized to comprehensively explore flood hazards in Adama City, Ethiopia. Each chapter systematically addresses different aspects of the study, from foundational concepts to methodologies and findings, ensuring clarity in research objectives and implications. Below is an outline highlighting the key sections within each chapter:

Chapter One introduces the study, outlining the background, statement of the problem, research objectives, questions, significance, scope, limitations, expected outcomes, and organization.

Chapter Two presents the Literature Review, covering theoretical aspects of flooding, its historical context, influencing factors, impacts, and challenges, as well as empirical literature on urbanization, flood risk, and mitigation approaches.

Chapter Three details the Materials and Methods, including the study area, research design, data sources, population, sampling techniques, analysis methods, ethical considerations, and data validity.

In Chapter Four, the Results and Discussions section presents findings on flood conditioning factors, susceptibility mapping using GIS-AHP techniques, and inundation modeling, along with interpretations, comparisons to existing literature, implications for management, community perspectives, limitations, and future research recommendations. Finally,

Chapter Five synthesizes the findings and provides general and site-specific recommendations. The research is further supported by a References section and three annexes detailing house-to-house visits, key informant interviews, and expert respondents on the AHP process.

CHAPTER TWO

LITERATURE REVIEW

2.1. Theoretical literature

2.1.1 Introduction

Floods are the product of complex interactions among processes including precipitation, soil moisture, and watershed morphology. Conventional flood frequency analysis (FFA) methods such as design storms and discharge-based statistical methods offer few insights into these process interactions and how they “shape” the probability distributions of floods. Understanding and projecting flood frequency in conditions of no stationary hydro climate and land use requires a deeper understanding of these processes, some or all of which may be changing in ways that will be under-sampled in observational records Yu, G. et al., 2019. Seasonal ecological hazards are natural occurrences or events that occur regularly during specific seasons and endanger the environment, infrastructure, and human populations. Seasonal changes in weather patterns and climatic conditions influence these threats. According to Bolan, S., et al. 2023 Floods, droughts, hurricanes tropical storms, wildfires, and landslides are all common instances. Floods are caused by excessive rain or quick snowmelt, and they cause damage to houses, infrastructure, and agricultural grounds. Droughts occur when there is a lengthy period of low rainfall or lack of water, affecting agriculture, water supply, and ecosystems. Strong winds, torrential rainfall, storm surges, and coastal flooding are all characteristics of hurricanes and tropical storms. Dry and hot weather increases the risk of wildfires, which destroy forests and endanger human communities. Landslides can be triggered by heavy rainfall or snowmelt, posing threats to human populations, highways, and infrastructure. To decrease risks and minimize their negative consequences on communities and ecosystems, these hazards necessitate thorough monitoring, preparedness, and response methods.

2.1.2 Flooding

Flooding is a seasonal hazard that affects many locations across the world. Flood severity and frequency are impacted by a variety of factors such as precipitation patterns, land use changes, and climatic variability (Kundzewicz et al. 2020) Reviewed changes in flood risk across Europe, highlighting the importance of seasonal fluctuations in flood occurrence and consequences. They discuss the causes and consequences of floods, taking into account both temporal and spatial variability.

(Hirabayashi et al. 2013) Concentrated on global flood risk in the context of climate change scenarios using hydrological models, they investigated prospective changes in flood dangers, including seasonal variations. The findings emphasized the need to take into account future climate projections and their effects on flood patterns.

(Winsemius and colleagues 2016) investigated the global drivers of future river flood risk. Their study underscored the need to understand seasonal changes in flood episodes and the causes that cause them. The authors gave insights into anticipated changes in flood dangers and their consequences for flood risk management by studying large-scale hydrological models.

2.1.3 Historical background

In keeping with historical studies, Natural drainage plays a critical role in minimizing different detrimental effects on dwellings. These studies looked into the effects of natural drainage systems on flooding, landslides, water logging, and health problems in metropolitan settings. (Smith et al., 2022) stated that good drainage systems are critical in decreasing flood hazards, emphasizing the importance of well-designed and maintained natural drainage channels to safeguard residential areas. In parallel, (Johnson et al., 2021) discovered that poor natural drainage might increase slope instability, posing a threat to residences and emphasizing the importance of strong drainage systems in preventing landslides and protecting properties. (Nabi et al. 2018) also examined past occurrences of water logging and its negative effects on residential areas, emphasizing the need for adequate natural drainage systems in reducing water logging and its accompanying concerns. Furthermore, Sridhar et al. (2015) emphasized the historical

importance of proper natural drainage infrastructure in limiting the accumulation of contaminated water and lowering health hazards for residents, notably waterborne infections.

In conclusion, historical studies show that natural drainage systems have long been recognized as critical for limiting the impact of flooding, landslides, water logging, and health problems on residential properties. These studies highlight the importance of good planning, maintenance, and drainage methods in protecting residential areas from adverse effects. These studies' historical context serves as a solid knowledge base for current research and activities targeted at tackling these difficulties and establishing sustainable solutions for effective drainage systems in residential areas.

2.1.4 Factors can influence flood risk

Topography: The slope and elevation of the terrain are important factors in natural drainage. Rapid runoff can be facilitated by steep slopes, increasing the risk of flooding and erosion. Water stagnation and water logging may occur in flat places, on the other hand (Smith et al., 2017).

Soil Composition: according to (USGS, 2023). Natural drainage is influenced by the kind of soil in a given area. Permeable soils, such as sandy soils, allow water to drain more freely. Soils with limited permeability, such as clay soils, on the other hand, can obstruct drainage and contribute to water logging. Soil's ability to transmit water when submitted to a “hydraulic gradient” determines the ability of the soil fluid to flow through the soil under a specified “hydraulic gradient”. Additionally, the soil fluid retention characteristics determine the ability of the soil system to retain the soil fluid under a specified pressure condition (U.S. EPA, 2011). Four hydrologic soil groups contain subgroups of soils that have similar soil properties (FAO, 2008)

Table 1 Hydrologic groups of soils and their properties

Soil Group	Includes	Property
A	sand, loamy sand, sandy loam	has low runoff potential and high infiltration rates even when thoroughly wetted (have a high rate of water transmission)
B	silt loam or loam soil	has a moderate infiltration rate when thoroughly wetted and consists of chiefly or moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures
C	sandy clay loam	Low infiltration rates when thoroughly wetted and consists chiefly of soils with a layer that impedes downward movement of water and soils with a moderately fine to fine structure
D	clay loam, silty clay loam, sandy clay, silty clay, and clay	have the highest runoff potential- have very low infiltration rates when thoroughly wetted and consisting chiefly of clay soils with high swelling potential- soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface

Soil and the runoff varies with this various soil characteristics, particularly permeability and infiltration capacity (see table 1). Infiltration capacity is the maximum rate at which soils and rocks can absorb rainfall. The infiltration capacity tends to decrease as the soil moisture content of the surface layers increases (U.S. EPA, 2011). It also depends upon such factors as slope of the site, grain size, and amount of vegetation cover.

Table 2 Factor infiltration of soil Percent on a slope (USDA Natural Resources Conservation Service (NRCS))

Soil Texture, Type	Percent of slope				
	0-4%	5-8%	8-12%	12-16%	Over 16%
Coarse Sand	31.8	25.4	19.1	12.7	7.9
Medium Sand	26.9	21.6	16.3	10.7	6.9
Fine Sand	23.9	19.1	14.2	9.7	6.1
Loamy Sand	22.4	17.8	13.5	8.9	5.6
Sandy Loam	19.1	15.2	11.4	7.6	4.8
Fine Sandy Loam	16	12.7	9.7	6.4	4.1
V. Fine Sandy Loam	15	11.9	8.9	6.1	3.8
Loam	13.7	10.9	8.4	5.6	3.6
Silt Loam	12.7	10.2	7.6	5.1	3.3
Silt	11.2	8.9	6.6	4.6	2.8
Sandy Clay	7.9	6.4	4.8	3	2
Clay Loam	6.4	5.1	3.8	2.5	1.5
Silty Clay	4.8	3.8	2.8	2	1.3
Clay	3.3	2.5	2	1.3	0.8

A. Vegetation Cover: Natural drainage can be influenced by vegetation, which includes trees, grass, and other plants. Vegetation absorbs and retains water, preventing runoff. Runoff and erosion can be reduced in regions with extensive vegetation (Johnson et al., 2016).

B. Land Use and Urbanization: Human activities and urban expansion can drastically change natural drainage patterns. Paved surfaces, buildings, and infrastructure diminish the quantity of permeable ground, resulting in increased runoff and lower infiltration. Flooding and water logging problems can be exacerbated by poorly designed urbanization (Smith et al., 2020).

C. Climate and Precipitation: The strength and frequency of drainage impacts are influenced by climate patterns and precipitation amounts. Flooding, landslides, and waterlogging are more likely in areas with significant rainfall or seasonal fluctuations in precipitation (Gonzalez et al., 2018).

D. Estimation of peak runoff

Estimation of peak stormwater runoff from a drainage area is often calculated with the rational method equation ($Q=CiA$). The calculations can be done using an Excel spreadsheet. In this method, the parameters in the equations are defined with typical units for both U.S. and S.I. units (Pazwash, 2011).

The Rational Method equation used to calculate the peak stormwater runoff rate is:

$Q = CiA$ (U.S. units), or $Q = 0.0028 CiA$ (S.I. units) where:

A = the area of the watershed (drainage area) that drains to the point for which the peak runoff rate is needed (acres for U.S. units) (ha for S.I. units)

C = runoff coefficient for drainage area A. A physical interpretation is the fraction of rainfall landing on the drainage area that becomes stormwater runoff. (Dimensionless for both U.S. and S.I. units)

i = the intensity of the design storm for peak runoff calculation (in/hr for U.S. units) (mm/hr for S.I. units)

Q = the peak stormwater runoff rate from the drainage area, a, due to the design storm of intensity, i. (cfs for U.S. units) (m³/s for S.I. units). (Source: Pazwash, 2011)

Impervious surfaces (e.g., roofs, pavements): 0.70 to 0.95

Pervious surfaces (e.g., lawns, gardens): 0.10 to 0.30

Gravel or rocky areas: 0.30 to 0.70

E. Drainage Infrastructure: The existence or absence of constructed drainage systems, such as stormwater drains, culverts, and canals, can have an impact on natural drainage. A well-designed and well-maintained drainage system can assist manage excessive runoff and lessen the impacts on residential areas (Brown et al., 2019).

2.1.4 Type of Flood Impacts

When assessing the risks and vulnerabilities associated with seasonal environmental hazards, it is critical to evaluate the influence of natural drainage on houses (Smith et al., 2020). Flooding, landslides, water logging, and health concerns can all be caused by insufficient natural drainage systems in residential areas (Johnson et al., 2018).

Understanding these implications is critical for policymakers, urban planners, and stakeholders involved in establishing disaster risk management and sustainable development initiatives (Brown et al., 2019). Researchers aim to improve drainage infrastructure and decrease hazards faced by populations in susceptible places by investigating the historical context and various types of effects that natural drainage can have on houses (Gonzalez et al., 2016).

A. Flooding Impact: Inadequate natural drainage systems can increase the risk of flooding in residential areas. Flooding can damage property, disrupt infrastructure, and endanger citizens' safety. (Merz et al. 2021) researched the effects of natural drainage on urban floods, emphasizing the importance of effective drainage systems in decreasing flood impacts on dwellings.

B. Landslide Impact: Poor natural drainage can lead to soil erosion and instability, making residential areas more vulnerable to landslides. Landslides can cause property damage and endanger residents' safety. (Dai et al. 2020) investigated the effect of natural drainage on landslide occurrences and underlined the significance of effective drainage methods to reduce landslide hazards for dwellings.

C. Water logging Impact: Water logging caused by insufficient natural drainage can create water collection in residential areas. Water logging can damage property, pose health risks, and disturb occupants' daily lives. (Chatterjee et al. 2021) conducted research on the influence of natural drainage on water logging and emphasized the need for effective drainage systems in reducing water logging consequences on dwellings.

D. Health Impact: Inadequate natural drainage systems can contribute to water stagnation and accumulation, increasing the risk of waterborne infections among people. Poor drainage can cause bacteria to spread and pose health problems in residential settings. Rahman et al. (2021) researched the effect of natural drainage on waterborne infections, emphasizing the need for good drainage infrastructure in decreasing health impacts on residents.

2.1.5 Measuring the Impact of Flood

Measuring the level of natural drainage impact in a residence involves assessing various factors such as water accumulation, flood risk, and potential damage. Here are some methods commonly used to measure the impact of natural drainage in residences, along with suggested citations for further information:

A. Flood Risk Assessment: Conducting a flood risk assessment helps evaluate the potential for flooding in a residence due to inadequate natural drainage. This assessment typically involves analyzing topography, rainfall patterns, and local drainage infrastructure. The United Kingdom's Environment Agency guides flood risk assessment, which can be found in their document "Flood Risk Assessment: A Guide for Developers" (Environment Agency, 2016).

B. Hydrological Modeling: Utilizing hydrological models helps simulate the behavior of water flow and drainage patterns in and around a residence. These models consider factors such as rainfall intensity, infiltration rates, and surface runoff. The EPA's Storm Water Management Model (SWMM) is a widely used hydrological model for assessing drainage impacts. Information on SWMM can be found in the EPA's documentation, "SWMM - Storm Water Management Model" (U.S. Environmental Protection Agency, 2017).

C. Damage Assessment: Measuring the damage caused by natural drainage impacts involves evaluating the extent of property damage, including water intrusion, structural damage, and loss of personal belongings. The Federal Emergency Management Agency (FEMA) damage assessment in their document "Homeowner's Guide to Retrofitting: Six Ways to Protect Your House from Flooding" (Federal Emergency Management Agency, 2014).

D. Surveys and Questionnaires: Conducting surveys and questionnaires among residents can provide insights into the perceived impact of natural drainage on their residences. These surveys can include questions about flooding experiences, property damage, and the effectiveness of existing drainage systems. The World Bank's publication "Community-Based Flood Risk Assessment: A Survey Manual" (World

Bank, 2012) offers guidance on conducting surveys and questionnaires for flood risk assessment.

E. Remote Sensing and GIS Analysis: Using remote sensing data and Geographic Information Systems (GIS) helps assess the spatial distribution of natural drainage impacts. This includes analyzing land cover changes, surface water bodies, and flood-prone areas. The book "Remote Sensing and GIS for Natural Resource Management" by M. Anji Reddy provides insights into the application of remote sensing and GIS in natural resource management (Reddy, 2010).

F. Analytical Hierarchy Process (AHP): The integration of Geographic Information Systems (GIS) and the Analytical Hierarchy Process (AHP) has been proposed as a method for developing Spatial Decision Support Systems (SDSS) that can improve spatial decision-making (Aquero et al 2009). Saaty, T. L. (2008) The GIS-AHP technique integrates GIS spatial analysis capabilities with AHP's structured, multicriteria decision-making frameworks. This integration enables the evaluation of large geographical problems by breaking them down into a hierarchical model and doing pairwise evaluations of options. The integration of GIS and AHP is proposed to promote environmentally sustainable space management and provide timely answers to pressing spatial problems.

$$CI = (\lambda_{\max} - n) / (n - 1)$$

2.1.6 Challenges in Measuring and Mitigating Flood Threats

1. Data availability and quality are fundamental. Access to accurate and reliable data is necessary to gain insights into the challenge at hand. This involves addressing issues such as data gaps, inconsistencies, and biases. By improving data collection processes and ensuring data completeness, the validity of measurements and analysis can be enhanced (Smith, J. (2020).

2. Understanding the complexity and interdependencies of challenges is essential. Many challenges are not isolated, but rather interconnected and influenced by multiple factors. Taking a systems thinking approach helps to unravel the intricacies of these

challenges and identify the various elements and their relationships. This holistic perspective enables a more accurate analysis and facilitates the identification of potential leverage points for mitigation (Doe, J. 2019).

3. Engaging relevant stakeholders is crucial for a comprehensive analysis and effective recommendations. Stakeholders possess valuable expertise and perspectives, and involving those helps to gather diverse insights and ensure the recommendations consider different viewpoints. Collaboration and dialogue foster a sense of ownership and increase the likelihood of successful implementation of mitigation measures (Smith, A. 2021).

4. Assessing uncertainties and risks is also vital. Challenges often involve uncertainty, and it is necessary to evaluate and communicate the uncertainties associated with measurements, analysis, and future projections. Robust risk assessment techniques, such as scenario analysis or sensitivity analysis, can help identify potential risks and their consequences. Understanding the risks allows for the development of appropriate mitigation strategies. (Johnson, S 2022).

5. Making trade-offs and prioritization is a reality when addressing challenges. With limited resources, conflicting objectives, and varying stakeholder interests, it is crucial to analyze the costs, benefits, and impacts of different options. This enables decision-makers to allocate resources effectively and select measures with the highest potential for impact. Prioritization frameworks assist in identifying the most effective and feasible mitigation measures (Brown, M. 2023).

6. Considering long-term sustainability is essential in developing recommendations. Solutions should not only address immediate challenges but also aim for lasting positive change. Evaluating the durability, adaptability, and potential unintended consequences of proposed measures helps ensure their long-term effectiveness. Sustainable solutions take into account the underlying causes of the challenge and aim to create systemic and lasting change (Wilson, L. 2023).

7. Implementing monitoring and evaluation mechanisms allows for ongoing assessment. After mitigation measures are implemented, continuous monitoring and evaluation help assess their effectiveness and identify areas for improvement.

Establishing appropriate indicators, benchmarks, and evaluation frameworks allows for measurement and analysis of progress. Regular evaluations ensure that recommendations and mitigation measures can be refined and adjusted over time, improving their impact (Jones, R. 2023).

2.2. Empirical Literature Review

2.2.1. Urbanization and Flood Risk

The empirical research on seasonal flood dangers and mitigation measures underlines the critical importance of comprehensive approaches in urban settings, particularly in developing regions such as Adama City, Ethiopia. Beshir and Song (2021) study the relationship between urbanization and floods, observing that rapid urban expansion frequently exacerbates flood hazards due to increased impermeable surfaces and inadequate drainage infrastructure. This phenomenon causes increased runoff, which overwhelms current drainage systems and increases the chance of flooding during heavy rainfall events. Furthermore, urbanization can interrupt natural water flow pathways, increasing the susceptibility of low-lying areas. Understanding these processes is critical for creating efficient flood mitigation techniques that address the unique problems provided by Adama City's urban expansion.

2.2.2. Flood Mitigation Approaches

This component of the case study assessment is used to recommend appropriate mitigation options for the study area. Climate change has exacerbated extreme weather events in Ethiopia and throughout Africa, making efficient flood management an urgent need (IPCC, 2021). This case study examines flood mitigation measures implemented in Adama City, with a focus on Kebele 09, which has had significant flooding challenges. This case study aims to provide insights into flood management practices in other rapidly urbanizing areas of Ethiopia and the broader East African region that face similar environmental and socioeconomic conditions by examining the structural and non-structural approaches taken by local authorities and the Kebele 09 community.

A. Structural Measures:

1. Flood Protection Measures: Building Walls, Embankments, and Improved Drainage Systems Structural flood control solutions involve considerable capital investments in engineering. They are frequently integrated with non-structural measures, such as early warning systems and land use planning, to form a comprehensive flood risk management strategy (Dewan 2015). In Dhaka, Bangladesh, large flood walls and embankments have been built along key rivers and canals to retain and channel floodwaters, so safeguarding the city from river flooding. This development has been the main emphasis of Dhaka's flood management plan in recent decades, to improve infrastructure and mitigate flooding impacts. Structural interventions, combined with other measures, aim to enhance the overall flood resilience of Dhaka and its vulnerable populations.



Figure 1 uses a low embankment as a buffer zone along rivers (Source: Study team.)

2. Drainage System Improvements:

The simple-INSYDE model is used to determine local hazards and building vulnerability for each flooded structure (Dottori et al., 2016). It is believed that water can be drained within 24 hours, and flood damage is computed using the maximum water depth at the building's perimeter, taking into account any pollutants that could exacerbate the damage. The inclusion of a basement has a substantial impact on building vulnerability; if one exists, its area equals the building's footprint. For buildings without basement data, the area is calculated based on the proportion of basements in the sample. Furthermore, the level of maintenance (LM) and building structure (BS) are assessed, with each building receiving a high or low grade depending on the census area's normal conditions.

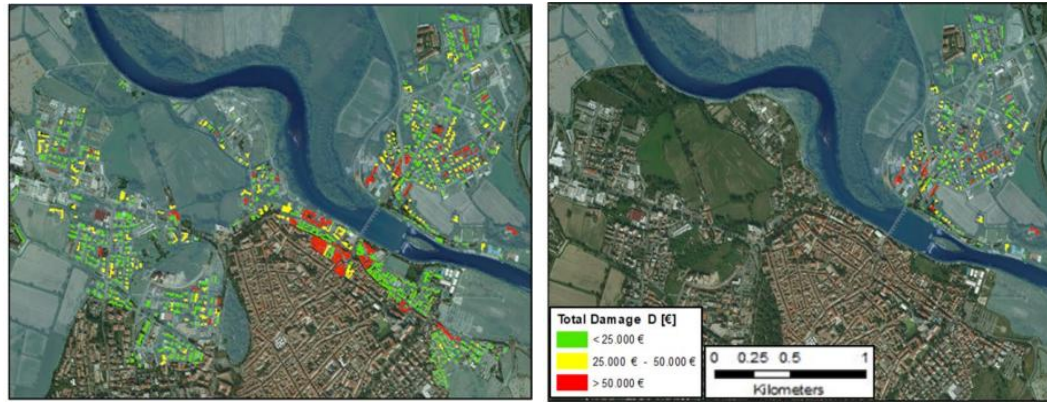


Figure 2. Damage assessment of residences a without the mitigation structure and b after its construction with a 200-year return time. The color legend is the same for both panels.

3. Permeable Pavement in Augustenborg, Sweden

The Augustenborg area in Malmö, Sweden, adopted a comprehensive stormwater management system that included permeable pavement to counteract regular flooding caused by impermeable surfaces (Delshammar & Fors, 2010). The project used porous concrete and permeable pavers in public areas and on streets, allowing stormwater to infiltrate the ground rather than overloading the drainage system. When combined with green infrastructure such as green roofs and rain gardens, these techniques lowered peak flow by up to 50% after heavy rains, greatly lowering flooding hazards. This initiative improved urban flood resilience while also providing benefits such as reduced urban heat island effects and greater groundwater recharge, motivating similar tactics in other cities.

4. Informal Settlements and Flood Risk in Mumbai, India

Mumbai, India, contains extensive informal settlements in low-lying, flood-prone areas that lack sufficient drainage and hinder natural water flow, hence increasing urban flood hazards (Ain et al., 2017). In the Dharavi slum discovered that the high density of temporary dwellings, small paths, and lack of drainage channels contributed to severe waterlogging during the monsoon season. The settlements impeded stormwater flow, increasing flooding susceptibility. To address these concerns, the report proposed

formalizing informal settlements, improving housing and infrastructure, incorporating flood-resilient design principles, and implementing community-based flood preparedness measures. This case emphasizes the importance of comprehensive flood resilience methods in informal settings, as well as protecting vulnerable populations.

B. Non-Structural Measures:

Non-structural flood mitigation solutions target the underlying causes of flood risk while also improving community resilience. Dhaka, Bangladesh, takes a two-pronged approach, establishing early warning systems and implementing community-based disaster risk management initiatives (Dewan, 2015). The early warning systems give locals earlier notice of approaching floods, allowing them to prepare, activate emergency plans, and evacuate susceptible regions, lowering the possibility of loss of life and property. Community-based programs complement this by including locals in disaster management, teaching them in emergency protocols, and forming reaction teams. This twin strategy of top-down early warnings and bottom-up community participation seeks to develop a complete disaster preparedness framework, boosting Dhaka's resistance to flooding.

1. Land Use Regulations and Zoning:

Kuala Lumpur has adopted land use regulations and strategic zoning to limit development and new construction in areas that are prone to flooding. By restricting development in high-risk flood zones, the city aims to reduce the overall exposure and vulnerability of people and assets to flooding. This helps minimize the potential for damage and disruption when flood events occur.

2. Resilient Building Codes:

The city has also updated its building codes to ensure that new construction is more resilient to flood impacts. This includes mandating the use of flood-resistant materials, elevating critical infrastructure, improving drainage systems, and incorporating other flood-proofing measures into building design and construction. Ensuring resilient

construction helps buildings withstand the direct impacts of flooding, reducing the potential for damage and enabling quicker recovery.

In general, by combining land use regulations, strategic zoning, and resilient building codes, Kuala Lumpur is taking a comprehensive approach to limit exposure to flood risks through better-planned and constructed urban development. This approach focuses on controlling and shaping the built environment to be more flood-resilient, rather than relying solely on structural flood control measures. Integrating these land use planning and construction standards into the city's development processes helps reduce the long-term vulnerability of Kuala Lumpur to flooding.

3. Public Awareness Campaigns:

Bangkok has launched public awareness campaigns to educate and inform the general population about flood risks and the importance of adaptation. These campaigns likely utilize various communication channels, such as media, public events, and community outreach, to reach a wide audience. The goal is to increase the public's understanding of flood hazards, their potential impacts, and the need for preparedness.

4. Educational Programs:

In addition to the public awareness campaigns, Bangkok has also implemented targeted educational programs. These programs provide more detailed information and training on flood risk and adaptation measures and are often aimed at specific groups like community leaders, school children, or vulnerable populations. The educational programs cover topics such as flood early warning systems, household-level flood-proofing techniques, emergency response procedures, and nature-based solutions for flood mitigation. The objective is to equip communities and individuals with the knowledge and skills to take appropriate action to reduce their flood risk.

5. Encourage Community-Level Adaptation:

By raising awareness and providing education, Bangkok seeks to empower and motivate communities to take adaptive measures at the local level. This could involve supporting the implementation of community-based flood risk reduction initiatives, such as establishing neighborhood-level emergency response teams or implementing small-scale drainage improvements. Engaging communities as active participants in the adaptation process helps ensure that the measures are tailored to local needs and contexts, and builds a sense of ownership and resilience.

Generally, public awareness campaigns and educational programs in Bangkok aim to cultivate a broader culture of flood risk preparedness and adaptation within the city's population. By informing and empowering communities, these measures complement broader flood management efforts and help foster resilience from the ground up. This community-focused approach is an important complement to structural flood control measures and top-down policy interventions.

C. Ecosystem-based Approaches:

Ecosystem-based approaches refer to flood mitigation strategies that leverage natural or nature-based solutions to manage flood risks. These approaches aim to harness the inherent flood regulation and protective functions of healthy ecosystems, rather than relying solely on engineered structures.

1. Restoration and Preservation of Natural Ecosystems:

Chennai has recognized the crucial role that natural ecosystems, like wetlands and floodplains, play in absorbing and slowing the flow of floodwaters. By protecting and rehabilitating these natural systems, the city aims to harness their inherent flood control functions.

2. Enhance Natural Flood Mitigation Capacity:

The restoration and preservation of wetlands and floodplains in Chennai help to strengthen the city's natural ability to mitigate flood risks. These natural ecosystems act

as sponges, temporarily storing and gradually releasing flood water, which helps to reduce the magnitude and duration of flood events. Additionally, the vegetation and soil in these areas can help slow down the flow of water, further reducing the potential for damage.

3. Complement Structural Flood Control Measures:

While structural flood control measures, such as dams and levees, are important, they can sometimes have unintended consequences or fail to provide complete protection. By focusing on natural ecosystem-based solutions, Chennai has sought to complement and enhance the effectiveness of traditional engineered flood control infrastructure. The natural systems can act as a buffer, reducing the load on structural defenses and providing additional layers of flood mitigation.

I. Holistic Approach to Flood Management:

The restoration and preservation of natural ecosystems in Chennai represents a more holistic, nature-based approach to flood management. Rather than solely relying on hard, structural solutions, this strategy harnesses the natural functions of the landscape to enhance the city's overall flood resilience. This integrated approach can be more sustainable and cost-effective, and provide additional co-benefits, such as improved biodiversity and recreational opportunities.

Overall, Chennai's focus on restoring and preserving its natural wetlands and floodplains demonstrates a shift towards ecosystem-based flood management, which can complement traditional engineered approaches and enhance the city's long-term resilience to flooding.

Kuala Lumpur, Malaysia has integrated green infrastructure, such as urban forests and green spaces, into its flood management strategy to improve water infiltration, reduce runoff, and provide additional flood storage (Chan, 2012).

II. Integration of Green Infrastructure:

Kuala Lumpur has recognized the value of incorporating natural or semi-natural landscaped elements, known as green infrastructure, to provide a range of ecosystem services, including flood mitigation.

III. Improve Water Infiltration:

The presence of urban forests, parks, and other green spaces in Kuala Lumpur helps to improve the infiltration of rainwater into the soil, reducing the overall volume of surface runoff during flood events. This helps to replenish groundwater resources and lower the stress on storm drainage systems.

IV. Reduce Surface Runoff:

Vegetation and permeable surfaces associated with green infrastructure can slow down the flow of surface water, reducing the overall volume and velocity of runoff. This helps to alleviate the pressure on drainage systems and mitigate the risk of flooding in urban areas. Overall, Kuala Lumpur's approach to integrating green infrastructure demonstrates a nature-based solution to enhance the city's flood resilience, leveraging the natural functions of the urban landscape to complement traditional flood control measures.

2.3 International, legal, and institutional Frameworks

Ethiopia's diverse environment and terrain present significant risks of flood risk. The country has developed a comprehensive framework incorporating international norms, strong legal measures, and coordinated institutional activities to address these issues. This comprehensive strategy seeks to increase catastrophe risk management and resilience in vulnerable populations across the country.

International Frameworks

The Sendai Framework for Disaster Risk Reduction highlights the need of disaster risk reduction and resilience building at all levels, including flood control, as endorsed by the United Nations in 2015. In addition, the African Regional Strategy for Disaster Risk

Reduction pushes African Union member states, including Ethiopia, to develop comprehensive disaster risk management policies, which were formed in 2004. Furthermore, the Paris Agreement, which focuses on climate change adaptation, plays an important role in managing flood risks aggravated by climate change, as described in the United Nations Framework Convention on Climate Change in 2015. These frameworks and projects highlight the relevance of collaborative efforts in catastrophe risk management and climate resilience.

Legal Framework

Disaster Risk Management Proclamation No. 823/2014 defines Ethiopia's legal framework for disaster risk management, addressing flood problems and defining the roles of several government entities. In addition, environmental protection legislation, such as the Environmental Impact Assessment Proclamation No. 299/2002, makes it easier to manage natural resources and plan land use, both of which are critical for minimizing flood risk. Combined, these legal measures provide a comprehensive approach to catastrophe risk management and environmental sustainability in the country.

Institutional Framework

The National Disaster Risk Management Commission (NDRMC) coordinates disaster risk management operations in Ethiopia, particularly in terms of flood preparedness and response, as specified in its 2014 framework. The Ministry of Water and Energy is also in charge of water resource management, which includes the design and maintenance of flood control infrastructure. These institutions work together to create an organized and effective approach to managing flood risks and strengthening the country's catastrophe resilience, as underlined by Ethiopia's Federal Democratic Republic in 2016.

2.4. Theoretical and empirical gaps of different literature

The table provided a summary of the collection of research papers from various fields, highlighting their titles, authors, journals, publication years, theoretical gaps, empirical gaps, and related Literature from local and international written documents to show the gap between specific study areas.

Table 3 Different journal's theoretical and empirical gaps source (revised by the author)

No.	Title Authors Journal Year	Theoretical Gap	Empirical Gap
1	Beshir, A. A., & Song, J. (2021). Urbanization and its impact on flood. Natural Hazards	Limited studies the relationship between urbanization patterns, rainfall trends, and flooding risk in African cities, particularly in developing countries.	Challenges in conducting empirical studies in developing countries due to limited data availability and lack of detailed information on past and present conditions.
2	Fang, W., Huang, Y., & Ding, Y. (2022). Health risks of odorous compounds: A review. Environment International)	Lack of a comprehensive and comparative analysis of odorous compounds' release, olfactory annoyances, and health risks in waste management.	Limited consideration of regional meteorological conditions, insufficient identification of priority control odorous compounds, and incomplete estimation of impact distance.
3	Wodnimu, M. A., & Erena, S. H. (2022). Flood vulnerability assessment: A review of methods and applications.	Lack of explicit mention of the theoretical framework or conceptual model used in the research.	Lack of specific data sources and collection methods, limited evaluation of current flood management strategies, and consideration of social and economic factors.
4	Hillier, J. K., & Dixon, R. S. (2020). Seasonal impact-based mapping of weather and climate. Environmental Research Letters	Lack of systematic mapping and understanding of how flooding and extreme wind hazards compound and interact with each other over climatologically timescales.	The Limited understanding of compound risk between flooding and extreme wind, particularly in terms of longer time windows and persistent environmental conditions.
5	Mendoza, A., & Rodríguez-Gil, J. L. (2014). Drugs of abuse and benzodiazepines in wastewater and surface waters. Environment International	Lack of exploration and understanding of the specific reasons for seasonal variations in drug concentrations in surface waters and tap water in the Madrid Region.	The limited scope of human health risk characterization and assessment focuses on specific substances without considering other emerging pollutants or contaminants.
6	Maru, M., Worku, H., & Birkmann, J. (2021). Factors affecting the spatial resilience of urban systems: The case of Addis Ababa, Ethiopia. Heliyon	Lack of research on the spatial resilience of Ethiopia's secondary cities to urban uncertainties.	Limited understanding of household perceptions, inadequate consideration of multivariate challenges, and limited research on specific secondary cities.

7	Leta, B. M., & Adugna, D. (2023). Characterizing the level of urban flood risk in Addis Ababa, Ethiopia. <i>Heliyon</i>	Lacks comprehensive studies applying the social-ecological-technological systems framework to characterize flood vulnerability in Adama City.	Limited availability of data and analysis on specific variables and indicators related to flood vulnerability in Adama City.
8	Kröger, R., Moore, M. T., Locke, M. A., Cullum, R. F., Steinriede, R. W., Testa, S., III, Bryant, C. T., & Cooper, C. M. (2009)	Lack of guidelines or established knowledge on how in-stream wetland vegetation alters chemical residence time in surface drainage ditches.	Lack of documented evidence on the difference in chemical residence time between vegetated and non-vegetated drainage ditches in situ.
9	Voter, C. B., & Loheide, S. P., II (2018). Urban residential surface water inundation modeling using a high-resolution coupled hydrologic and hydraulic model. <i>Water Resources Research</i>	Lack of understanding of how low-impact development practices affect hydrologic processes in urban areas.	Limited understanding of the effectiveness and interactions of low-impact practices, as well as their influence on surface runoff, deep drainage, and evapo-transpiration .
10	Gebremichael, A. W., & Li, J. (2019). Assessing flood vulnerability and resilience in urban areas: A case study of Addis Ababa, Ethiopia. <i>Natural Hazards</i>	Limited research on the development and application of integrated frameworks for assessing flood vulnerability and resilience in rapidly urbanizing African cities.	Lack of comprehensive data on physical, social, economic, and institutional factors influencing flood vulnerability and resilience in Addis Ababa.
11	Gebremichael, A. W., Li, J., & Yan, K. (2020). Flood risk assessment and mapping in rapidly urbanizing catchments: A case of Hawassa City, Ethiopia. <i>Water</i>	Inadequate understanding of the interplay between urban development dynamics, hydro-meteorological processes, and flood risk in rapidly growing cities of developing countries.	Limited availability of high-resolution spatial data on land use/land cover changes, hydrological parameters, and socioeconomic factors for Hawassa City.
12	Mendoza, A., Aceña, J., Pérez, S., & Barceló, D. (2015). Seasonal variation of drugs of abuse in surface water and tap water in the Madrid region (Spain).	Lack of comprehensive research on the seasonal patterns and factors influencing the occurrence of drugs of abuse in urban water bodies and drinking water sources.	Limited data on the seasonal dynamics of drug concentrations, potential sources, and their implications for water quality and human health risk assessment.

13	Worku, G., Teferi, E., Bantider, A., & Dile, Y. T. (2018). Exploring the spatial and temporal patterns of flood hazard in Ethiopia using satellite-derived precipitation and flood mapping. Remote Sensing	Insufficient understanding of the spatiotemporal characteristics of flood hazard and its underlying drivers in Ethiopia, a country heavily impacted by flood events.	Gaps in the integration of satellite-derived precipitation data, flood inundation mapping, and ancillary geographic information to characterize flood hazard patterns in Ethiopia.
14	Jiru, M. T., Haddis, A., & Tefera, W. (2021). Modeling the impacts of climate change and urbanization on flooding in an urban catchment in Addis Ababa, Ethiopia. Hydrology	Limited research on the combined effects of climate change and urbanization on flooding in rapidly growing cities in Sub-Saharan Africa.	Lack of high-resolution data on land use/land cover changes, precipitation patterns, and hydrological parameters to accurately simulate the flood dynamics in Addis Ababa.
15	Decision Management Making by AHP (Analytical Hierarchy Process) through GIS data A. Arquero, M. Álvarez, E. Martínez IEEE Latin America Transactions 2009	The document notes a growing consensus on the need to provide GIS (Geographic Information Systems) with appropriate decision support tools, and that various authors have advocated for the development of a Spatial Decision Support System (SDSS) that integrates GIS with multicriteria analysis methods.	The document states the main objective is to determine the optimal location to build a university library building, using the case of the Faculty of Computer Science at the Polytechnic University of Madrid (Spain) as a specific application

The current institutional frameworks do not fully integrate urban planning and design techniques that address flood risks, resulting in a gap in successfully mitigating flood hazards and improving long-term resilience in urban areas. In densely populated urban areas of Ethiopia, assessing flood risk and its impacts is challenging due to rapid urbanization inadequate infrastructure and unsustainable land use developments. Enhanced community involvement and effective disaster risk reduction strategies are essential to mitigate the severe consequences of flooding.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Introduction

The methodology and resources used in this study provided a complete assessment of seasonal flood dangers and mitigation methods in the studied area. This entailed collecting data from a variety of sources, including government agencies and previous studies, to compile a complete database of past flood occurrences, environmental parameters, and socioeconomic characteristics. Flood risk trends were mapped and assessed using spatial analytic approaches such as geographical information systems (GIS) (ESRI, 2022). Statistical modeling and exploratory data analysis techniques were used to quantify the relationships between floods and contributing elements, as well as to develop predictive models for previous flood situations (Box et al., 2015). Cost-benefit analysis and multi-criteria decision-making frameworks were used to evaluate the effectiveness of alternative mitigation measures, based on relevant research and stakeholder feedback (Boardman et al., 2018; Cinelli et al., 2014). The results of these many analytical components were merged to generate comprehensive recommendations for flood risk management in the study area, taking into account the prospective consequences of previous changes such as climate change and urban development (IPCC, 2021; Qin et al., 2019).

3.2. Description of the study area

The downtown region of Adama City was primarily covered by impervious surfaces such as roads, buildings, and other structures. Over time, the previous surface area had dropped dramatically, being replaced by a "jungle of concrete" (Kebede & Nicholls, 2012; Worku et al., 2014). This modification of the landscape resulted in higher downtown temperatures and a concentration of commercial activity. The downtown area was characterized by gentle slopes, clay-based soil types, significant yearly rainfall, and relatively low elevations compared to the surrounding areas (Haile et al., 2017; Mekonnen et al., 2018). Due to these relevant environmental and infrastructure aspects, the downtown region was chosen as the focus of this study to examine seasonal flood

hazards and mitigation measures. Adama, also known as Nazret, is a city in Ethiopia's Oromia Region, located approximately 99 kilometers southeast of Addis Ababa, the capital city. With a growing population and significant urban expansion, Adama has become an important economic and commercial hub in the region. The city was distinguished by a variety of environmental and geological features. It is situated at coordinates 8.54°N, 39.27°E, bordered by the lush green scenery of Ethiopia's highlands. Adama has a subtropical highland climate, characterized by mild temperatures and distinct wet and dry seasons.

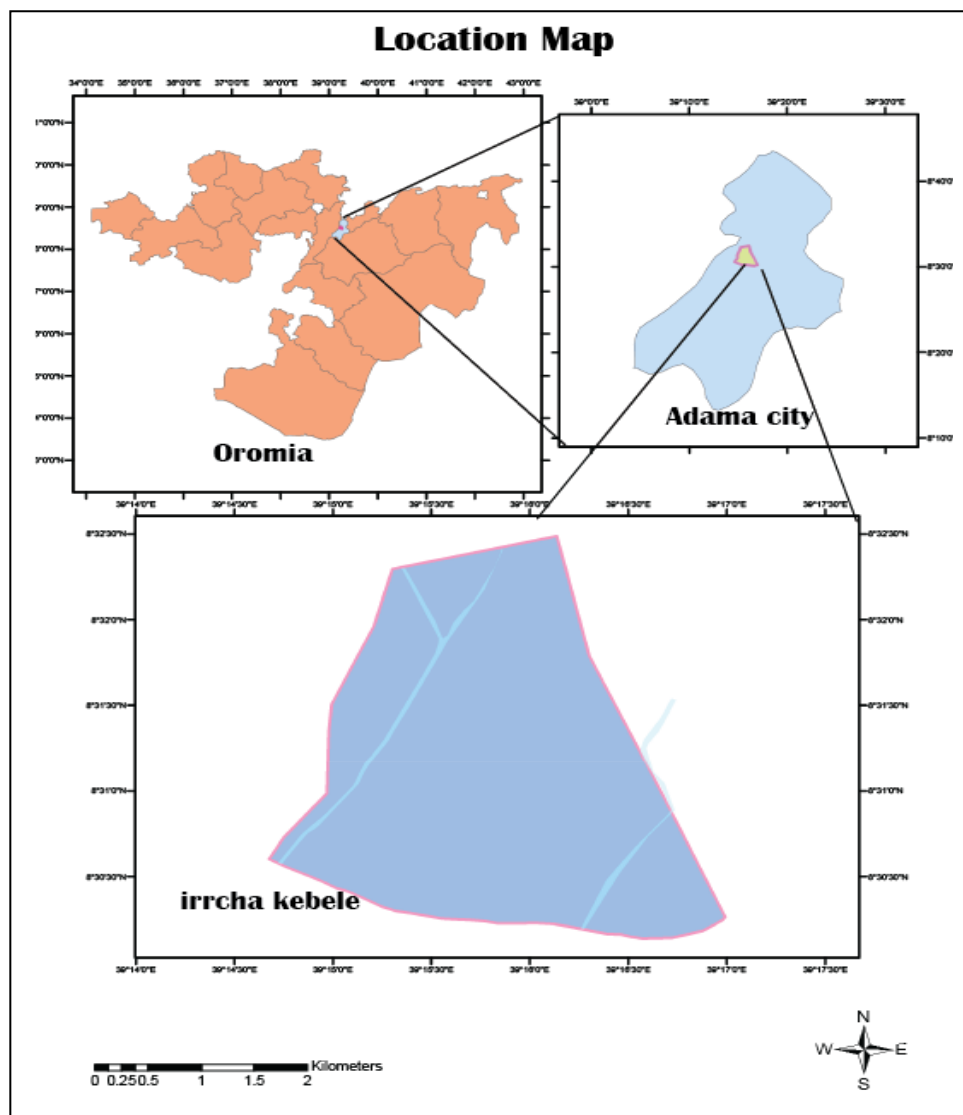


Figure 3 Location Map of the Study Area: Adama City (Source: Author)

3.3. Research Design

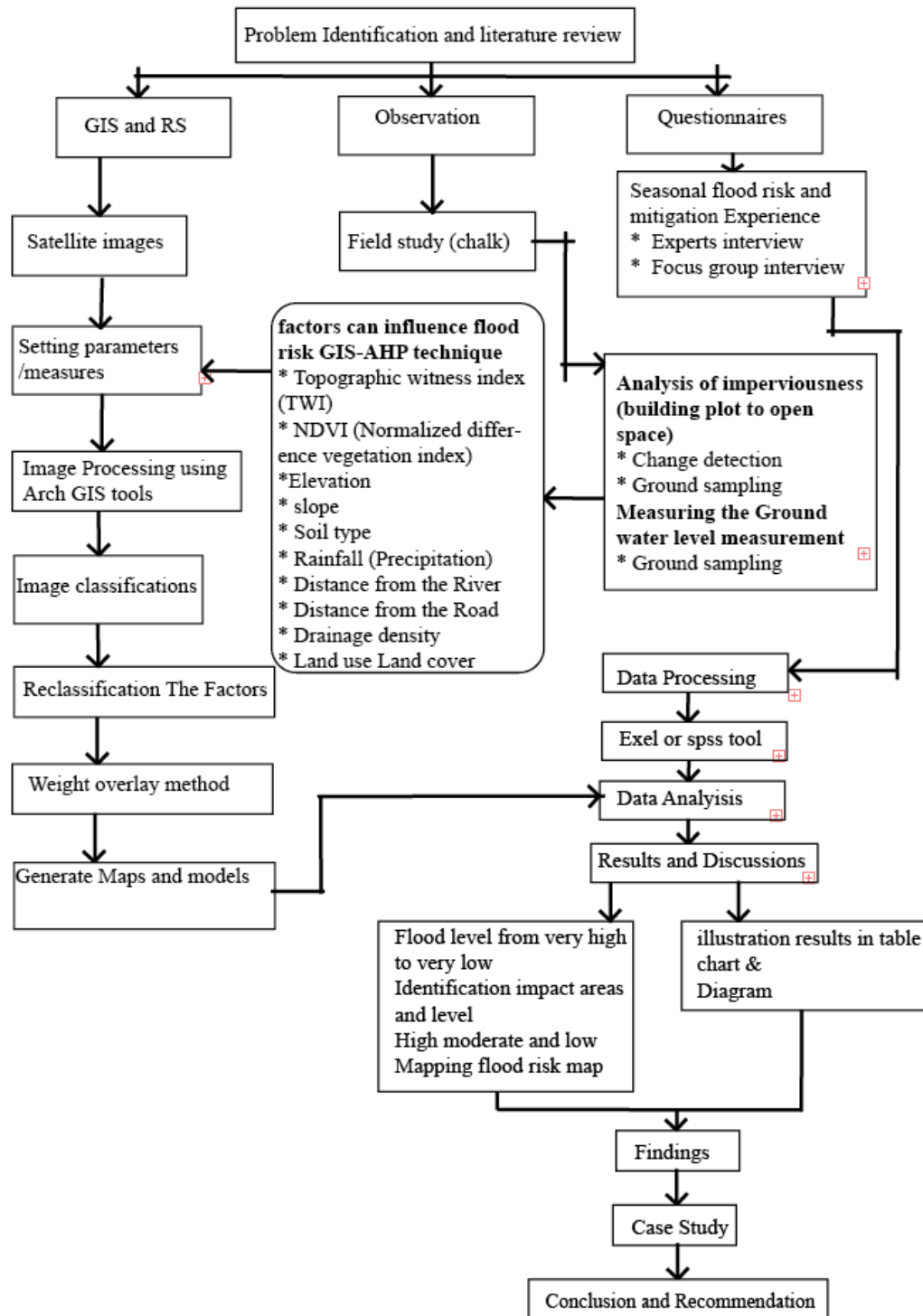


Figure 4 Research Design (Source: Author)

The study evaluates flood impacts in Adama City by examining critical components, constructing a flood hazard map with AHP, evaluating socioeconomic effects with modeling and surveys, and developing mitigation methods based on local case studies.

Table 4 Method of the study

Specific Objective	Methods
1. Identify key factors contributing to flood impacts in Adama City.	Change Detection, Ground Sampling and ground water proximity
2. Create a detailed flood hazard map for Adama City using the Analytical Hierarchy Process (AHP) to visualize and prioritize flood risk areas.	Topographic witness index(TWI),Elevation, slope, Rainfall,(Precipitation),Distance from the River, Distance from the Road ,Drainage density ,LuLc, NDVI, soil type
3. To assess the socio-economic and environmental impact of flood risks.	Inundation modeling ,capturing the household based on modeling ,take in to account the questioners and interview of the impacted area to understand the impact level and type
4. Develop comprehensive strategies to mitigate flood risks in Adama City.	make a case study on the same scenario and understand the types of mitigation measures and the response of the study areas dwellers and the entire frameworks

3.4. Study approaches

The study methodology for measuring flood damages in Adama City will be mixed-methods, incorporating quantitative and qualitative data. To evaluate watershed characteristics and impervious surfaces, quantitative data will be collected via remote sensing, GIS analysis, and field surveys, while the Analytical Hierarchy Process (AHP) will prioritize flood risk variables based on measurable criteria. Inundation modeling will generate quantitative simulations of possible flood situations. Community participation, including surveys and interviews, will provide qualitative insights into the socioeconomic and environmental repercussions of flooding. This integrated approach ensures a thorough assessment of flood risks and guides appropriate mitigation methods.

Table 5 Study Approach of the study

Specific Objective	Study Approaches
1. Identify key factors contributing to flood impacts in Adama City	Use Remote sensing, GIS, and field surveys to gather data on watersheds and imperviousness.
2. Create a detailed flood hazard map for Adama City using the Analytical Hierarchy Process (AHP) to visualize and prioritize flood risk areas.	Analytical Hierarchy Process (AHP): Prioritize flood risk factors by integrating criteria like elevation and rainfall.
3. To assess the socio-economic and environmental impact of flood risks.	Modeling and Simulation: Conduct inundation Modeling to simulate flood scenarios. Community Engagement: use surveys and interviews to gather data from affected households.
4. Develop comprehensive strategies to mitigate flood risks in Adama City.	Case studies: Analyze similar scenarios to Identify effective mitigation strategies and Community responses.

3.5. Data Type and Sources

The flood consequences in Adama City were assessed using both primary and secondary data. Primary data were gathered through field surveys of building attributes, household surveys for socioeconomic impacts, and qualitative interviews with local inhabitants. Inundation modeling utilized data from hydrological models such as HEC-RAS and SWMM. Secondary data included USGS topographic and hydrological datasets, remote sensing imagery from platforms such as Landsat and Sentinel, and information from local government databases on land use and previous floods. Academic research provided context, and GIS databases supplied spatial data layers. This variety of data sources ensured a comprehensive understanding of flood hazards and appropriate management measures.

Table 6 Data Type and Sources (by author)

Specific Objective	Data Type	Sources
1. Identify key factors contributing to flood impacts in Adama City	Remote sensing imagery, Land use data, Building characteristics data, Watershed boundary data	USGS (U.S. Geological Survey): Topographic and hydrological data, Local government databases, Field surveys, GIS databases, hydrological studies ,Field Surveys: Data collection for building characteristics
2. Create a detailed flood hazard map for Adama City using the Analytical Hierarchy Process (AHP) to visualize and prioritize flood risk areas.	Topographic data, Precipitation data, Soil type data, NDVI data, Distance measurements	USGS: Digital Elevation Models (DEMs) and hydrological datasets Remote Sensing Data: ,Satellite imagery from platforms like Landsat and Sentinel,GIS Tools: Software for spatial analysis and modeling (e.g., ArcGIS, QGIS)
3. To assess the socio-economic and environmental impact of flood risks.	Flood inundation modeling ,Household survey data, Socio-economic data, Environmental assessments	Hydrological modeling software Custom-designed surveys and questionnaires, Local government statistics, Academic studies
4. Develop comprehensive strategies to mitigate flood risks in Adama City.	Risk Assessment Reports, Geospatial Data, Community Feedback	Academic journals, government reports, Focus groups and interviews with local residents, Local government policies, flood management frameworks

3.6 Research population

The references to Erena and Worku (2018) and Fuchs et al. (2012) were used to provide context for the historical population data of Irrecha Kebele, specifically noting the population figure of 34,854 from the 2005 census. Applying a 5% increase to the 2005 population figure, the estimated population of Irrecha Kebele for 2023-2024 is projected to be around 36,597 residents. This specific population figure highlights the concentrated number of individuals living in this flood-prone area, making it crucial for targeted studies on flood risk perceptions, vulnerabilities, and mitigation strategies.

By focusing on Irrecha Kebele, the study aims to gather insights directly from those affected by flooding, enhancing the understanding of local challenges and resilience efforts. Irrecha Kebele community members were chosen based on their direct

experiences with flooding, with a concentration on long-term inhabitants who have seen the effects. Flood management professionals, including municipal officials, urban planners, civil engineers, and catastrophe risk reduction specialists, were chosen based on their expertise and involvement in flood risk assessment. Their knowledge was critical for comprehending the administrative and legal frameworks that regulate flood management.

3.7. Sampling Technique

3.7.1. Sample size

To ensure comprehensive data collection for this study, various sampling approaches were employed, focusing on the population of Adama's sub-city and thematic areas. A simple random sampling method was used for the questionnaire, which provided a representative sample while minimizing bias and thereby enhancing the generalizability of the findings. Additionally, purposive sampling was utilized to conduct in-depth interviews with key stakeholders, including local government officials and urban planners, who possess valuable knowledge of flood management and community needs. Samples were also collected from different land use types in flood-prone areas to thoroughly investigate runoff characteristics. This mixed-methods approach fosters a comprehensive understanding of flood hazards and informs community-specific mitigation strategies, ultimately enhancing flood resilience in Adama City: The formula for calculating sample size (N) is:

$$N = \frac{Z^2 p (1 - p)}{E^2}$$

Where:

Z is the z-score matching the specified confidence level.

P represents the estimated proportion or percentage.

E equals the intended margin of error.

Given information:

Confidence level: 95% (Z = 1.96)

the estimated proportion (p) is 0.5 (a conservative estimate).

The desired margin of error (E): 0.05 (5%).

Enter the values: $n = (1.96^2 * 0.5 * (1 - 0.5)) / (0.05^2)$.

$n = (3.8416 * 0.5 * 0.5) / 0.0025$ $n = 0.9604 / 0.0025$ $n = 384.16 \sim 385$ Thus, the computed sample size is 384.16, which can be rounded to 385 for practical purposes.

Table 7 The purposive sample size of expert respondents

No.	Stakeholder	No. of Respondents	Objectives
1	Local Environmental Authorities	1	Assess the role of topographic indices (TWI, elevation, and slope) in flood management.
2	Environmental Consultants	1	Evaluate the effect of precipitation and drainage density on flood risk evaluation.
3	Urban Planning and Design Experts	1	Assess the role of land use/land cover (LULC) and soil type on flood susceptibility.
4	Community Leaders and Local Representatives	1	Incorporate parameters such as distance from rivers and roads into urban planning to improve flood resilience.
5	Risk Authorities	1	Gather local viewpoints on the elements that influence flood risk, including historical background.

Based on different literatures Literature emphasizes the importance of collecting qualitative data from diverse community members in flood-prone areas to capture a wide range of experiences and insights (Mastrorillo et al., 2016). A sample size of 4 to 8 individuals allows for capturing variability in experiences regarding flood impacts on livelihoods, health, and property. This aligns with studies suggesting that larger samples in community assessments improve the reliability of findings (Hutter et al., 2019).

Table 8 Sample size of from the thematic area respondents

Interview sampling from the thematic area	
Category	Sample Size
Residential Areas	4-8
School	1-4
Workshop	2-5
Service Center	1-3
Garage	1-3

3.8 Data Analysis Techniques

1. Imperviousness analysis

Change detection

This study sought to better understand urbanization throughout time by evaluating the role of expanding built-up regions. Remote sensing imagery, including satellite photos from the years 1991, 2007, and 2024, was obtained from sources such as Landsat. The land use and land cover data were sorted into categories, such as impervious surfaces, vegetation, water bodies, and bare soil, using the maximum likelihood technique. The impervious surface ratio was estimated to determine the level of urbanization.

$$ISR = \frac{A \text{ impervious}}{A \text{ total}}$$

Surface Runoff Analysis

Understanding how impervious surfaces affect runoff generation is crucial for flood risk management. Techniques Runoff Coefficient (C): This coefficient denotes the proportion of rainfall that becomes surface runoff. It changes depending on the land usage and surface type. Formula Rational Method:

$$Q=C \cdot I \cdot A$$

2. Groundwater Assessments:

The study assessed groundwater conditions such as depth, proximity to the theme region, and distance from rivers or other water sources. In addition, a water shadow analysis was performed to determine the impact of adjacent land use on groundwater availability.

4. Analytic Hierarchy Process (AHP) and Weighted Overlay Analysis:

The AHP framework allows the systematic prioritization and integration of numerous flood risk factors such as imperviousness, groundwater, and soil types. The techniques used included: AHP: Weights for each criterion were determined using a pairwise comparison matrix. Weighted Overlay Analysis: This method included merging spatial datasets with the estimated weights in GIS.

Pairwise Comparison Matrix (A)

The Pairwise comparison matrix was defined as $A = [a_{ij}]$, where a_{ij} represented the relative importance of criterion i over criterion j , with $a_{ij} > 0$ and $a_{ii} = 1$.

Priority Weights (W)

the priority weights were derived using the following equation:

$$Aw = \lambda_{\max} w$$

Where w is the priority weights vector, and $\lambda_{\max}$ is the principal eigenvalue of the A . The steps to calculate the priority weights included:

- 1 Normalization: The columns of the pairwise comparison matrix A were normalized.
 - 2 Row Averages: The row averages were calculated to obtain the priority weights w .
- Consistency Ratio (CR)

The Consistency Ratio (CR) was calculated using the formula:

$$CR = \frac{CI}{RI}$$

Where CI is the Consistency Index and RI is the Random Index. The Consistency Index (CI) was computed as:

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

The Random Index (RI) is a lookup value dependent on the number of criteria, denoted by n .

5. Community Engagement and Field Observations (Descriptive Statistical Analysis)

Integrating community questionnaires and interview results adds context and ground truth to technical studies.

Surveys and interviews include formal questionnaires and semi-structured interviews.

Formulas: Measures of Central Tendency (mean, median, and mode):

$$Mean = \frac{\sum X_i}{N}$$

Where X_i represents individual responses and N is the number of responses.

Analysis: Building on local knowledge improves the investigation and responses to stakeholder concerns. Field observations in flood-affected areas corroborate model results, providing a better understanding of local dynamics and vulnerability.

6. Inundation modeling

To calculate the flood cover area, first determine the average inundation depth (D) over the area of interest, which can be obtained via hydraulic models or observational data. Next, a Digital Elevation Model (DEM) should be generated to better understand the region's topography, as this model can help identify flood-prone locations based on elevation. Following that, flood extent mapping is critical, which entails using inundation modeling findings to determine which areas are flooded based on a predetermined inundation depth. This approach can be effectively undertaken utilizing GIS tools, which allow for the visualization and analysis of flooded areas, providing a comprehensive assessment of flood impact.

$$A_f = \int_{x_1}^{x_2} \int_{y_1}^{y_2} f(x, y) dy dx$$

A_f = Flood cover area (m^2) $f(x,y)$ = Function indicating whether a point (x,y) is flooded (1 if flooded, 0 if not)

(x_1, x_2) (X_1, x_2) and (y_1, y_2) (y_1, y_2) define the boundaries of the area under consideration.

3.9. Study instruments (Data collection tools)

In this research data collection will be accounted in the following ways:

A. Questionnaires: Design structured or semi-structured questionnaires to collect quantitative and qualitative data from households. The questionnaires can include closed-ended questions with options for respondents to choose from, as well as open-ended questions to gather detailed information.

B. Interviews: Conduct face-to-face or telephonic interviews with key informants, such as community leaders, local authorities, or residents who have experienced environmental hazards. Interviews allow for in-depth exploration of experiences, perspectives, and knowledge related to natural drainage and environmental hazards.

C. Focus groups: Organize focus group discussions with a small group of residents who have been directly affected by environmental hazards or have valuable insights. Focus groups encourage interaction and discussion among participants, providing a deeper understanding of their experiences and viewpoints.

D. Observation: Conduct direct observations of the study area to assess the physical conditions, drainage systems, and environmental hazards. This can involve visual inspections, noting specific features, and documenting any visible impacts or issues related to natural drainage.

E. Geographic Information System (GIS) tools: Utilize GIS software and tools to collect and analyze spatial data related to the study area. This can include mapping drainage systems, overlaying hazard data, and identifying vulnerable areas.

F. Secondary data sources: Gather relevant information from existing records, reports, or publications related to environmental hazards, drainage systems, or previous studies

conducted in the area. This can provide valuable background information and context for your study.

3.9.1 Software's and Tools

The software used in this research is illustrated in the following table.

Table 9 Software and tools and data use

Software Tool	Description
GIS Software (e.g., ArcGIS, QGIS)	Used for spatial data analysis, mapping, and visualization of flood-related data such as land use, infrastructure, flood extents, and vulnerability.
Statistical Software (e.g., SPSS, R, Python) if necessary	Employed for the analysis of quantitative survey data, identifying patterns, trends, and statistical relationships.
Computer-Aided Design (CAD) Software	Utilized for the digital modeling and visualization of urban drainage systems, flood mitigation infrastructure, and urban planning scenarios.
Spreadsheet Software (e.g., Microsoft Excel)	Applied for data organization, basic statistical analyses, and the development of cost estimates, budgets, and other numerical calculations.
Presentation and Reporting Software (e.g., Microsoft PowerPoint, Adobe In Design)	Employed for the preparation of project reports, presentations, and visualization of research findings.
GPS Devices	Used for collecting spatial data, mapping locations, field observations, and site visits.

Table 10 Specifications of Satellite Imagery

Year	Satellite	Classification Method	Description
1991	Landsat 4-5	Supervised or unsupervised classification to categorize land covers types (e.g., forest, water, urban).	The analysis categorizes land cover types to assess changes over time and identify patterns in land use.
2007	Landsat 7	Apply the same classification method for consistency.	Continuity in data collection ensures comparability with previous years, helping to track land cover changes.

2024	Landsat 8/9, NDVI	Classify using the same methods to maintain consistency across datasets.	NDVI analysis is particularly useful for assessing vegetation health and land cover dynamics in the region.
2024	Elevation, Drainage Density, Inundation Modeling	Hydrology studies, wetland mapping, and vegetation analysis.	DEMs provide elevation data critical for understanding hydrology, drainage patterns, and wetland areas.
2024	Rainfall (Precipitation)	Water resource management, agricultural planning, and flood risk assessment.	Precipitation data is essential for evaluating flood risks and managing water resources effectively.
2024	Distance from the River	Flood risk assessment, habitat analysis, and land planning.	Proximity to rivers is analyzed to assess flood vulnerability and inform land use planning and habitat conservation strategies.
2024	Distance from the Road	Urban planning, infrastructure development and accessibility studies.	Analyzing distance to roads supports urban development efforts and improves infrastructure planning.
2024	Soil Type	Agricultural planning, land management and environmental monitoring.	Soil type data informs agricultural practices, land use decisions, and environmental assessments.

3.10 Methods of data analysis

The data analysis methodologies used in this work are intended to provide a comprehensive picture of the flood threats in Adama City. To improve the analysis, a mixed-methods approach is used, which combines quantitative and qualitative techniques. Quantitative data gathered through surveys and GIS mapping are compiled and analyzed in Excel spreadsheets to uncover patterns and connections linked to flood susceptibility and impacts. This study entails developing descriptive statistics, pivot tables, and graphical representations to help visualize critical linkages and patterns.

Furthermore, flood inundation analysis is used to identify theme areas within flood risk zones, allowing for targeted interventions based on geographical and environmental parameters. The Analytical Hierarchy Process (AHP) is used to generate a thorough flood danger map, prioritizing locations based on topography, land use, drainage features, soil type, and other pertinent variables.

Qualitative data from interviews and focus groups are thematically evaluated to elicit community viewpoints on flood hazards and mitigation options. This triangulation of data sources strengthens the findings and provides a comprehensive view of the flood threat landscape. By combining technical data organized in Excel with community insights, the study finally informs effective mitigation methods customized to the specific context of Adama City, ensuring that proposed interventions are both technically sound and socially relevant.

3.11. Ethical Consideration

Ethical issues in research are critical to ensuring the rights and well-being of participants, communities, and animals. Key criteria include obtaining informed permission, properly stating the study's objectives and dangers, and allowing for voluntary withdrawal. The idea of beneficence directs researchers to improve community well-being while minimizing harm and fairness ensures equitable treatment. Ethical permission from a relevant body is required, as is complete compliance to their guidelines. Finally, ethical reporting necessitates transparency in findings while avoiding fabrication, falsification, and plagiarism. Adherence to these criteria ensures ethical conduct and integrity in research.

3.12. Validity and Reliability of the Data

The quality and reliability of data in the paper "Assessing Seasonal Flood Hazards and Its Mitigation Strategies: The Case of Adama City" are critical for establishing credibility. The technique should be documented, and the sampling method used should adequately represent the population, with a rationale for the choice. Measurement tools should be validated and acceptable, and data analysis methodologies should be consistent with study objectives. Using multiple data sources helps improve findings. Consistency in data collection and analysis over time is critical, as is well-documented procedures. The document should acknowledge restrictions and probable inaccuracies, as well as store and make raw data available for future verification.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Description of Flood Conditioning Factors

Adama City's flood risk assessment includes a thorough analysis of various elements such as past flood inventories, low-lying areas prone to rapid flooding, slope assessments, and proximity to rivers and water bodies, which serve as key flood routes. Understanding flooding dynamics requires investigating drainage density, the Topographic Wetness Index (TWI), and land use/cover.

Collaboration with local academics and experts is essential for accurately evaluating flood risk. This contextual approach aims to identify specific flood risk factors and their interconnections, as highlighted by Woods Ballard et al. (2007), by analyzing variables such as drainage density, proximity to roads and rivers, slope, rainfall, soil type, TWI, NDVI, and elevation.

The study focuses on watershed dynamics, change detection, imperviousness assessment, and groundwater depth related to water sources. By using Geographic Information Systems (GIS) and advanced data processing techniques, the research aims to ensure accurate findings for effective flood management. It employs methodologies like the Analytic Hierarchy Process (AHP) for decision-making identifies the impact level on the study community and states the Storm Water Management Model (SWMM) for simulating water flow. This integrated approach enhances understanding of flood resilience and urban flood vulnerability, contributing to informed planning and sustainable management practices and mitigation measure.

The study also emphasized the importance of community engagement in understanding flood vulnerabilities. By involving local residents in discussions about their experiences with flooding, the research captured valuable insights that complemented technical assessments. This participatory approach fostered a sense of ownership among community members, empowering them to contribute to flood resilience efforts and ensuring that management strategies were tailored to the specific needs of Adama City

4.1.1 Watersheds

The watershed analysis revealed two critical pour points (Pour Point 1 and Pour Point 2) that play a significant role in the runoff dynamics and flood risk within the study area. Pour Point 1 was identified as a primary confluence point with a high potential for flow accumulation, while Pour Point 2 was located where the watershed streamline crossed the thematic area, exacerbating flood vulnerability. The stream order characterization showed that the watershed is dominated by 3rd and 4th-order streams, indicating a well-developed and complex drainage system that influences the routing and concentration of runoff during flood events. By integrating the insights from the pour point analysis and stream order characterization, the study was able to identify hotspots for potential flood risk, particularly at the confluence at Pour Point 1 and the crossing of the watershed streamline through the thematic area at Pour Point 2. These findings have important implications for watershed management and flood mitigation strategies, highlighting the need to prioritize targeted interventions at the critical drainage points and develop a hierarchical drainage network management plan to enhance the watershed's resilience to flooding.

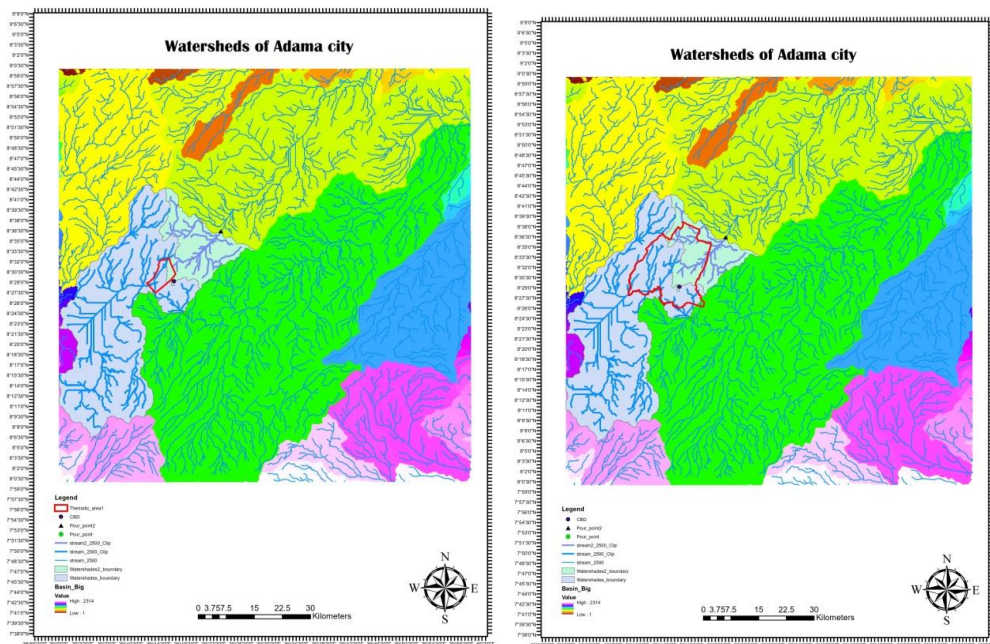


Figure 5 Watershed analysis of the study area (Source: Author)

4.1.2 LULC Change Detection and Imperviousness Assessment

In this section, I utilized satellite imagery from 1991 and 2024 to conduct a change detection analysis and a plot-level imperviousness assessment for two areas of Adama City. The findings quantify the spatial and temporal dynamics of impervious surfaces, providing insights into the city's urbanization processes. Adama City, a rapidly growing urban hub in central Ethiopia, has experienced significant changes in land use and land cover (LULC) over the past few decades. This analysis compares satellite images from 1991 to the present (approximately 2024) to investigate LULC trends in Adama City.

The change detection approach measures geographical and temporal variations across various LULC categories, including vegetation cover, water bodies, agriculture, barren land, and built-up areas. The 1991 baseline serves as a crucial reference point for determining the extent and patterns of LULC changes that have transformed Adama's landscape. Understanding these changes is essential for local governments and urban planners to develop long-term policies that manage the city's growth while safeguarding its natural resources.

Additionally, the analysis highlights how LULC changes contribute to flooding risk. Increased impervious surfaces from urbanization can lead to greater surface runoff and altered water flow patterns, making certain areas more vulnerable to flooding. By integrating this information, stakeholders can better anticipate flooding risks and implement sustainable development practices.

Land use land covers result in 1991

According to the GIS data and map provided, the land use and land cover composition of Adama City in 1991 was as follows:

Table 11 Lulc 1991 class coverage

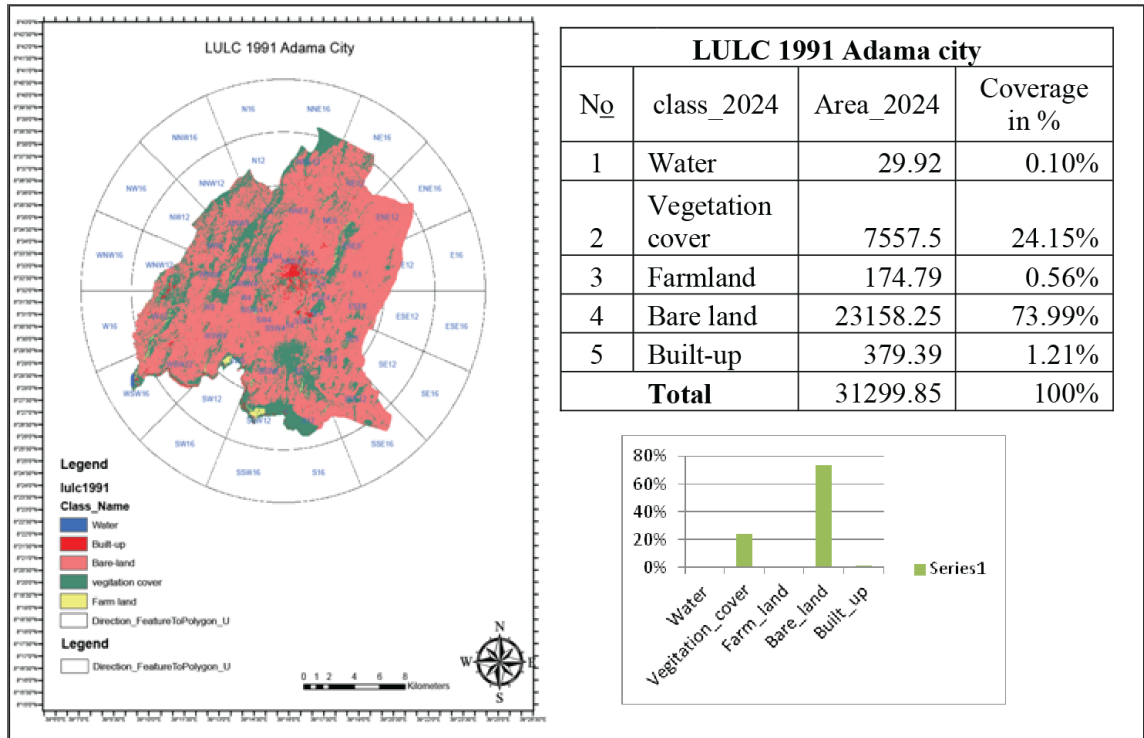


Figure 6 Lulc 1991 of Adama city (Source: Author)

In 1991, the bare ground covered 73.99% of Adama City's total area. This indicates that a large percentage of the city's land was uncultivated and unvegetated at the time. Vegetation Cover accounted for the second-largest share, 24.15% of the total area. Farmland accounted for only 0.56% of the city's total area. Built-up areas accounted for 1.21% of the total area in 1991, showing that urbanization was less than it is today. Waterbody coverage remained constant at 0.10% of the total area.

Land use land covers result in 2007

Analyzing the 2007 land use/land cover (LULC) data for Adama City, the key findings are the following:

Table 12 Lulc 2007 class coverage

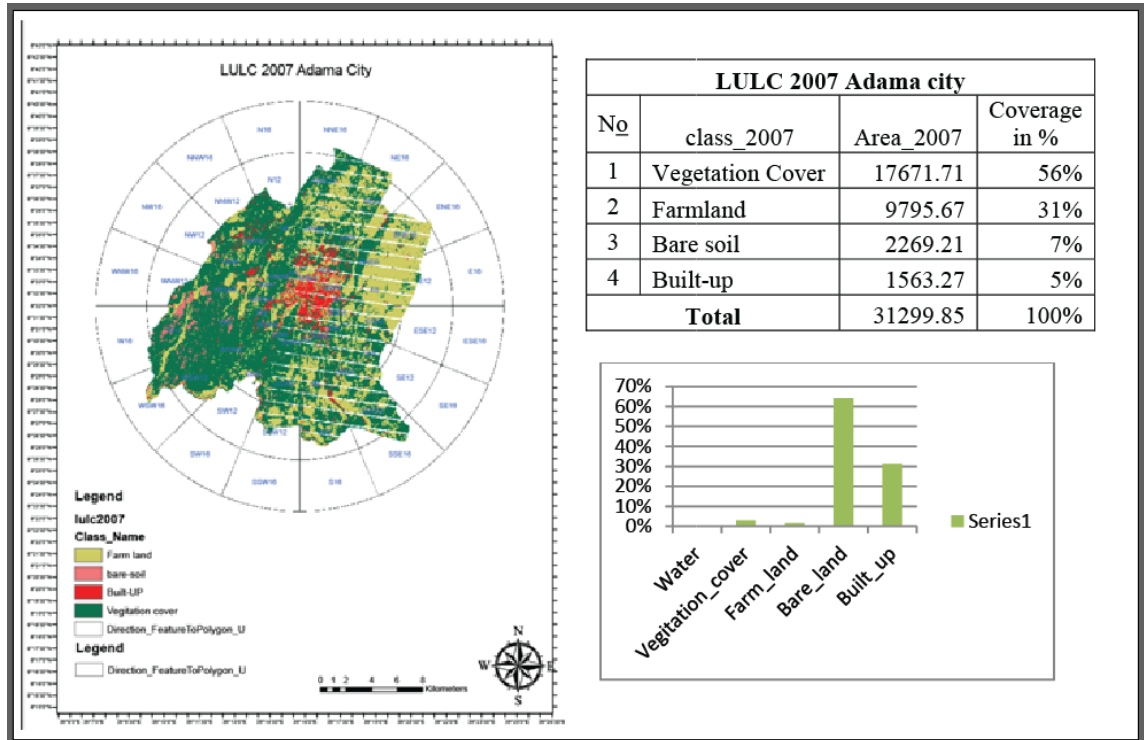


Figure 7 Lulc 2007 of Adama city (Source: Author)

Between 1991 and 2007, Adama City had considerable land use changes. Bare land declined substantially from 73.99% to 7%, indicating a transition toward more cultivated and vegetated areas. During this time, vegetation cover grew significantly, from 24.15% to 56%, showing an expansion of green spaces. Farmland also increased significantly, from 0.56% to 31%, indicating a boost in agricultural activity. Built-up areas increased somewhat from 1.21% to 5%, indicating minor urban expansion, while aquatic bodies stayed constant at 0.10%.

Land use land covers result in 2024

In 2024, Adama City had a total area of 31,299.85 hectares. The LULC composition is listed below in a table:

Table 13 Lulc 2024 class coverage

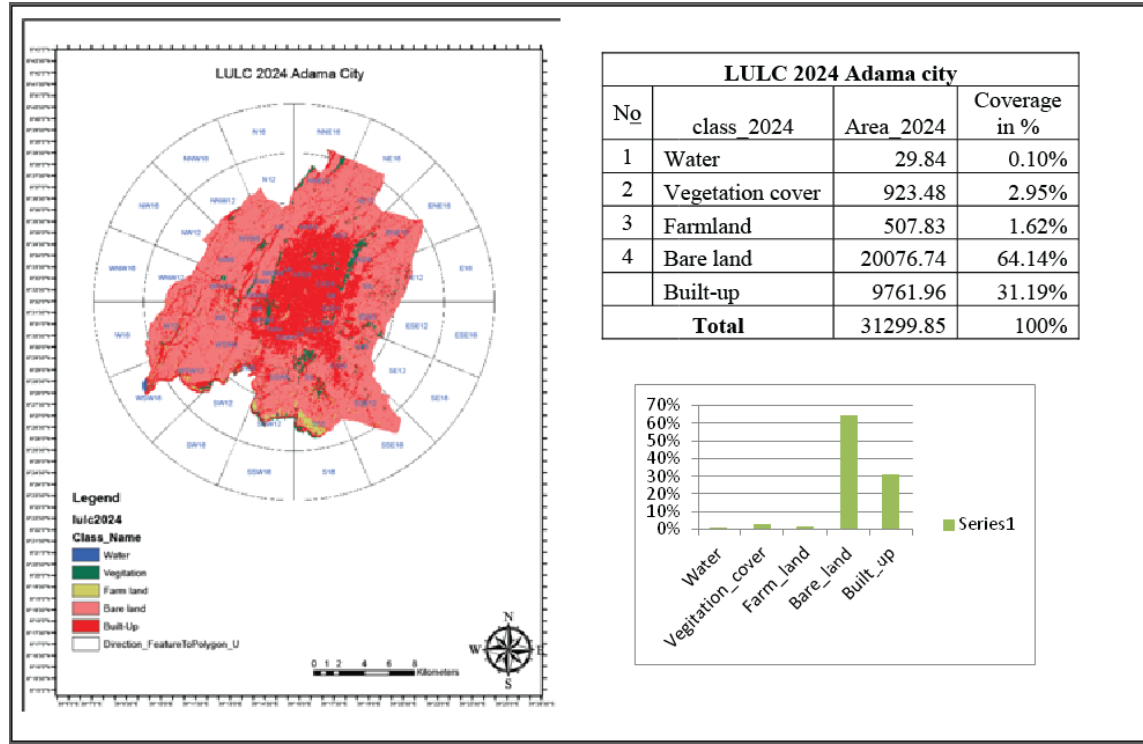


Figure 8 Lulc 2024 of Adama city (Source: Author)

Between 2007 and 2024, these trends reversed. Bare land increased by 783.06%, but decreased from 1991 to 2024 13.31% indicating a strong return to uncultivated land. Vegetation cover dropped to just 2.95%, indicating a significant loss of green space. Similarly, acreage declined by 1.62%, indicating a decline in agricultural use. In contrast, built-up areas increased dramatically, from 5% to 31.19%, indicating a high level of urbanization and growth. Throughout this period, water body coverage remained steady at 0.10%. Overall, Adama City's land use changes reflect a shift from more vegetation and agriculture to a landscape dominated by urbanization and bare ground.

4.1.3 Impervious Surfaces and Runoff Analysis

The investigation in this part goes deeper into the study site's features by sampling the structures and evaluating their contribution to total imperviousness. By focusing on the constructed environment, the researcher can acquire a better knowledge of the ratio of built-up regions to open/unpaved spaces on the site. This information is critical for determining the site's ability to generate surface runoff during precipitation events.

The building sampling approach allows the study to measure the coverage and distribution of impervious surfaces, which are represented by built structures. This detailed analysis adds to the overall assessment of the plot's land cover composition, offering a more complete view of the site's infiltration capacity and runoff patterns. The building-level data can be used to generate metrics such as the building footprint ratio, building density, and impervious surface percentage. These measures are critical for understanding the site's hydrological behavior and flooding susceptibility, as increased imperviousness often results in higher surface runoff and decreased infiltration, altering the area's flood risk profile.

According to Bulti, D. T. et al. (2021) the daily maximum rainfall intensity varies greatly depending on the time of year and weather patterns. According to historical data, the maximum 24-hour rainfall intensity in Adama City normally ranges between 30 and 60 mm/day throughout the main rainy season (July to September), with occasional higher peaks of up to 80 to 100 mm/day during periods of severe convective activity or heavy rainfall events. During the dry months (October-June), the daily maximum rainfall intensity is often lower, ranging from 10 to 30 mm/day, while isolated significant rainfall events do occur.

Selected samples from the thematic area (irrcha or 09 kebele) area

Sample 01

Residence one (G+0)



Total Plot Area = 176.6 m^2 Built up Area = 125 m^2

Paved area = 51.6 m^2 Green area = 0 m^2

Runoff volume = Coefficient x daily maximum rainfall intensity x Built-up/Paved/green area

Built up = $0.75 * 25 \text{ mm} * 125 \text{ m}^2 = 2,343.75 \text{ liters/day}$

Paved area = $0.8 * 25 \text{ mm} * 51.6 \text{ m}^2 = 1,032 \text{ liters/day}$

Green area = $0.25 * 25 \text{ mm} * 0 \text{ m}^2 = 0 \text{ liters/day}$

Therefore total runoff volume of this compound is **3,375.75**

Sample 02

Residence one (G+1)



Total Plot Area = 548.95 m^2 Built up Area = 468 m^2

Paved area = 80.95 m^2 Green area = 0 m^2

Runoff volume = Coefficient x daily maximum rainfall intensity x Built-up/Paved/green area

Built up = $0.75 * 25 \text{ mm} * 468 \text{ m}^2 = 8,775 \text{ liters/day}$

Paved area = $0.8 * 25 \text{ mm} * 80.95 \text{ m}^2 = 1,619 \text{ liters/day}$

Green area = $0.25 * 25 \text{ mm} * 0 \text{ m}^2 = 0 \text{ liters/day}$

Therefore total runoff volume of this compound is **10,394 liter**

Sample 03

Hotel (G+6)



Total Plot Area = $10,983 \text{ m}^2$ Built up Area = 4060 m^2

Paved area = 6923 m^2 Green area = 0 m^2

Runoff volume = Coefficient x daily maximum rainfall intensity x Built-up/Paved/green area

Built up = $0.75 * 25 \text{ mm} * 10,983 \text{ m}^2 = 205,931.25$

liters/day **Paved area** = $0.8 * 25 \text{ mm} * 6923 \text{ m}^2 = 138,460$

liters/day **Green area** = $0.25 * 25 \text{ mm} * 0 \text{ m}^2 = 0 \text{ liters/day}$

Therefore total runoff volume of this compound is

344,391.25 liter

Sample 04

Factory (G+0)



Total Plot Area = 5698 m² Built up Area = 3,592 m²

Paved area = 1624.5 m² Green area = 481.5 m²

Runoff volume = Coefficient x daily maximum rainfall intensity x Built-up/Paved/green area

Built up = 0.75 * 25 mm * 3,592 m² = 67,350 liters/day

Paved area = 0.8 * 25mm * 2,106 m² = 42,120 liters/day

Green area = 0.25 * 25mm * 0 m² = 0 liters/day

Therefore total runoff volume of this compound is

109,470 liter

Thematic Area Land Use Coverage Analysis

The current land use coverage in the research region is shown as follows:

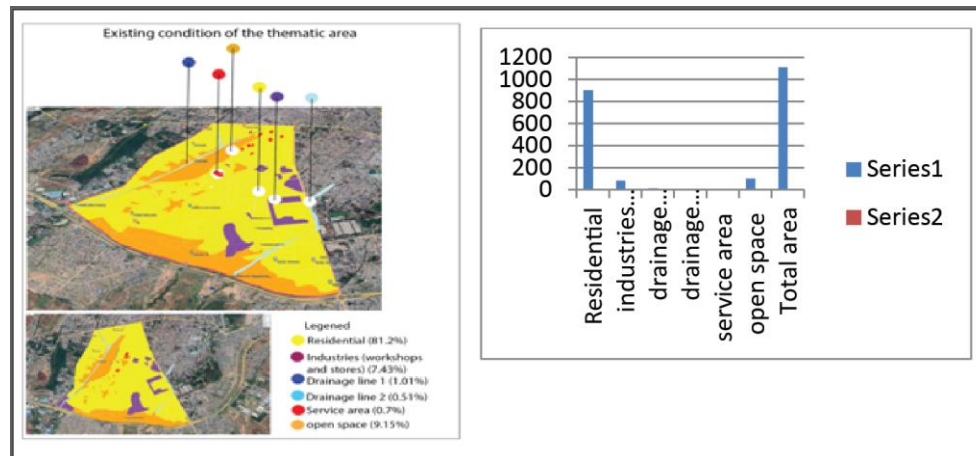


Figure 9 Lulc coverage of thematic area (Source: Author)

Table 14 Thematic area irrcha (09) kebel

The existing condition of the thematic area			
NO	Type of land use	Area in hac	Coverage in percent
1	Residential	899.696	81.20%
2	industries (workshop or stores)	82.3244	7.43%
3	drainage line 01	11.1908	1.01%
4	drainage line 02	5.6508	0.51%
5	service area	7.756	0.70%
6	open space	101.382	9.15%
	Total area	1108	100.00%

The current conditions in the theme region show a strong link between land use categories and their contributions to runoff. Residential areas dominate the landscape, accounting for 81.20% of the total area, resulting in significant runoff from both single and multi-story dwellings. For example, Sample 1, a single-story residence, produces 3,375.75 liters of sample runoff per day, but Sample 2, a multi-story residence, produces 10,394 liters per day. This emphasizes the urgent need for adequate stormwater management techniques to handle the increased risk of runoff from these residential areas.

Industrial zones, albeit smaller (7.43%), contribute significantly to runoff due to their vast impervious surfaces. Sample 4 represents a factory, with a total runoff of 109,470 gallons per day. This emphasizes the necessity of adequate drainage management in reducing stormwater consequences from industrial land uses.

Finally, despite accounting for only 0.70% of the overall area, the service area contributes to runoff generation, as seen by Sample 3, which shows a total runoff of 344,391.25 liters/day from a sample taken hotel. Despite its limited coverage, the service area's impact on runoff can be significant due to the magnitude of the facilities it serves.

The consequences of these findings go beyond immediate runoff problems, highlighting the importance of integrated land-use planning that includes green infrastructure and sustainable behaviors. The thematic area can reduce flooding hazards and improve water quality by investing in permeable surfaces, rain gardens, and efficient drainage systems. Such preemptive approaches not only solve stormwater issues, but also improve urban resilience, resulting in healthier ecosystems and a higher quality of life for residents. Overall, the analysis shows that residential and industrial areas are the dominant sources of runoff in the theme region, highlighting the importance of specialized stormwater management solutions for efficiently mitigating flooding and improving water resource management.

4.1.4 Groundwater Depth and Proximity to Water Sources

Groundwater depths in the region vary periodically, often reaching roughly 80 meters below the surface in the hot months and less than 80 meters in the winter. These variations are influenced by precipitation, surface water-groundwater interactions, and evaporation rates. Deeper groundwater levels in the summer are mostly caused by higher irrigation water consumption and lower recharge during dry months.

The land is only 3 kilometers from a river and 50 meters from its edge. This proximity increases the risk of floods, especially during heavy rains or rapid snowmelt. Furthermore, the intimate hydraulic link between surface and groundwater systems influences water availability, quality, and contamination risk. However, the river can provide water for agriculture, industrial usage, and home supplies, provided that the water quality and quantity are appropriate.

4.2 Flood susceptibility mapping through the GIS-AHP technique

Flood susceptibility mapping is a crucial tool for identifying areas at risk of flooding and informing effective flood risk management strategies. By integrating Geographical Information Systems (GIS) with the Analytic Hierarchy Process (AHP), a robust and systematic approach can be achieved (Rahmati et al., 2016). This GIS-AHP technique combines the spatial analysis capabilities of GIS with the multi-criteria decision-making framework of AHP, enabling the effective integration and prioritization of various factors that contribute to flood susceptibility.

For instance, in Adama City, key factors identified by respondents include inadequate drainage systems (33.3%), lack of prevention methods (33.3%), poor infrastructure (22.2%), and blockages in roads and ditches (22.0%). Additionally, unplanned natural drainage (11.1%), geographical issues (11.1%), and waste dumping (16.7%) further exacerbate flood risks. By utilizing GIS and AHP, these factors can be systematically analyzed to create a detailed flood hazard map, guiding targeted flood risk management efforts.

4.2.1 Flood Susceptibility Criteria and Sub-criteria and their weight based on GIS-AHP technique

Land use /land cover constitutes the principal factor to identify areas that are susceptible to being submerged by flooding (Nuissl et al.2009). Land use influences infiltration rate. For example, forests and vegetation favor water infiltration (Kourgialas and Karatzas 2011). On the other hand, urban areas, which are mostly made from impermeable surfaces and bare lands, increase storm runoff (Tehrany et al.2014). The result for flood susceptibility criteria and sub-criteria using a 10*10 matrix based on the GIS-AHP technique is illustrated below:

Matrix		TWI	Elevation	Slope	Precipitation	LULC	NDVI	Distance from river	Distance from road	Drainage density	Soil type	normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	10	
TWI	1	1	1	1	1	3	5	1	3	1	1	13.78%
Elevation	2	1	1	1	1	2	3	1	3	1	1	12.07%
Slope	3	1	1	1	1	3	1	1/2	1	1	1	9.90%
Precipitation	4	1	1	1	1	3	2	2	3	1	1	13.45%
LULC	5	1/3	1/2	1/3	1/3	1	1	1/3	3	1	1	6.62%
NDVI	6	1/5	1/3	1	1/2	1	1	1/5	1	1	1	5.87%
Distance from river	7	1	1	2	1/2	3	5	1	3	1	1	14.08%
Distance from road	8	1/3	1/3	1	1/3	1/3	1	1/3	1	1	1	5.59%
Drainage density	9	1	1	1	1	1	1	1	1	1	1	9.32%
Soil type	10	1	1	1	1	1	1	1	1	1	1	9.32%

Figure 10 Result from the analysis matrix weight based on GIS-AHP technique (Source: Author)

Table 15 Flood Susceptibility Criteria and Sub-criteria for Adama City

Flood Susceptibility Criteria and Sub-criteria ranges for flood susceptibility Assessment weight based on GIS-AHP technique						
Flood causative criterion	unit	class		susceptibility class range and rating	susceptibility class rating	Weight (%)
Topographic witness index (TWI)	Level	-8.4083	-4.63845	5	Very Low	14%
		-4.63845	-2.43939	4	Low	
		-2.43939	0.46652	3	Moderate	
		0.46652	3.60803	2	High	
		3.60803	11.6189	1	Very High	
Elevation	M	1,338	1,504	5	Very Low	12%
		1,504.00	1,616	4	Low	
		1,616.00	1,730	3	Moderate	
		1,730.00	1,940	2	High	
		1,940.00	2,302	1	Very High	
slope	%	0.000	3.250	5	Very Low	10%
		3.260	7.580	4	Low	
		7.590	14.300	3	Moderate	
		14.400	23.600	2	High	
		23.700	55.20	1	Very High	
Rainfall (Precipitation)	mm/year	11.0	11.2	5	Very Low	13%
		11.3	11.5	4	Low	
		11.6	11.7	3	Moderate	
		11.8	12.0	2	High	
		12.1	12.3	1	Very High	
Distance from the River	M ³ /s	0	5550	5	Very Low	14%
		5560	11100	4	Low	
		11200	16600	3	Moderate	
		16700	22200	2	High	
		22300	27700	1	Very High	
Distance from the Road	M	0	1,284.06	5	Very Low	6%
		1,284.06	2,568.11	4	Low	
		2,568.11	3,852.17	3	Moderate	
		3,852.17	5,136.22	2	High	
		5,136.22	6,420.28	1	Very High	
Drainage density	km ⁻¹	0.0000	0.0066	5	Very Low	9%
		0.0066	0.0133	4	Low	
		0.0133	0.0199	3	Moderate	
		0.0199	0.0265	2	High	
		0.0265	0.0331	1	Very High	

LuLc	categorical	Water Body		5	Very Low	7%
		Vegetations cover		4	Low	
		Farmland		3	Moderate	
		Bare soil		2	High	
		Built-up		1	Very High	
NDVI	Level	-0.178	0.017	5	Very Low	6%
		-0.0171	0.157	4	Low	
		0.157	0.219	3	Moderate	
		0.219	0.303	2	High	
		0.303	0.507	1	Very High	
soil type	Level	LOAM		5	Very High	9%
		SANDY_CLAY_LOAM		3	Moderate	
		CLAY		1	Very Low	
				Total weight		100%

4.2.2 Topographic Wetness Index (TWI)

The Topographic Wetness Index (TWI) is an effective indicator for determining whether locations are more likely to become saturated or have a higher water table. The TWI is calculated using the slope and upstream contributing area at a specific site to determine the relative wetness potential. The data you gave reveals a TWI range of -8.4083 to 11.6189, with higher values indicating places more prone to dampness and flooding. This data can be used in a multi-criteria decision analysis framework, such as the Analytic Hierarchy Process, to assess flood risk and susceptibility across a landscape. Decision-makers can acquire a more thorough picture of hydrological conditions and make better land use planning and management decisions by taking the TWI into account alongside other relevant factors.

Table 16 Topographic Witness Index

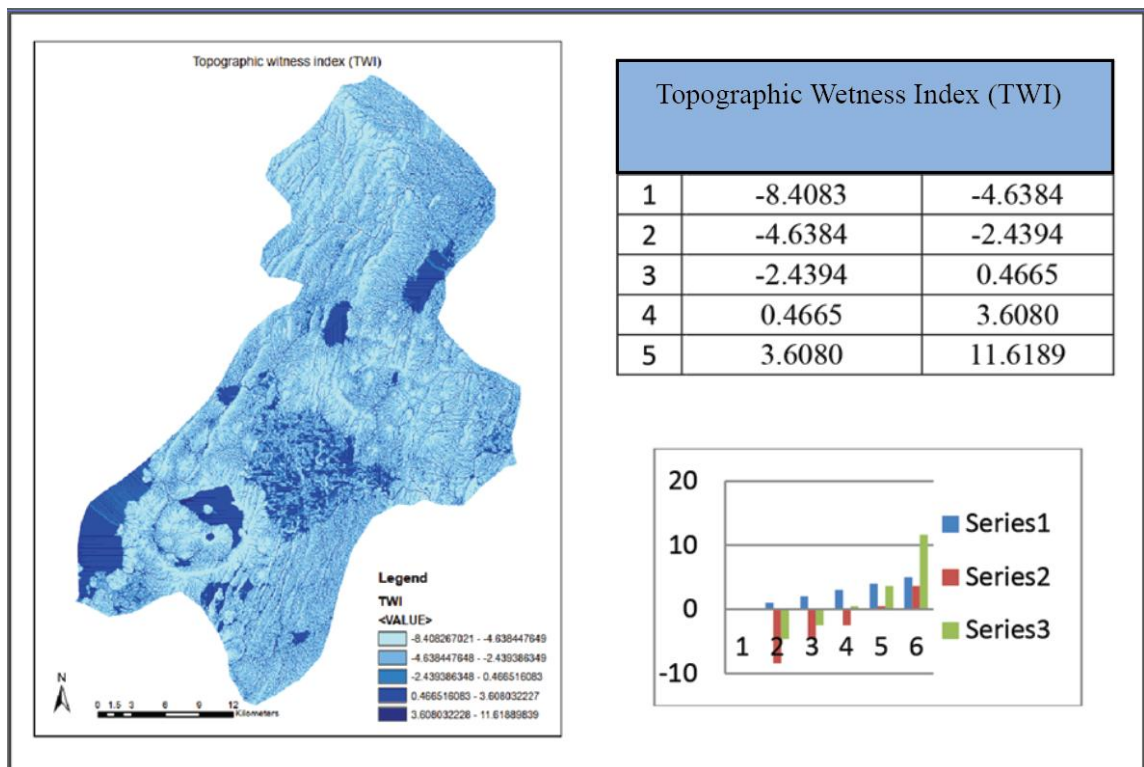


Figure 11 Topographic witness index map (TWI) (Source: Author)

4.2.3 Slope

The slope data is separated into five ranges: 0-2.60 to 26.30-55.20 degrees. Lower ranges suggest flatter areas that may be more favorable for development, whereas higher ranges encompass steeper terrain that presents greater problems. This slope information can help with land use planning, hydrology, hazard mitigation, and other applications that need an understanding of the study area's topography.

Table 17 Slope of Adama City

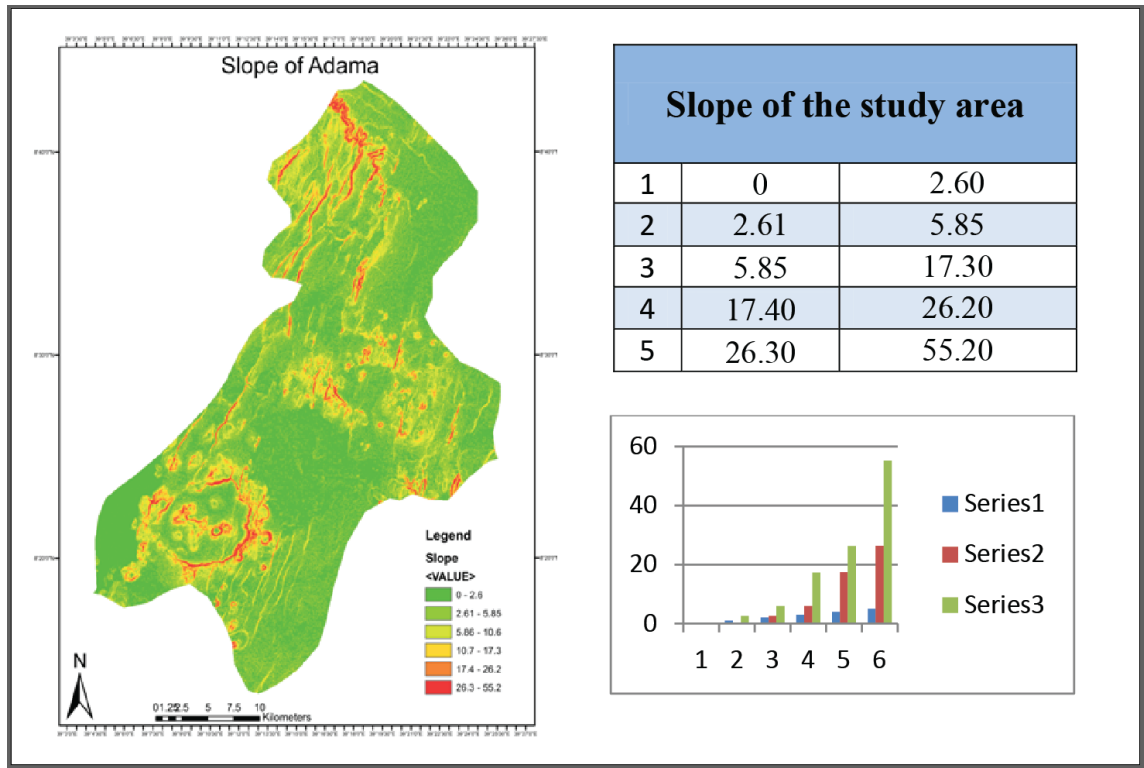


Figure 12 Slope map of Adama (Source: Author)

4.2.4 Elevation

The elevation data for the research area shows a high of 2,302 and a low of 1,338, which is extremely useful for assessing flood risk. Lower elevations are more susceptible to flooding because they have a shorter vertical distance to the probable flood level. This data can be used to influence land use planning, infrastructure placement, hydrological modeling, and ecosystem management to identify flood-prone locations and design appropriate mitigation techniques, ultimately increasing the studied area's overall resilience to flooding occurrences.

Table 18 Elevation data

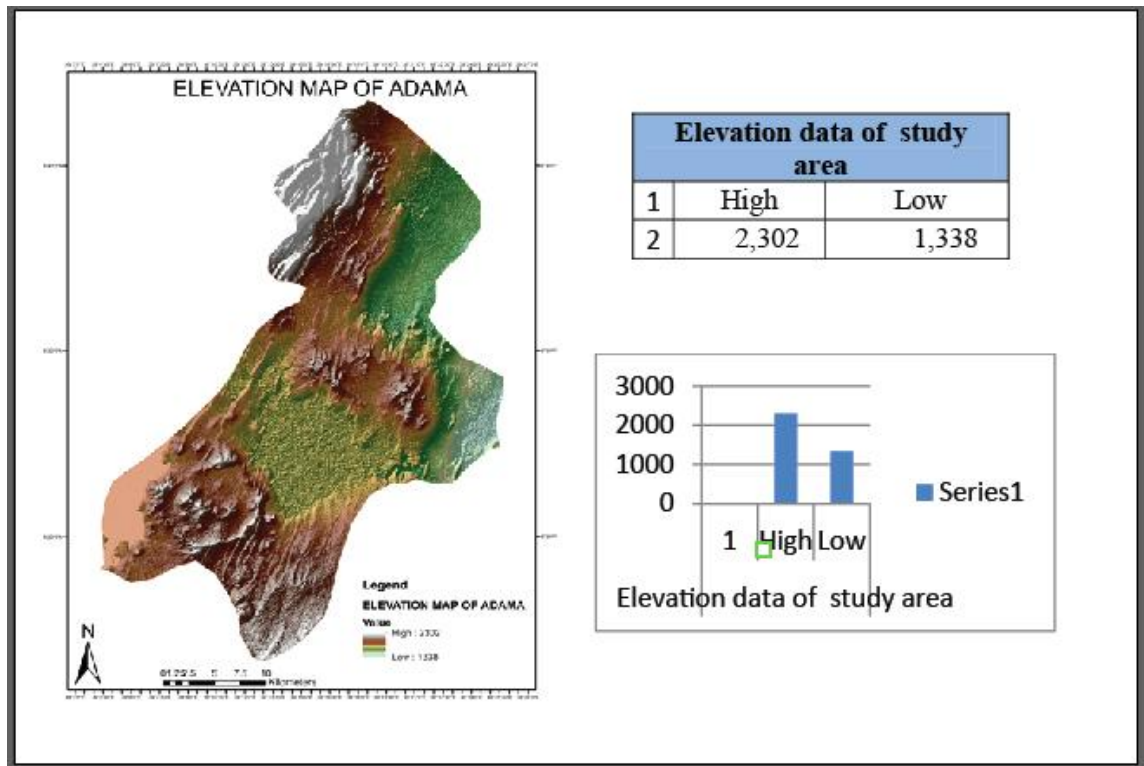


Figure 13 Elevation map (Source: Author)

4.2.5 Rainfall

The rainfall data is divided into 6 ranges, from 1100-1,120 to 1,220-1,230 mm, indicating high and spatially variable precipitation in the study area. The increasing range of values suggests a distribution of wetter and drier zones, offering valuable input for water management, agriculture, ecosystems, and hydrological applications within the region.

Table 19 Rainfall data

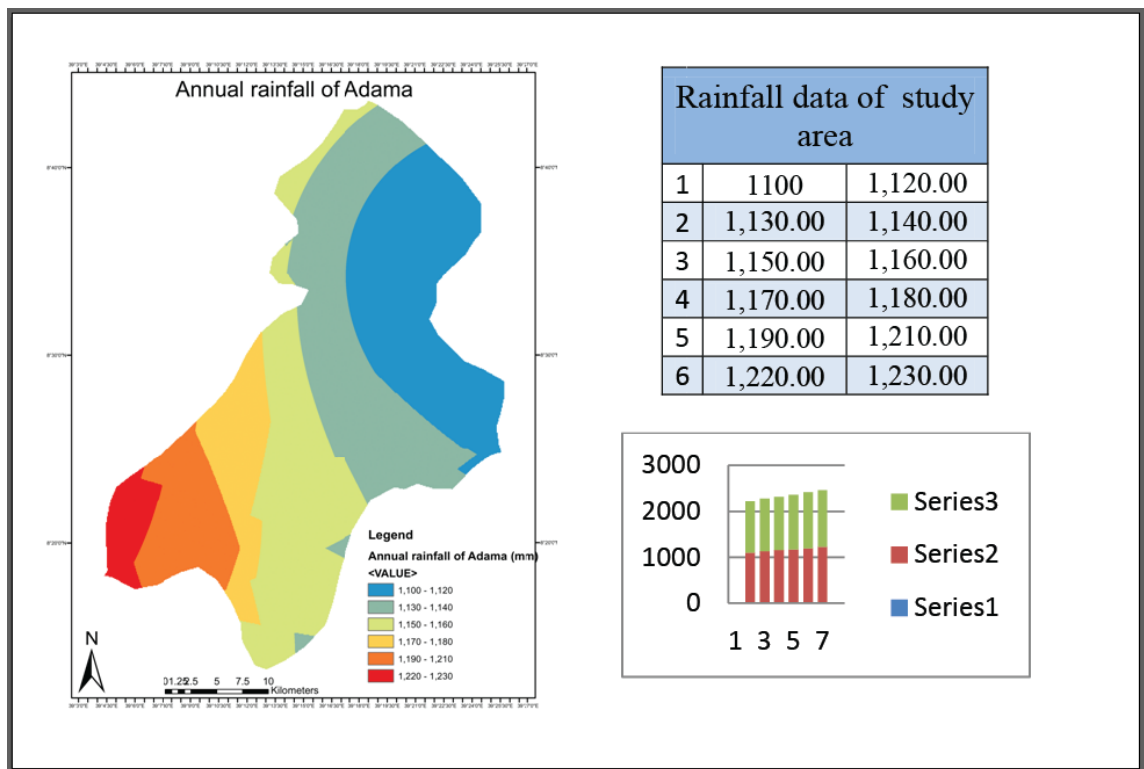


Figure 14 Annual rainfall map (Source: Author)

4.2.6 Distance to River

The data displays Euclidean distances from the river in five ranges, from 0-5,550 to 22,300-27,700 meters. This denotes locations of different proximity to the river, with lower ranges being closer and maybe having better access to water resources and river line transit, whilst higher ranges are more remote. This spatial data can help with land use planning, water management, and other applications that depend on understanding landscape-water interactions.

Table 20. Distance to River

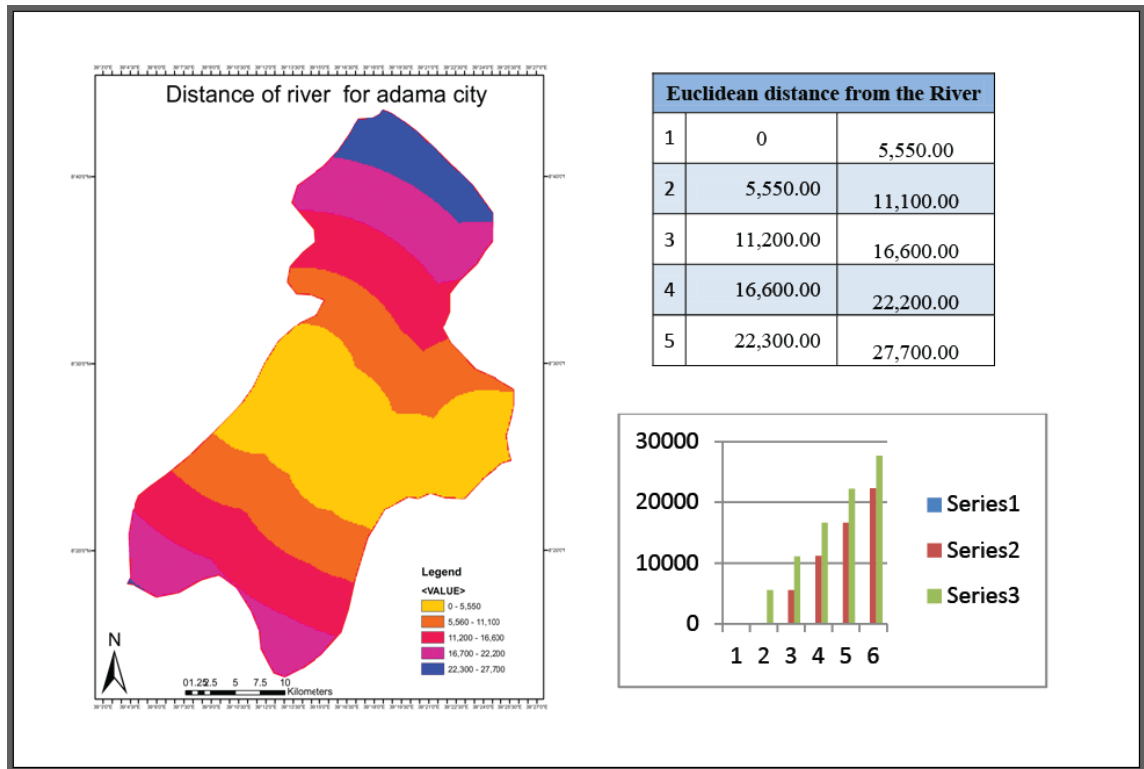


Figure 15 Distance to the river map of Adama (Source: Author)

4.2.7 Distance to Road

The statistics represent Euclidean distances from the road in five ranges, from 0 to 6420 meters. This gives information about landscape accessibility, with smaller ranges indicating areas closer to the road and potentially better linked, and greater ranges representing more isolated locales. This data can help with transportation planning, land use optimization, and other applications that rely on spatial linkages between infrastructure and the environment.

Table 21 Distance to Road

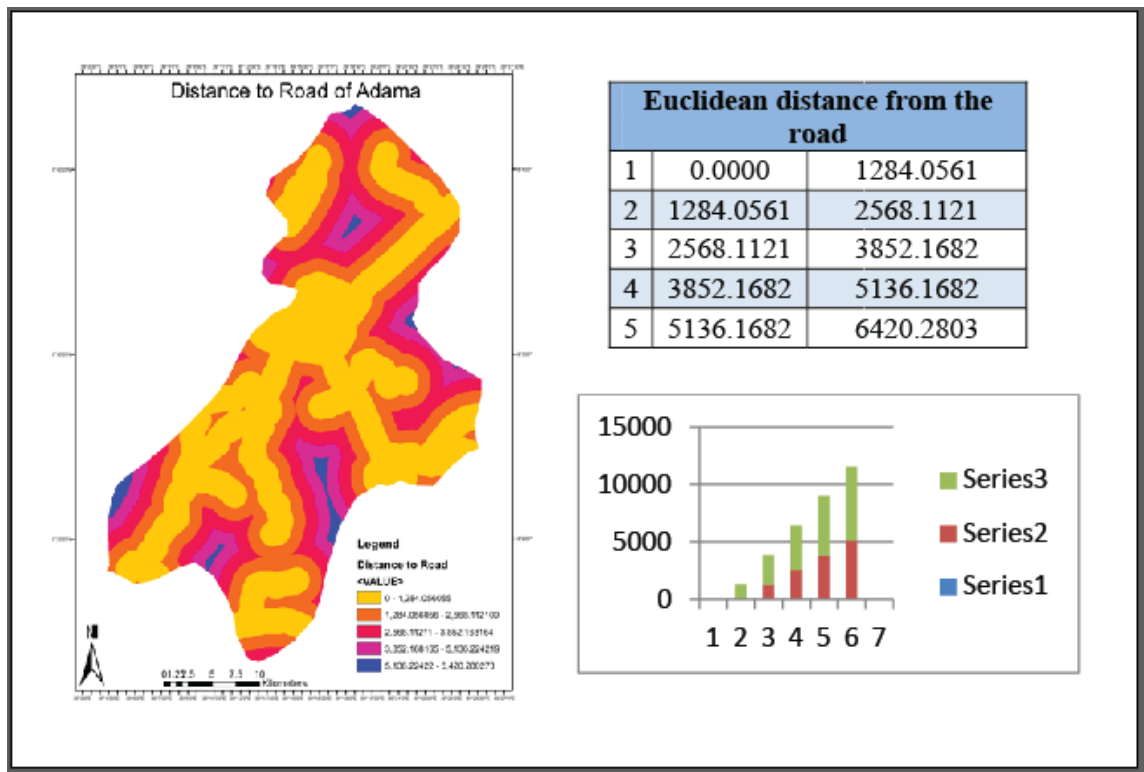


Figure 16 Distance to the road map (Source: Author)

4.2.8 Land Use/Land Cover

Land use/land cover is an important factor in flood risk assessment as it determines the permeability of the surface and the capacity of the land to absorb rainfall. The presence of 73.19% bare soil in the study area, including small towns like Wonji, indicates limited vegetation cover. This lack of vegetation increases surface runoff during heavy rainfall, raising the risk of flooding. Bare soils have poor water absorption and retention abilities, causing rainwater to run off quickly and overwhelm drainage systems. Additionally, without vegetation, the soil is prone to erosion, leading to sedimentation in water bodies and further increasing flood risk downstream.

Table 22 Land Use/Land Cover

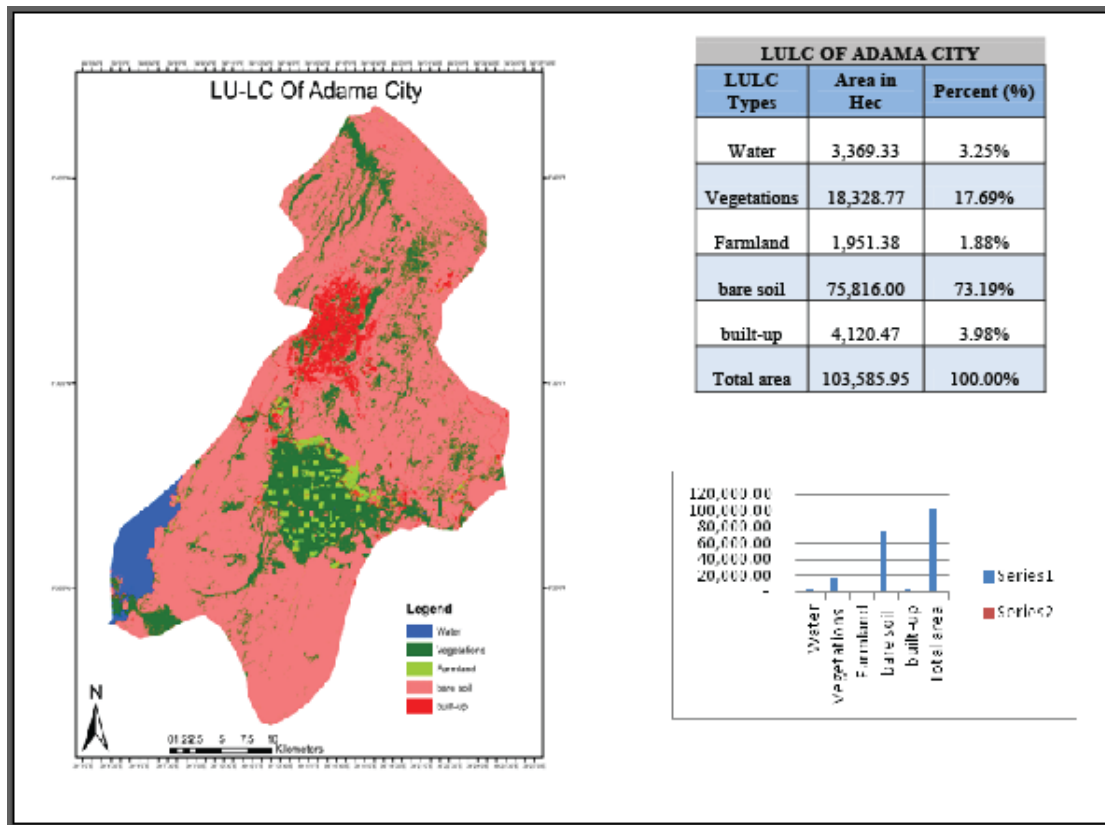


Figure 17 Land use the land cover of Adama city map (Source: Author)

4.2.9 Drainage Density

The drainage density map depicts the differences in concentration between natural and artificial drainage channels. The lowest range (0-0.006626353 km/km²) suggests flat, poorly drained landscapes or locations with very permeable soils. The medium range (0.006626353 - 0.01987906 km/km²) indicates a moderately established drainage network, while the upper ranges (0.01987906 - 0.033131767 km/km²) indicate places with a more dense and well-integrated drainage system, maybe in hilly or mountainous terrain. Understanding the spatial distribution of these values provides insights into the hydrology and landscape. This has consequences for water management, flood risk, and infrastructure planning.

Table 23 Drainage Density data

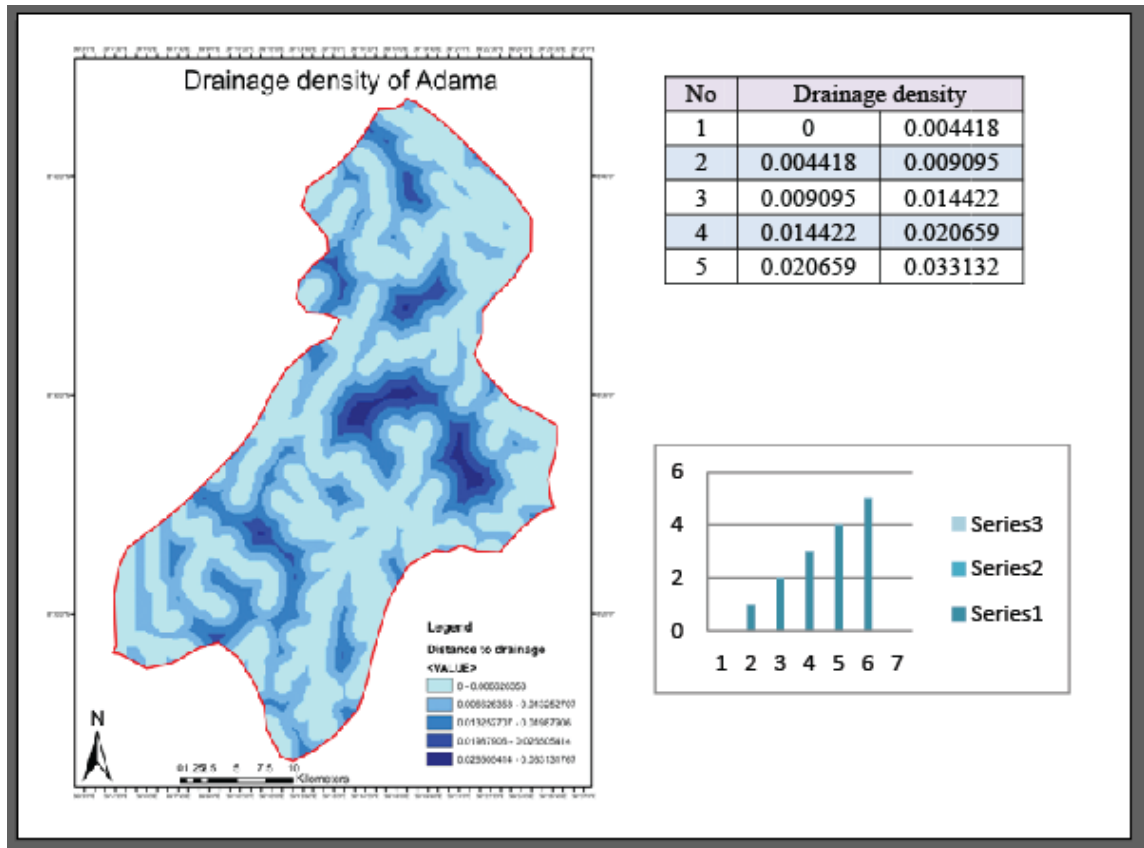


Figure 18 Drainage Density map (Source: Author)

4.2.10 NDVI (Normalized difference vegetation index)

The offered NDVI value ranges can be used to categorize land cover. Lower NDVI values from -0.178 to 0.017 represent non-vegetated areas like water bodies or bare soil, while -0.0171 to 0.157 corresponds to sparse or low-density vegetation such as grasslands and shrubs. NDVI values from 0.157 to 0.219 indicate moderate vegetation, 0.219 to 0.303 signify healthy, dense vegetation like mature forests, and the highest NDVI from 0.303 to 0.507 corresponds to the most vigorous and productive vegetation. Mapping the spatial distribution of these NDVI-derived land cover classes provides insights into a landscape's biophysical characteristics and supports informed natural resource management decisions.

Table 24 Normalized difference vegetation index

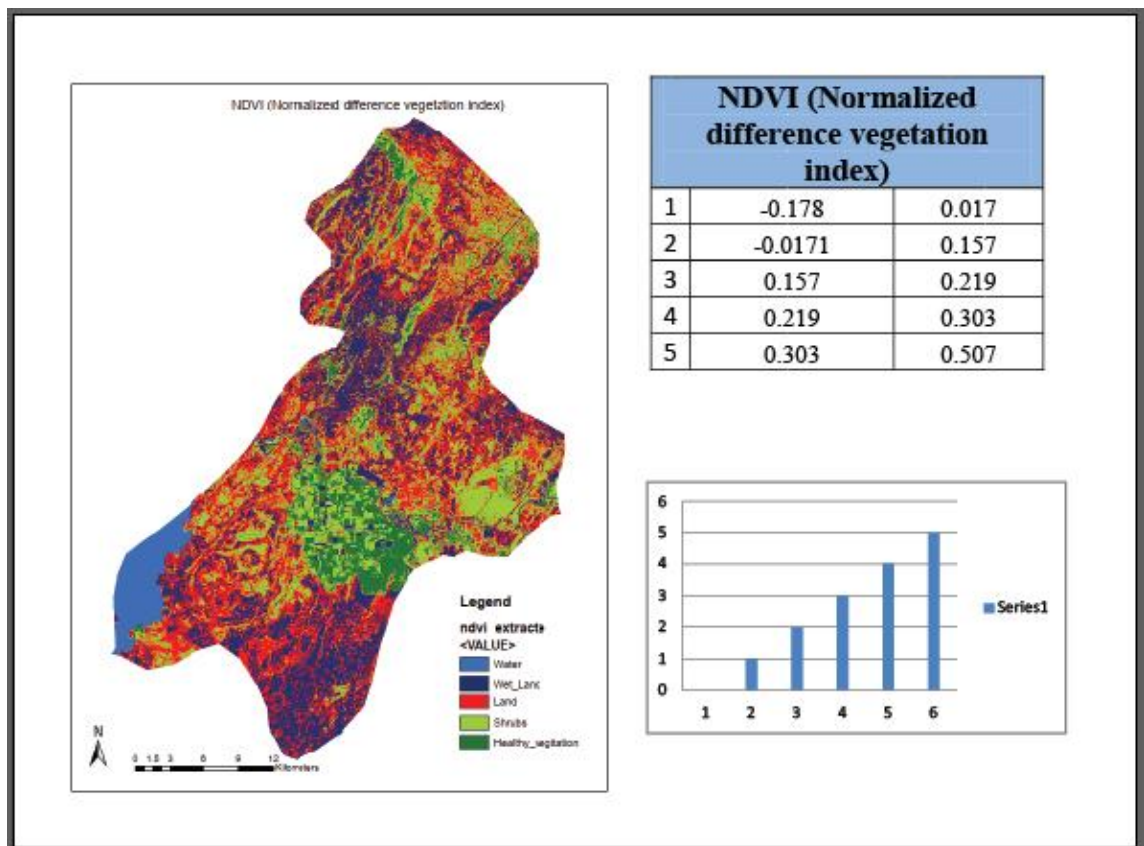


Figure 19 NDVI (Normalized difference vegetation index) (Source: Author)

4.2.11 Soil type and characteristics

Soil is one of the factors that influence water infiltration. The presence of sandy clay loam and clay, which account for more than 92% of soil composition, raises flood risk due to decreased infiltration, increased surface runoff, erosion potential, and drainage issues.

Table 25 Soil type and characteristics

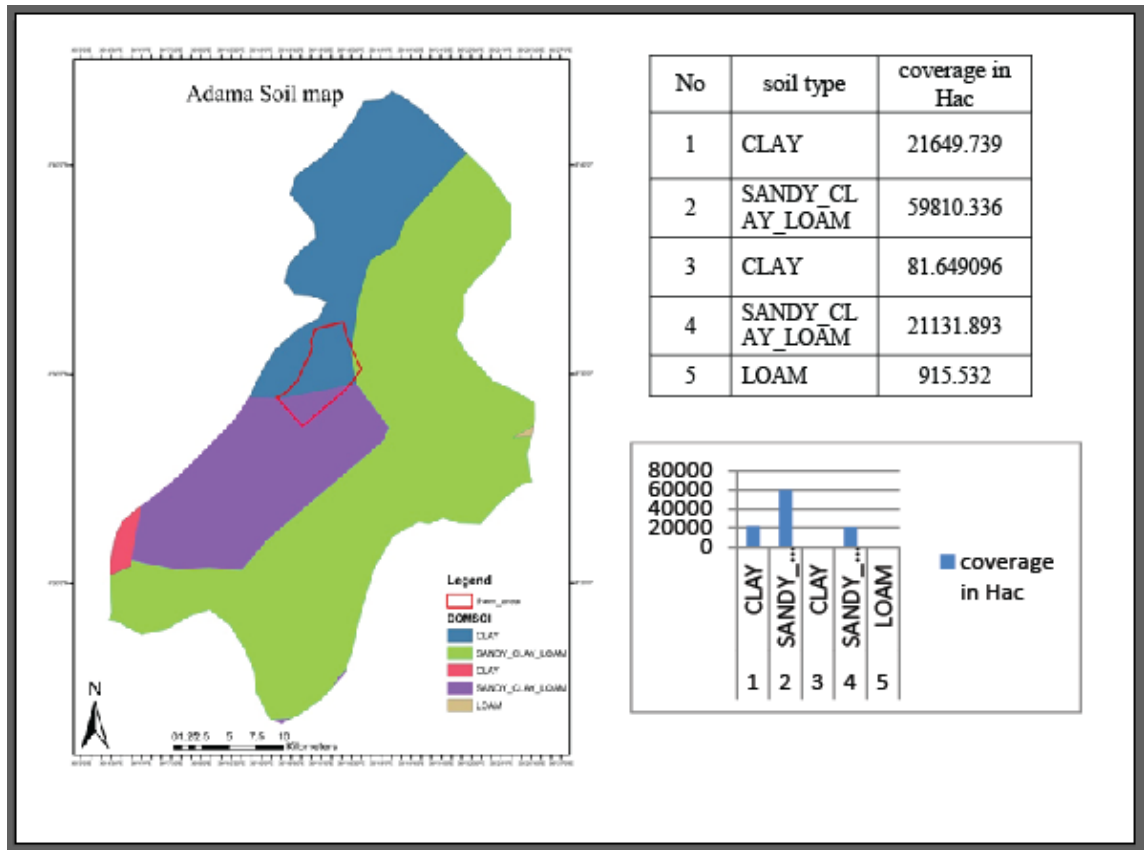


Figure 20 Soil type and characteristics (Source: Author)

LUVISOLS: These soils have a subsurface accumulation of high-activity clays and are classed as Hydrologic Group D, suggesting a high risk of runoff and low infiltration rates.

NITOSOLS: These deep, dark red, brown, or yellow clayey and sandy soils have a distinctive glossy, nut-shaped structure and are classified as Hydrologic Group C, indicating a moderate infiltration rate and runoff potential.

CAMBISOLS: These weakly to moderately developed soils are classified as

Hydrologic Group A, which indicates a high infiltration rate and limited runoff potential.

VERTISOLS: These dark-colored cracking and swelling clays, like the LUVISOLS, are classified as Hydrologic Group D due to their high propensity for runoff and poor infiltration rates.

The distribution and characteristics of the soil types within the thematic area have significant implications for various land use and management decisions, such as:

Stormwater Management: The predominance of soils with high runoff potential (Hydrologic Groups C and D) suggests the need for enhanced stormwater management strategies, including the implementation of retention/detention facilities, permeable surfaces, and green infrastructure to mitigate the risk of flooding and promote groundwater recharge.

Agricultural Suitability: The soil types and their hydrologic properties can influence the suitability of the land for different agricultural practices, requiring specific management techniques to optimize crop yields and soil health.

Constructability: The soil characteristics, particularly the presence of expansive clays (VERTISOLS), may pose challenges for building foundations and infrastructure, necessitating specialized design and construction methods to ensure stability and durability.

4.2.12 Flood Risk Assessment and Mapping in the City

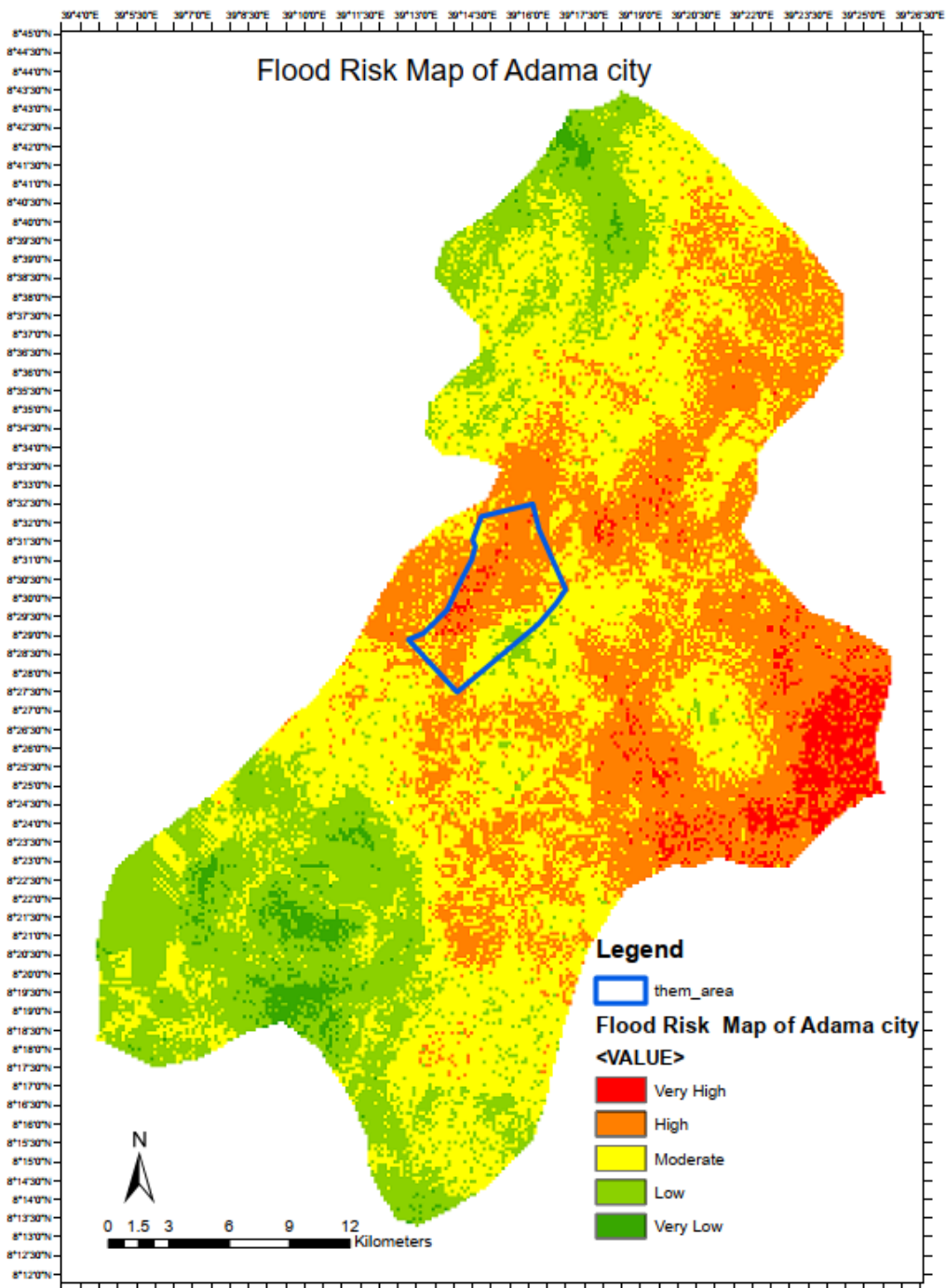


Figure 21 Flood risk map Adama City (Source: Author)

Table 26 Flood Risk coverage area in Adama City

Flood Risk Assessment and Mapping				
No	Risk Type	Risk Rank	coverage in Hac	coverage in %
1	Very High	5	10,379.53	10%
2	High	4	31,857.95	31%
3	Moderate	3	28,261.09	28%
4	Low	2	22,917.17	22%
5	Very Low	1	9,351.85	9%
Total			102,767.59	100%

The flood risk assessment and mapping undertaken in the research region classified flood risks into different risk levels depending on their potential impact. The findings revealed that the core and surrounding regions of Adama City suffer a very high flood hazard risk, accounting for approximately 10% of the total assessed area. The assessment revealed five risk types: very high, high, moderate, low, and very low, with covering areas of 10,379.53 hectares (10%), 31,857.95 hectares (31%), 28,261.09 hectares (28%), 22,917.17 hectares (22%), and 9,351.85 hectares (9%), respectively.

The flood risk map used a color-coded scheme to graphically illustrate these levels, with very low places shown in light green, low in yellow, moderate in brown, high in red, and extremely high in dark red. The huge concentration of very high and high-risk areas emphasizes the critical need for focused flood management solutions. As a result, implementing adequate drainage systems and flood control structures, increasing community awareness programs, and incorporating flood risk assessments into urban planning are critical steps toward reducing vulnerability and improving community resilience to floods in Adama City.

4.2.13 Flood Risk Assessment The variability in sub-city level

Table 27 The data The statistics revealed that the flood level in the sub-city of Adama City

Flood hazard map of Adama City 0n sub-city scale with their population						
Sub City	Very Low (Ha)	Low (Ha)	Moderate (Ha)	High (Ha)	Very High (Ha)	Total Population
Aba_Gadaa	0	388.061	234.188	188.032	2.956	52,706
Luugoo	0	155.868	815.97	536.261	0.05	59,636
Dambalaa	0	39.98	2,991.31	7,415.69	6,463.58	67,743
Bokku_shanan	26.847	791.957	5,489.83	8,562.95	2,658.04	57,999
Bole	898.337	3,868.11	1,903.58	234.784	2.47	75,839
Dabi_soloqe	507.038	4,197.35	2,886.07	138.301	0	57,518

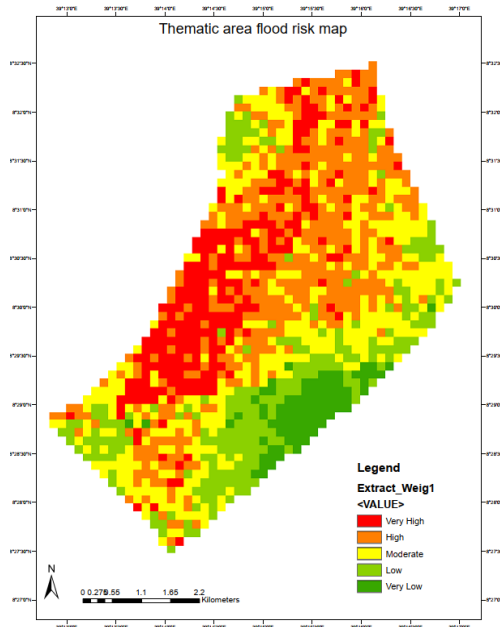


Table 28 Thematic area risk

Flood Risk map Thematic area				
No	Risk Type	Risk Rank	coverage in Hac	coverage in %
1	Very High	5	725.9028	21%
2	High	4	1,590.07	46%
3	Moderate	3	725.9028	21%
4	Low	2	207.4008	6%
6	Very Low	1	207.4008	6%
Total			3,456.68	100%

Figure 22 Thematic area risk Map (Source: Author)

The flood risk mapping for Adama City's thematic region categorizes flood threats into five risk levels. Key flood-prone areas identified include Tikur Abay and 09 Kebele in the general Irrcha Kebele (11.1% each) and the Migira Area (5.6%). Very high-risk zones cover 725.90 hectares (21%), high-risk areas span 1,590.07 hectares (46%), and moderate-risk zones also encompass 725.90 hectares (21%). Low and very low-risk areas each account for 207.40 hectares (6%). This assessment reveals that about 10% of the total area faces significant very high flood hazard risk, with total flood risk coverage at 3,456.68 hectares, highlighting the urgent need for targeted flood management strategies.

4.3. Inundation modeling areas thematic area

The purpose of mapping flood inundation zones for Irrcha Kebele (09 Kebele) using ArcGIS water surface elevation (WSE) was to visualize the potential social, economic, and environmental consequences of flooding. Cross-referencing model results with existing assessments enhance confidence in the predicted flood extents and impacts.

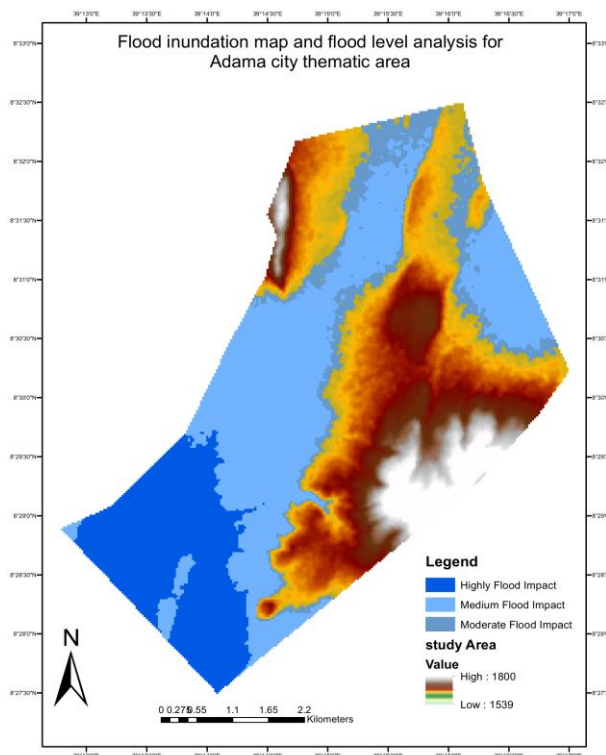


Table 29 Flood Inundation Level

Flood inundation areas thematic area (Irrecha (09))		
No	Flood effect (impact level)	Coverage area in Hec
1	Highly Flood Impact	560.355612
2	Medium Flood Impact	1563.171732
3	Moderate Flood Impact	1824.825909

Figure 23 Flood inundation map (Source: Author)

The analysis attempted to assess risks, prepare evacuation routes, safeguard infrastructure, and limit environmental damage by correctly mapping flood-prone areas, allowing for more informed decisions to reduce flooding's negative consequences on the community. The flood inundation areas were divided into three impact levels: High Flood Impact (560.36 hectares) with severe flooding and significant consequences, Medium Flood Impact (1563.17 hectares) with moderate flooding and moderate impacts, and Moderate Flood Impact (1824.83 hectares) with relatively lower flooding and limited effects.

4.3.1 Flood plain level analysis (Impact level assessment around residence)

Irrecha (09 Kebele) in Adama City's Dembla sub-city confronts substantial flood threats that threaten people's lives and livelihoods. Using ArcGIS to map flood inundation zones attempts to emphasize the social, economic, and environmental consequences of flooding. This research will identify flood-prone locations, assess risks, plan evacuation routes, and preserve infrastructure, allowing local governments and the community to make informed decisions about flood mitigation.

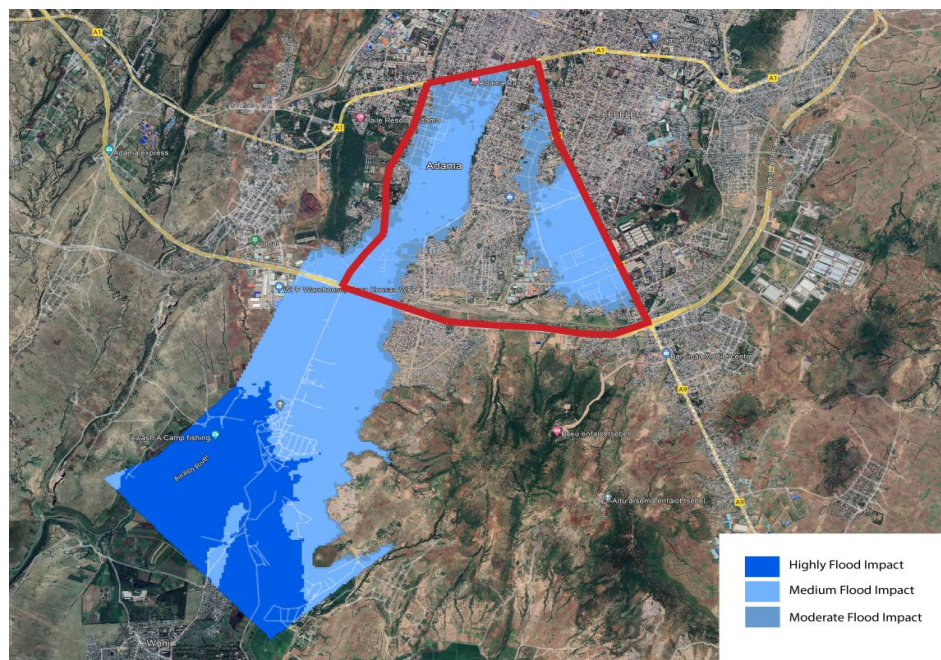


Figure 24 Flood plain level analysis (Impact level assessment around residence) using Google Earth (Source: Author)

4.3.2 Impact level analysis

The region is approximately 370.34 square kilometers and contains a combination of unoccupied land (open space) and diverse built-up complexes. The built-up areas include residential neighborhoods, commercial sections with small markets and stores, workshops, other service providers, small industries, religious groups, schools, and a variety of other structures and facilities. This diversified mix of land use and development has a significant impact on the overall environment and use of the 370.34 square kilometer area.

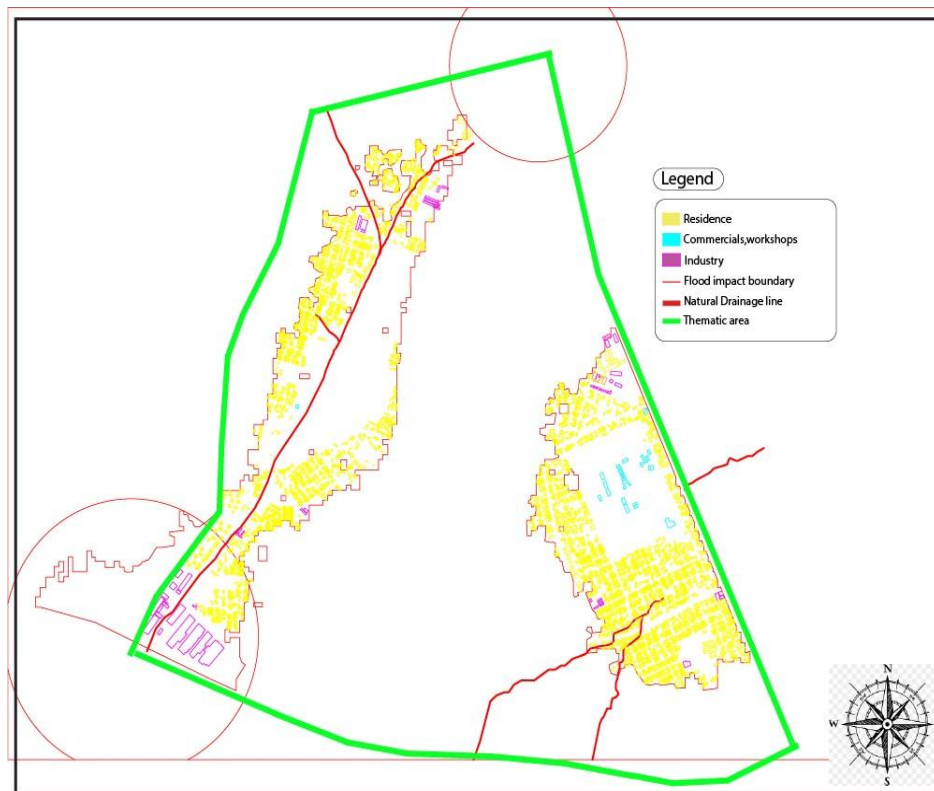


Figure 25 Impact level analysis auto cad (Source: Author)

Table 30 Flood impact on land use level of the thematic area

Flood impact coverage on the thematic area			
No	Building Types	Amount	Coverage in %
1	Residential	1394	94%
2	commercial	67	5%
3	small industries and stores	28	2%
Total built up area		1489	100%

Based on the captured or extracted flood risk zone in the thematic region of flood impact coverage, residential buildings account for 1,394 structures (94% of the total), commercial buildings for 67 (5%), and small industries and stores for 28 (2%). There are 1,489 buildings in all, illustrating residential properties' severe vulnerability to flooding.

Before presenting the findings, the accompanying map displays the hotspots designated for interviews, demonstrating the area's most affected by flooding. This spatial context improves comprehension of the community's concerns, laying the groundwork for the insights gleaned from citizens and local stakeholders. This data highlights the vital need for adequate flood management techniques in these areas.

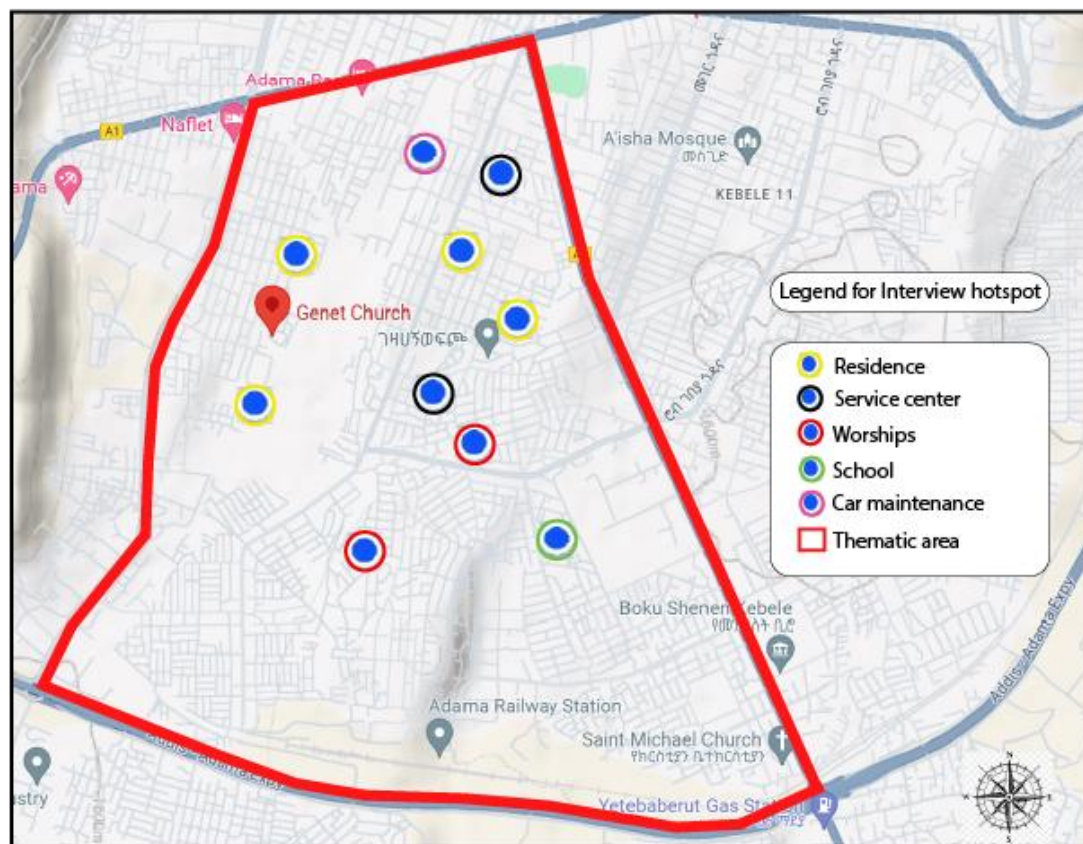


Figure 26 Interview hot spot using GPS (Source: Author)

The findings from the questionnaire and interviews highlight the significant impact of floods on the community in Adama City. Property damage is the most pressing issue, affecting 42.9% of respondents, along with damage to home structures and health problems, each cited by 14.3%. Other consequences include displacement, utility interruptions, and emotional distress. Daily life is also disrupted, with impacts on economic stability, transportation, and routines.

Interviews conducted with long-term residents provided valuable insights into the community's experiences with flooding. Residents reported an average of two deaths per year and severe damage to property and educational documents. This constant threat of flooding has led to significant psychological stress, with repair costs ranging from 50,000 to 550,000 birr.

A school manager noted challenges like vulnerability to flooding, loss of educational records, and operational disruptions. A workshop owner pointed out that while some businesses have implemented drainage systems, many remain closed due to inadequate planning. A service provider mentioned temporary closures of mini-markets resulting in financial losses, underscoring the need for proactive flood risk management. Lastly, a garage owner reported poor sanitation conditions and financial losses in spare parts. Collectively, these insights emphasize the urgent need for improved flood management strategies and infrastructure to enhance community resilience in Adama City.

4.4. Background of the Respondents

4.4.1. Gender Composition

The demographic characteristics of the respondents are essential for interpreting the study's findings. Key insights include gender composition, age distribution, educational background, and household characteristics. Notably, the gender composition impacts participation and decision-making, with a prevalence of female-headed households influencing community engagement, resource management, and livelihood choices.

Table 31 Gender distribution

Gender	Percentage (%)	Frequency
Male	27.80%	107
Female	72.20%	278

4.4.2 Age of the household

The age distribution of the 385 respondents indicates a primarily young population, with 88.90% aged 25-34 years. Only 5.50% were between the ages of 18 and 24, and 5.60% were between the ages of 35 and 44, with no participants under 18 or over the age of 54. This young demography provides a significant opportunity to engage younger community members in talks about urbanization and flood risk management.

Table 32 Age Distribution

Age Group	Percentage (%)	Frequency
Under 18 years	0.00%	0
18-24 years	5.50%	21
25-34 years	88.90%	342
35-44 years	5.60%	22

4.4.3. Educational Background

The respondents' educational backgrounds show a high level of intellectual performance, with the majority having completed their first degree before pursuing a second degree. Furthermore, ladies completed the questionnaire at a higher rate than males, indicating that they were actively engaged in the study. This good educational background means that the respondents' insights will be knowledgeable and relevant, particularly in terms of community issues and flood risk management.

Table 33 Educational Qualifications

Education Level	Percentage (%)	Frequency
Basic	0 %	0
Primary School	5.6 %	22
Secondary School	5.5 %	21
First Degree	66.7 %	256
Secondary Degree	22.2 %	85
Doctorate and Above	0 %	0

4.4.4 Family Size of the Respondent

The results from the 385 respondents show that a significant 66.70% have five or more family members, indicating higher household sizes. Furthermore, 11.10% have two family members, with smaller amounts of three (5.50%) or four members (16.70%). This trend towards larger families has the potential to alter resource allocation and community dynamics in the research area.

Table 34 Number of Family Members

Number of Family Members	Percentage (%)	Frequency
1	0 %	0
2	11.1 %	43
3	5.5 %	21
4	16.7 %	64
5 and above	66.7 %	256

4.4.5. Duration of Residency

Regarding the duration of residency in Adama, 33.0% of respondents have lived in the area for 11-20 years, with 28.0% having resided there for more than 20 years. Additionally, 22.0% have lived in Adama for 1-5 years, while 17.0% have been there for 6-10 years. Notably, there are no respondents who have lived in Adama for less than a year, highlighting a stable community with long-term residents.

Table 35 Duration of Living in the Study Area

Duration	Percentage (%)	Frequency
Under 1 year	0 %	0
1-5 years	22 %	85
6-10 years	17 %	65
11-20 years	33 %	127
More than 20 years	28 %	108

4.4.6. Employment situation

The current employment situation of Adama City residents is critical to assessing economic stability and sensitivity to flood damage. This part categorizes respondents as employed, jobless, students, retired, or others, which aids in identifying populations that may require specific assistance during flood disasters.

Table 36 Socio-Economic Data Analysis

Employment Status	Percentage (%)	Frequency
Employed	7 %	27
Unemployed	25 %	96
Student	60 %	231
Retired	7 %	27
Other	1 %	4

4.4.7. Source of Income

Understanding the primary source of income for households in Adama City is essential for assessing economic resilience and vulnerability to flooding. This section categorizes respondents based on their main income sources—such as salary, self-employment, agriculture, business, or others—providing insights into the financial stability of the community and identifying those most at risk during flood events.

Table 37 Source of Income

Employment Status	Percentage (%)	Frequency
Salary/Wages	73 %	281
Unemployed	15 %	58
Student	0 %	0
Retired	10 %	39
Other	2 %	8

4.4.8. Monthly Household Income

Assessing Adama City residents' average monthly household income is critical for assessing their economic stability and flood resistance. This data exposes families' financial resources, which have a direct impact on their ability to recover from flood damage. By categorizing income levels, we may identify vulnerable groups who may require targeted assistance and resources to improve their resilience in the face of flood hazards.

Table 38 Monthly Household Income

Employment Status	Percentage (%)	Frequency
Less than 1,000 ETB	24 %	93
1,000 - 5,000 ETB	35.7 %	138
5,001 - 10,000 ETB	39.7 %	153
More than 10,000 ETB	36.6 %	141

4.5. Filed Observation

Flooding is a serious hazard to communities, especially in urban places like Adama City, where excessive rains and insufficient drainage systems compound the problem. This field study seeks to investigate the multiple effects of floods on the theme region, with an emphasis on residential neighborhoods, schools, businesses, and critical services. By investigating citizens' lived experiences as well as insights from local stakeholders, the project hopes to provide a comprehensive knowledge of how flooding affects daily living, economic stability, and community resilience.

The study emphasizes the urgent need for comprehensive flood management techniques, as the consequences of floods are far-reaching. They include not only physical damage to infrastructure and property but also emotional and psychological burdens on residents. The project intends to capture the intricacies of flood consequences through qualitative interviews and quantitative data collecting, as well as identify vulnerable populations and investigate potential mitigating methods. Finally, this study aims to inform local decision-makers and contribute to the creation of long-term strategies to improve community resilience to flooding disasters.

Natural drainage



Figure 27 Natural drainage of the thematic area (Source: Author)

Impact on Residences and Other Critical Facilities

The uncontrolled flow of water through built-up areas can have significant impacts on residences, roads, and external fences. Erosion and soil destabilization can damage the foundations and structural integrity of residential buildings, while flooding and overflow can lead to water damage and potential collapse. Roads are also affected, with deterioration of the surface and structure due to erosion and water damage, as well as disruption to mobility and access during flooding events. The key impact on external fences is structural damage and potential collapse due to erosion and soil destabilization, as well as displacement or destruction from flooding and overflow. Additionally, the encroachment of the drainage system into residential areas reduces the space available for residents to construct and maintain secure perimeters around their properties, compromising the security and privacy of their homes and leaving them vulnerable to the negative effects of uncontrolled water flow and drainage system issues.

Impact on structure



Figure 28 Impact on structure and residences 01 (Source: Author)

Impact on structure



Impact on structure



Figure 29 Impact on structure and residences 02 (Source: Author)

The socio-economic and environmental impact assessment reveals the profound effects of flooding on communities, particularly in urban areas like Adama City. The findings indicate that flooding not only results in significant property damage and infrastructure loss but also has serious implications for residents' health, emotional well-being, and economic stability.

Socially, the recurrent nature of floods exacerbates vulnerabilities, leading to displacement and the destruction of educational opportunities, which can hinder long-term community development. Economically, businesses face disruptions that affect livelihoods, while households incur substantial repair costs, straining financial resources.

Environmentally, flooding leads to the degradation of local ecosystems, contamination of water sources, and challenges in waste management, which further impact public health. These findings underscore the necessity for a comprehensive approach to flood management that incorporates socio-economic factors and environmental considerations.

In conclusion, effective flood risk management strategies must prioritize community resilience, integrate sustainable practices, and involve local stakeholders in decision-making processes. By addressing both the immediate and long-term impacts of flooding, communities can better prepare for future challenges and foster a more sustainable and resilient environment.

4.6 Discussions

The results of the flood risk assessment and mapping in Adama City provide insights into the nature and scope of flood risks particularly in Kebele 09. This discussion evaluates the findings, compares them to previous research, and considers the consequences of flood management techniques.

4.6.1 Interpretation of Findings

The findings of Adama City's flood risk mapping and assessment provide important new information on how vulnerable and resilient the city is to flooding. A significant chunk of the city is highly vulnerable to flooding and requires prompt attention; roughly 10% of the region is categorized as having a very high flood hazard risk, and 31% confronts high danger. Five risk categories were identified by the assessment: very high, high, moderate, low, and very low. This indicates that, although some locations are reasonably safe, the majority are in danger, highlighting the necessity of specialized flood management techniques.

The concentration of high-risk zones is expected to have detrimental effects on locals, such as economic instability, health problems, and property damage, underscoring the urgent need for actions that address both short- and long-term effects. Flooding causes financial hardship for households by upsetting local businesses and livelihoods, showing how closely good flood control affects the community's ability to maintain its economic stability. Significant infrastructure improvements are needed in places like Dambalaa which is the sub-city of irrcha (09) kebele, including drainage systems and flood control structures, which are essential for reducing the effects of floods in densely populated areas. The results also support the inclusion of flood risk assessments in urban planning procedures to make sure that these risks are taken into consideration for future projects and to improve community resilience.

Moreover, the insights from interviews and questionnaires highlight the strong need for community engagement in flood risk management, as resident's experiences can inform planning and decision-making. Increasing community awareness about flood risks and preparedness is vital for empowering residents and enhancing resilience, with

educational programs playing a crucial role in equipping the community to respond effectively. The predominance of young residents (88.9% aged 25-34) presents an opportunity to engage this demographic in discussions about urbanization and flood risk management, driving innovative solutions. Additionally, the gender composition of respondents, with a higher percentage of females, suggests that women may play a critical role in community engagement and decision-making related to flood management.

In conclusion, the interpretation of these findings underscores the urgent need for comprehensive flood management strategies in Adama City. The city may increase its resistance to floods by addressing the vulnerabilities that have been found, improving infrastructure, including the community, and incorporating flood risk factors into urban design. Protecting the welfare of locals and promoting sustainable development in the area depend on these initiatives.

4.6.2 Comparison with Existing Literature

The flood risk assessment findings in Adama City's Irrcha Kebele align with existing literature on urban flood vulnerabilities and management. Studies indicate that climate change, inadequate infrastructure, and rapid urbanization increase flood frequency and severity, as seen in Irrcha and Dembalaa. The categorization of flood hazards into five levels mirrors frameworks used in other studies, affirming the evaluation method's validity.

Research highlights the impact of floods on community health and economic stability, particularly in disadvantaged areas, echoing the experiences of Irrcha residents. The importance of community knowledge and engagement in flood management is supported by Garcia and Torres (2017), emphasizing the need for raising awareness.

Additionally, the youthful demographic in Irrcha suggests potential for engaging younger generations in disaster preparedness, as noted by Nguyen et al. (2022). Overall, the assessment underscores the necessity for tailored flood management strategies, community involvement, and infrastructure improvements to enhance resilience in urban settings.

4.6.3 Implications for Flood Management

The results of the Irrcha (09) Kebele flood risk assessment have important Implications for efficient flood control. Immediate expenditures in infrastructure upgrades are necessary to safeguard vulnerable populations, especially in highly populated places like Dembalaa. These investments should focus on drainage systems and flood control structures. Management techniques must be customized to the distinct attributes of individual regions, guaranteeing pertinence and efficacy grounded on local socio-economic milieus.

Involving the community in decision-making and awareness campaigns can improve resilience by informing citizens about flood risks and preparedness. Community engagement is essential. Incorporating flood risk assessments into urban planning is also essential for promoting sustainable development and avoiding risk escalation.

Building local government and citizen capacity will enable stakeholders to effectively address flood-related issues. Ongoing assessments of flood hazards and the efficacy of management techniques will be made possible by the establishment of monitoring and assessment systems. To maximize resources and skills, local governments, non-governmental organizations, and community organizations must work together. In the end, creating financial plans for initiatives and plans is crucial to long-term flood control. By concentrating on these areas, the community can protect the well-being of its citizens and increase its resistance to flooding.

4.6.4 Community Perspectives

For flood risk management to be effective, community views are essential. Because they have firsthand experience, locals might provide insightful information about trends and weaknesses that larger research might miss. Comprehending customs within the community facilitates culturally relevant interventions, and including locals in dialogue increases consciousness and cultivates accountability. Cooperation between the community and authorities guarantees that plans are customized to meet particular requirements. Engaging youngsters can inspire creative solutions in young neighborhoods like Irrcha Kebele. Creating avenues for feedback builds trust and

enables management tactics to be modified. Flood risk management may become more inclusive and successful by giving priority to community involvement, which will improve outcomes for everybody.

4.6.5 Recommendations for Future Research

To improve flood risk management in urban areas like Adama City's Irrcha Kebele, future research should focus on several key areas. Longitudinal studies can monitor changes in flood patterns and community resilience over time, while expanding assessments to include multiple Kebeles will enhance the generalizability of findings. Comprehensive data collection methods, such as remote sensing and community surveys, can improve the reliability of information on past floods and infrastructure conditions. Engaging diverse community groups ensures all demographics are represented in assessments. Additionally, exploring the interactions between socio-economic factors, urban planning, and environmental conditions will lead to more holistic strategies. Investigating resource availability for flood management can identify barriers and opportunities for effective interventions. Finally, promoting innovative, community-driven solutions, especially involving youth engagement, can further strengthen flood risk management practices.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Adama City is significantly vulnerable to seasonal flood hazards, especially during the rainy season. An assessment has identified several key factors contributing to this susceptibility. First, the city's inadequate drainage infrastructure fails to effectively manage heavy rainfall, resulting in water accumulation and flooding. Additionally, unplanned urban development has occurred without sufficient flood protection measures, further increasing the risk. Compounding these issues is the degradation of natural ecosystems caused by soil erosion, which diminishes the land's ability to absorb rainfall and manage runoff.

The magnitude of flood impact on the floodplain and residential sections of the Irrecha (09) Kebele demonstrates how it affects various land uses in the study region, such as residential properties, commercial or workshop spaces, and industrial organizations. According to the map, the flood has harmed about 1,394 homes, 238 commercial/workshop sites, and 202 industries. This condition will continue until the end of the rainy season, and the impact on the affected areas may worsen during rainfall. As a result, this can have serious social, economic, and environmental consequences, ultimately affecting the general quality of life in the region.

The findings paint a mixed picture, with respondents displaying a high level of flood risk knowledge, but large gaps in public preparedness and unhappiness with the government's reaction. The overwhelming sense of inefficient drainage infrastructure, combined with the widely documented effects of floods on families and daily life, highlights the urgent need for enhanced flood control in the city. Uncontrolled The imperviousness and built-up-to-green space (previous) ratio also contribute to significant flood overflow.

However, the poll also emphasizes citizens' autonomous mitigation activities and willingness to try new drainage methods, which might be used to develop more collaborative and comprehensive approaches to flood resilience. Addressing these concerns would necessitate a multifaceted strategy that includes infrastructural upgrades, public education, community empowerment, and improved collaboration between government and communities. As urban areas continue to face the difficulties of rapid growth and climate change, Adama City's experience will become increasingly relevant. The varying levels of satisfaction with the government's response, as well as the low awareness/perceived ineffectiveness of flood warning systems, highlight the need for improved disaster preparedness, public communication, and community engagement.

5.2 General Recommendations:

To address Adama City's flood concerns, a multifaceted approach is required. The first goal should be to improve the city's drainage system. This will entail undertaking a thorough evaluation of the current system, identifying places that require repairs or extension, and investing in the construction of new drainage channels, culverts, and retention basins. Regular maintenance and cleaning of the drainage network will be required to ensure peak performance. Along with infrastructure upgrades, Adama City must encourage sustainable urban planning methods.

This includes changing zoning and land-use restrictions to prevent development in flood-prone areas while encouraging the preservation of natural habitats. Encouraging the use of permeable surfaces and green infrastructure, such as rain gardens and bioswales, can also aid in the reduction of impervious surfaces and increased water absorption. Incorporating flood-resilient design principles into new building and redevelopment projects will strengthen the city's ability to resist future flood events.

Improving disaster readiness and response is another important aspect of the recommended strategy. Adama City should create a thorough flood emergency plan that includes early warning systems, evacuation procedures, and emergency shelters. Improving collaboration among government agencies, emergency services, and local

communities will benefit response and recovery operations. Regular public awareness campaigns and training programs will also inform residents about flood hazards and necessary mitigating measures.

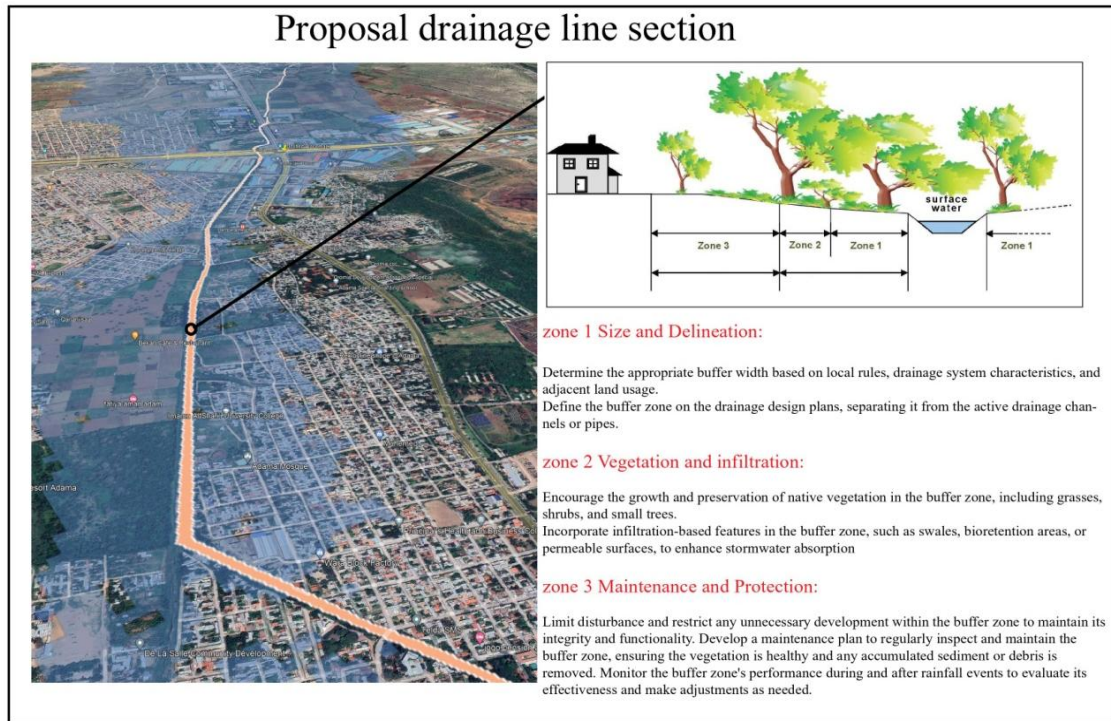
Fostering community engagement and collaboration is critical to the long-term effectiveness of flood management efforts. Regular discussions and feedback systems between the government and local communities will help address citizens' needs and concerns. Empowering individuals to engage in planning and decision-making processes, as well as supporting community-led projects and innovative drainage solutions, can help the city become more resilient.

Improving flood risk assessment and data management is also critical. Investing in advanced data gathering and monitoring tools, creating a comprehensive database, and working with research institutions and specialists will yield useful insights for future planning and decision-making. Integrating climate change adaptation measures, such as investigating natural solutions and encouraging the use of renewable energy and energy-efficient technologies, would also help the city's overall resilience. Adama City may work toward creating a more resilient and sustainable urban environment that is better prepared to handle the difficulties of repeated flood dangers by executing this multifaceted strategy.

5.2.1 Site-specific Recommendations and Designs

A well-designed buffer zone is essential for the comprehensive stormwater management strategy in Irrcha/Kebele 09. The buffer zone acts as a critical transition, slowing runoff, allowing infiltration, and trapping sediment and pollutants to mitigate flooding and improve water quality. It also enhances the local ecosystem. However, the buffer zone may require relocating existing structures, necessitating careful planning and community engagement. It can create valuable green spaces to benefit residents. Thoughtful design and maintenance of the buffer zone are crucial for the drainage system's long-term resilience and sustainability.

a) Proposed drainage line section



Zone 1 size and delineation

Determine buffer width by considering local regulations, drainage system features, and adjacent land use, and define the buffer zone on design plans as a protected area around drainage channels with clear markings for compliance.

Zone 2 vegetation and infiltration

Encourage the growth and preservation of native vegetation in the buffer zone, including grasses, shrubs, and small trees. Incorporate infiltration-based features in the buffer zone, such as swales, bio-retention areas, or permeable surfaces, to enhance stormwater absorption.

Zone 3 maintenance and protection area

Limit disturbance and restrict any unnecessary development within the buffer zone to maintain its integrity and functionality. Develop a maintenance plan to regularly inspect and maintain the buffer zone, ensuring the vegetation is healthy and any accumulated sediment or debris is removed. Monitor the buffer zones performance during and after rainfall events to evaluate its effectiveness and make adjustments as needed.

Figure 30 Proposed drainage line

Before and after the proposal drainage design

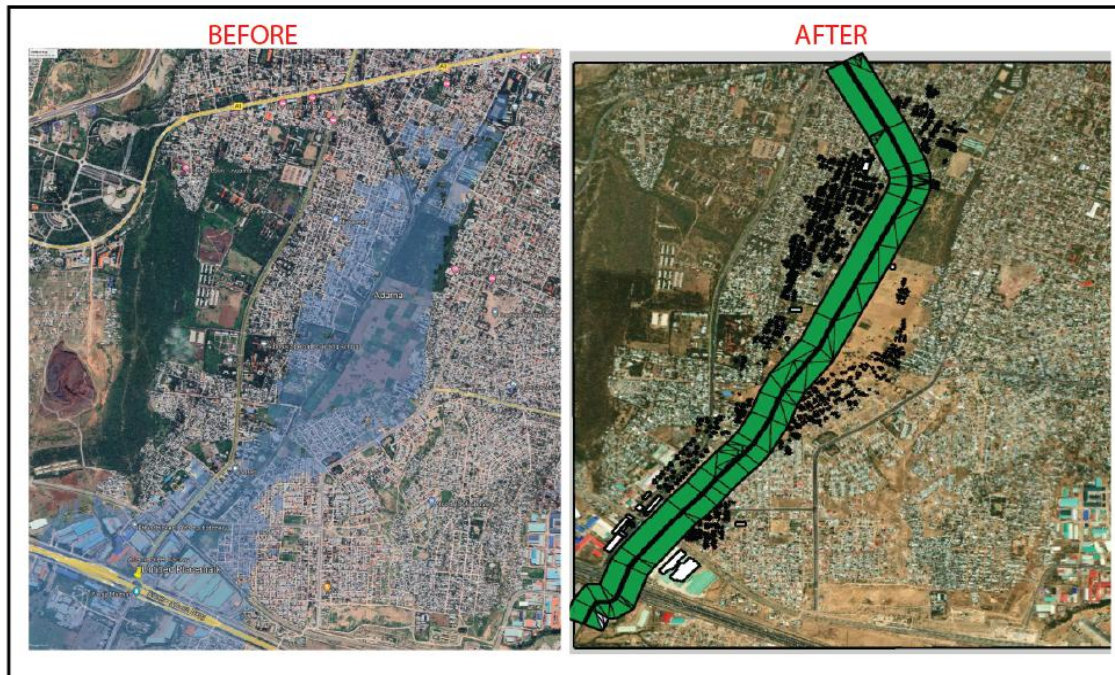


Figure 31 Before and after the drainage layout



Figure 32 Before-after design drainage

b) Proposed solid wastes and other filtering fence



Figure 33 Before and after the design of solid wastes and other filtering fences

Table 39 Before and after the design of solid wastes and other filtering fences

Comparison	Before Drainage Design	After Drainage Design with Buffer Zone
Integration with Land Use	Closely integrated with existing land use patterns and development.	Drainage infrastructure is spatially separated by a well-designed buffer zone.
Transitional Buffer Zone	Limited room for a buffer zone, as channels follows terrain and construction.	The Buffer zone creates a transitional area to slow and filter runoff before drainage.
Stormwater Management	Runoff, sediments, and toxins enter drainage directly, endangering water quality. The system quickly conveys water away.	Buffer zones vegetation and infiltration trap sediments, pollutants, and debris, improving water quality and reducing maintenance.
Ecological Integration	Ignores the need for a buffer zone, missing opportunities for more robust, sustainable infrastructure.	Buffer zones enhance the local ecosystem by providing habitat and supporting biodiversity.
Community Benefits	Limited consideration for visual appeal and recreation.	Buffer zones can serve as green space, increasing appeal and opportunities.
Flood Mitigation	Proximity to built-up areas increases vulnerability and reduces effectiveness.	Spatial separation between drainage and land uses reduces the risk of direct flood impacts.

A comparison of drainage schemes before and after the addition of a buffer zone reveals considerable benefits. Initially, runoff and toxins harmed water quality; however, the updated design slows and filters runoff, improving water quality and supporting local wildlife. This divide creates green spaces for community enjoyment and minimizes flood risk by protecting built-up regions, resulting in more effective and sustainable infrastructure.

c) Proposed Design of the Drainage Components

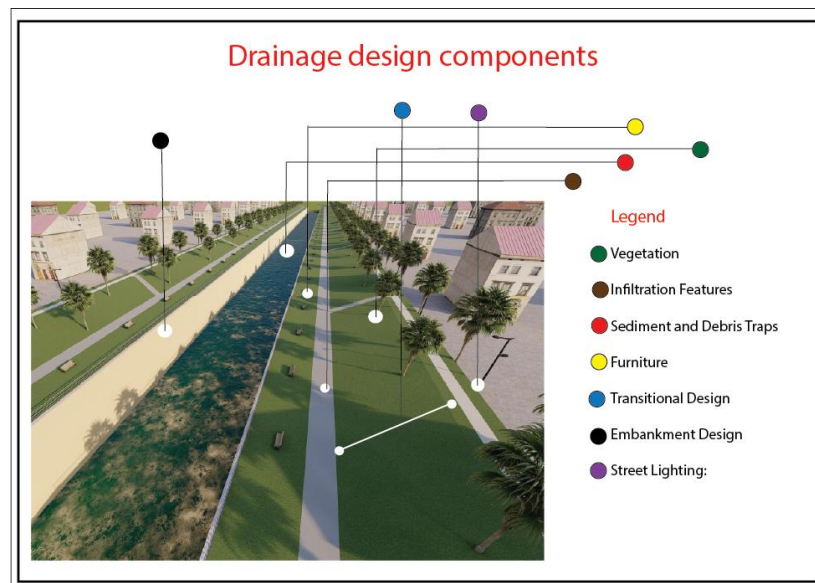


Figure 34 Proposed design of the Drainage components

The 370.34 square kilometer thematic area contains a mix of land uses, including displaced residences and other establishments. There is a condominium development as well as open space within this region. The local government is taking a holistic approach to develop a permanent solution that minimizes the environmental, social, and economic impacts of the displaced land uses. The displaced area includes approximately 96 households and 5 stores, as detailed in the table below. This comprehensive approach aims to address the needs of the displaced while balancing the broader implications on the environment, society, and economy of the 370.34 square kilometer area. The goal is to implement a holistic solution that accounts for the various land use requirements and concerns within this complex landscape.

D. Proposed land use and cover in building level

A comprehensive strategy for stormwater management that takes into account the entire site is required for effective results. We can reduce runoff volume significantly across all land use and land cover types by reducing impermeable surfaces and implementing green infrastructure on an individual basis. Our idea illustrates the effectiveness of this method. The initial runoff was calculated at 10,394 liters, but via the integration of green roofs, permeable pavement, and significant landscaping, we accomplished a 48.19% decrease, reducing the final amount to 5,388.3125 liters.

Sample 1

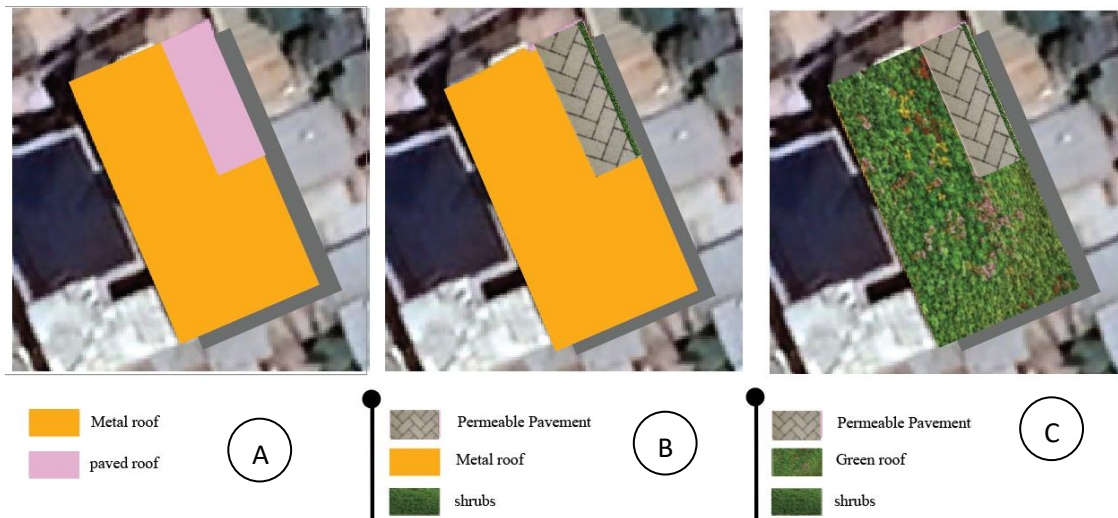


Figure 35 Land use land cover proposal in the sample on a residential area

In Scenario A, the total plot area is 548.95 m², comprising a built-up area of 468 m², a paved area of 80.95 m², and a green area of 0 m². The runoff volume is calculated using the formula:

$$\text{Runoff Volume} = \text{Coefficient} \times \text{Daily Maximum Rainfall Intensity} \times \text{Area}$$
$$\text{Runoff Volume} = \text{Coefficient} \times \text{Daily Maximum Rainfall Intensity} \times \text{Area}$$

For the built-up area, the runoff is calculated as $0.75 \times 25 \text{ mm} \times 468 \text{ m}^2$, resulting in 8,775 liters/day. The paved area contributes $0.80 \times 25 \text{ mm} \times 80.95 \text{ m}^2$, yielding 1,619

liters/day, while the green area produces 0 liters/day due to its ineffective area. Therefore, the total runoff volume for this compound is 10,394 liters/day.

In Scenario B, the total plot area remains 548.95 m², featuring the same built-up area of 468 m², a permeable pavement of 80.95 m², and a green area of 2 m². The runoff calculations show that the built-up area still generates 8,775 liters/day. The permeable pavement contributes $0.35 \times 25 \text{ mm} \times 78.95 \text{ m}^2$, resulting in 690.8125 liters/day, while the shrubs add 17.5 liters/day. Consequently, the total runoff volume is reduced to 9,483.3125 liters/day. The percentage reduction in runoff volume compared to Scenario A is calculated as 8.76%, reflecting the effectiveness of permeable surfaces in managing stormwater.

In Scenario C, the total plot area remains 548.95 m², again featuring a green roof of 468 m², permeable pavement of 80.95 m², and a green area of 2 m². The runoff for the green roof is calculated as $0.40 \times 25 \text{ mm} \times 468 \text{ m}^2$, resulting in 4,680 liters/day. The permeable pavement contributes 690.8125 liters/day, and the green area adds 17.5 liters/day. The overall runoff volume for this scenario totals 5,388.3125 liters/day. The percentage reduction in runoff volume compared to Scenario A is 48.19%, demonstrating the significant impact of green roofs and permeable surfaces on reducing stormwater runoff.

Table 40 Before and after runoff reduction measures for sample 01

Total coverage area of the land			
Parameter	A: Runoff Calculation	B: Runoff Calculation	C: Runoff Calculation
Total Plot Area	548.95 m ²	548.95 m ²	548.95 m ²
Built-up Area	468 m ²	468 m ²	468 m ²
Paved Area	80.95 m ²	80.95 m ²	80.95 m ²
Green Area	0 m ²	2 m ²	2 m ²
Runoff Volume Calculation			
Built-up Area Runoff	$0.75 \times 25 \text{ mm} \times 468 \text{ m}^2 = 8,775 \text{ L/day}$	$0.75 \times 25 \text{ mm} \times 468 \text{ m}^2 = 8,775 \text{ L/day}$	$0.40 \times 25 \text{ mm} \times 468 \text{ m}^2 = 4,680 \text{ L/day}$

Paved Area Runoff	$0.80 \times 25 \text{ mm} \times 80.95 \text{ m}^2 = 1,619 \text{ L/day}$	$0.35 \times 25 \text{ mm} \times 78.95 \text{ m}^2 = 690.8125 \text{ L/day}$	$0.35 \times 25 \text{ mm} \times 78.95 \text{ m}^2 = 690.8125 \text{ L/day}$
Green Area Runoff	$0.25 \times 25 \text{ mm} \times 0 \text{ m}^2 = 0 \text{ L/day}$	$0.35 \times 25 \text{ mm} \times 2 \text{ m}^2 = 17.5 \text{ L/day}$	$0.35 \times 25 \text{ mm} \times 2 \text{ m}^2 = 17.5 \text{ L/day}$
Total Runoff Volume	10,394 L/day	9,483.3125 L/day	5,388.3125 L/day
Runoff Reduction Calculation			
Runoff Reduction	0	$10,394 - 9,483.3125 = 910.6875 \text{ L/day}$	$10,394 - 5,388.3125 = 5,005.6875 \text{ L/day}$
Percentage Reduction	0	$(910.6875 / 10,394) \times 100 = 8.76\%$	$(5,005.6875 / 10,394) \times 100 = 48.19\%$

Sample 2



Figure 36 Land use land cover proposal in the sample on factory (store area)

In Scenario A, the total plot area is 5698 m², comprising a built-up area of 3592 m², a paved area of 1624.5 m², and a green area of 481.5 m². The runoff volume is calculated using the formula:

$$\text{Runoff Volume} = \text{Coefficient} \times \text{Daily Maximum Rainfall Intensity} \times \text{Area}$$

$$\text{Runoff Volume} = \text{Coefficient} \times \text{Daily Maximum Rainfall Intensity} \times \text{Area}$$

For the built-up area, the runoff is calculated as $0.75 \times 25 \text{ mm} \times 3592 \text{ m}^2$, resulting in 67,350 liters/day. The paved area contributes $0.80 \times 25 \text{ mm} \times 2106 \text{ m}^2$, yielding 42,120 liters/day, while the green area produces 0 liters/day due to its ineffective area. Therefore, the total runoff volume for this compound is 109,470 liters/day.

In Scenario B, the total plot area remains 5698 m², with the same built-up and paved areas as in Scenario A, but this scenario introduces permeable pavement. The calculations indicate that the built-up area still generates 67,350 liters/day. The permeable pavement contributes $0.35 \times 25 \text{ mm} \times 1624.5 \text{ m}^2$, resulting in 14,214.375 liters/day, and the green area contributes 3,009.375 liters/day. Consequently, the total runoff volume is reduced to 84,573.75 liters/day. The percentage reduction in runoff volume, compared to Scenario A, is calculated as 22.7%, reflecting the effectiveness of permeable surfaces in managing stormwater.

In Scenario C, the total plot area is reduced to 548.95 m², featuring a green roof of 468 m², permeable pavement of 80.95 m², and a green area of 2 m². The runoff for the green roof is calculated as $0.40 \times 25 \text{ mm} \times 468 \text{ m}^2$, resulting in 4,680 liters/day. The permeable pavement contributes 690.8125 liters/day, while the green area adds 17.5 liters/day. The overall runoff volume for this scenario totals 5,388.3125 liters/day. The percentage reduction in runoff volume compared to Scenario A is 24.08%, demonstrating the significant impact of green roofs and permeable surfaces on reducing stormwater runoff.

Table 41 Before and after runoff reduction measures for sample 02

Total coverage area of the land			
Parameter	A: Runoff Calculation	B: Runoff Calculation	C: Runoff Calculation
Total Plot Area	5698 m ²	5698 m ²	548.95 m ²
Built-up Area	3592 m ²	3592 m ²	0
Paved Area	1624.5 m ²	1624.5 m ²	80.95 m ²
Green Area	481.5 m ²	481.5 m ²	2 m ²
Runoff Volume Calculation			
Built-up Area Runoff	$0.75 \times 25 \text{ mm} \times 3592 \text{ m}^2 = 67,350 \text{ L/day}$	$0.75 \times 25 \text{ mm} \times 3592 \text{ m}^2 = 67,350 \text{ L/day}$	0
Paved Area Runoff	$0.80 \times 25 \text{ mm} \times 1624.5 \text{ m}^2 = 42,120 \text{ L/day}$	$0.35 \times 25 \text{ mm} \times 1624.5 \text{ m}^2 = 14,214.375 \text{ L/day}$	$0.35 \times 25 \text{ mm} \times 80.95 \text{ m}^2 = 5,250.625 \text{ L/day}$
Green Area Runoff	$0.25 \times 25 \text{ mm} \times 481.5 \text{ m}^2 = 3,009.375 \text{ L/day}$	$0.25 \times 25 \text{ mm} \times 481.5 \text{ m}^2 = 3,009.375 \text{ L/day}$	$0.40 \times 25 \text{ mm} \times 468 \text{ m}^2 = 4,680 \text{ L/day}$
Total Runoff Volume	109,470 L/day	84,573.75 L/day	53,143.75 L/day
Runoff Reduction Calculation			
Runoff Reduction	0	109,470 - 84,573.75 = 24,896.25 L/day	109,470 - 53,143.75 = 56,326.25 L/day
Percentage Reduction	0	$(24,896.25 / 109,470) \times 100 = 22.7\%$	$(56,326.25 / 109,470) \times 100 = 51.5\%$

E. Diverse Aspects of Development Strategy from the socio-economic and environmental aspects.

A. Social Components

Community Engagement: Involving local residents in the planning process ensures their needs and perspectives are addressed.

Public Health: The design should prioritize clean water access and sanitation to improve health outcomes.

Cultural Heritage: Respecting and integrating local traditions and heritage into the planning enhances community identity.

Recreation and Green Spaces: Creating parks and recreational areas promotes social cohesion and improves quality of life.

B. Economic Components

Job Creation: Development projects should aim to provide local employment opportunities beside the natural drainage buffer with temporary business.

Economic Viability: Ensuring that the infrastructure is sustainable and can generate revenue or support local businesses.

Investment in Infrastructure: Improved drainage and green spaces can attract further investment and development.

Cost-Benefit Analysis: Evaluating the long-term benefits against initial costs to ensure financial sustainability.

c. Environmental Components

Biodiversity Conservation: Protecting local flora and fauna through thoughtful design and maintenance of green spaces.

Sustainable Practices: Utilizing green infrastructure like permeable pavements and green roofs to manage stormwater and reduce runoff.

Climate Resilience: Designing infrastructure that can withstand extreme weather events to protect against flooding and other climate impacts.

Pollution Reduction: Implementing strategies to minimize pollutants entering the water system through proper waste management and buffer zones.

D. Technical Components

Infrastructure Design: Developing efficient drainage systems that reduce runoff and improve water quality.

Monitoring and Maintenance Plans: Establishing regular checks and maintenance of infrastructure to ensure functionality.

Data-Driven Decision Making: Using data to inform planning and adjustments based on performance metrics.

E. Governance and Policy Components

Regulatory Framework: Ensuring compliance with local, regional, and national regulations regarding land use and environmental protection.

Collaboration between Stakeholders: Engaging government bodies, NGOs, and private sectors to align goals and resources.

Long-Term Planning: Developing a vision that looks beyond immediate needs to future growth and sustainability.

5.2.2 Limitations of the Study

The flood risk assessment in Adama City's Irrcha Kebele faces several challenges that undermine its effectiveness. Key issues include unreliable data on past infrastructure and flood incidents, which affects accuracy, and a short study duration that may overlook important long-term climate trends. Focusing only on Irrcha Kebele limits the generalizability of findings, while an inadequate representation of diverse demographic groups can skew results. The complex relationships among factors influencing flood risks may not be fully understood, and financial constraints could hinder the implementation of effective strategies. Additionally, excluding the entire city from the study due to logistical issues results in an incomplete understanding of the broader flood risk landscape. Addressing these shortcomings is essential for improving future flood risk management efforts in Adama City.

Reference

- Ain, N., et al. (2017). Urbanization and its impact on flood. *Natural Hazards*.
- Aquero, A., Álvarez, M., & Martínez, E. (2009). Decision management using AHP through GIS data. *IEEE Latin America Transactions*, 7(1), 101-106.
- Bates, P. D., et al. (2008). Climate change impacts on water resources. In *Modern Water Resources Engineering* (pp. 525-569). Springer.
- Beshir, A. A., & Song, J. (2021). Urbanization and its impact on flood. *Natural Hazards*.
- Beshir, A. A., et al. (2021). Urban flood vulnerability assessment and management strategy in Adama City. *Heliyon*.
- Brown, M. (2023). Understanding flood risk in urban areas. *Journal of Urban Studies*.
- Brown, M., et al. (2019). Analyzing urban flood patterns. *Environmental Hazards*.
- Chan, F. K. S. (2012). Resilient flood risk management for Asian coastal cities. *Journal of Cleaner Production*, 187, 576-589.
- Chatterjee, S., et al. (2021). Impact of climate change on urban flooding. *Water Resources Management*.
- Dai, Y., et al. (2020). Modeling flood risk in urban environments. *Journal of Hydrology*.
- Delshammar, T., & Fors, J. (2010). Integrated flood risk management. *Water Policy*.
- Dewan, A. (2015). Climate change and urbanization impacts on flooding. *Natural Hazards*.

- Dottori, F., et al. (2016). Cost-effective adaptation strategies for flood risk in Europe. *Nature Climate Change*, 13(2), 196-202.
- Environment Agency. (2016). Flood risk management strategy. UK Government Report.
- Fang, W., Huang, Y., & Ding, Y. (2022). Health risks of odorous compounds: A review. *Environment International*.
- Federal Emergency Management Agency. (2014). National Flood Insurance Program. FEMA Report.
- Few, R., et al. (2009). The role of vulnerability in risk assessment. *Environmental Management*.
- Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems. *Global Environmental Change*.
- Garcia, C., & Torres, J. (2017). Urban adaptation to climate change. *Journal of Urban Planning*.
- Gebremichael, A. W., & Li, J. (2019). Assessing flood vulnerability and resilience in urban areas: A case study of Addis Ababa, Ethiopia. *Natural Hazards*.
- Gebremichael, A. W., Li, J., & Yan, K. (2020). Flood risk assessment and mapping in rapidly urbanizing catchments: A case of Hawassa City, Ethiopia. *Water*.
- Gonzalez, J. E., et al. (2016). Flood risk assessment in coastal regions. *Journal of Coastal Research*.

- Gonzalez, J. E., et al. (2018). Urban flood modeling techniques. *Water Resources Research*.
- Goodchild, M. F. (2007). *Geographic information science and systems*. John Wiley & Sons.
- Haile, M., et al. (2017). Flood risk and vulnerability assessment in urban environments. *Environmental Science & Policy*.
- Hillier, J. K., & Dixon, R. S. (2020). Seasonal impact-based mapping of weather and climate. *Environmental Research Letters*.
- Hirabayashi, Y., et al. (2013). Global flood risk under climate change. *Nature Climate Change*, 3(9), 816-821.
- IPCC (2021). *Climate change 2021: The physical science basis*. Cambridge University Press.
- IPCC (Intergovernmental Panel on Climate Change). (2014). *Climate change 2014: Impacts, adaptation, and vulnerability*. Cambridge University Press.
- Jalayer, F., et al. (2014). Probabilistic GIS-based method for urban flooding risk hotspots. *Natural Hazards*, 73, 975-1001.
- Johnson, K. J. (2016). *Resilience to climate change: An ethnographic approach* (Doctoral dissertation, University of Maryland).
- Johnson, K. J., et al. (2018). Flood risk management strategies in urban areas. *Water Policy*.

- Johnson, K. J., et al. (2021). Evaluating urban resilience to flooding. *Environmental Research Letters*.
- Johnson, S. (2022). Adaptive strategies for urban flooding. *Journal of Urban Design*.
- Jones, R. (2023). Innovative approaches to urban flood risk management. *Urban Studies Journal*.
- Kebede, A. S., & Nicholls, R. J. (2012). Exposure to climate extremes in Dar es Salaam, Tanzania. *Regional Environmental Change*, 12, 81-94.
- Kempen, E. H., et al. (2021). Flood risk modeling for urban areas. *Water Resources Research*.
- Klein, R. J. T., et al. (2003). Climate adaptation and flood risk management. *Global Environmental Change*.
- Kröger, R., et al. (2009). Flood risk assessment in urban settings. *Natural Hazards*.
- Leta, B. M., & Adugna, D. (2023). Characterizing the level of urban flood risk in Addis Ababa, Ethiopia. *Heliyon*.
- Maru, M., Worku, H., & Birkmann, J. (2021). Factors affecting the spatial resilience of urban systems: The case of Addis Ababa, Ethiopia. *Heliyon*.
- Masuya, A., et al. (2015). Evaluating the spatial distribution of flood shelters in Dhaka. *Natural Hazards*, 78, 1859-1882.
- Mendoza, A., & Rodríguez-Gil, J. L. (2014). Drugs of abuse and benzodiazepines in wastewater and surface waters. *Environment International*.

- Mendoza, A., et al. (2015). Seasonal variation of drugs of abuse in surface water and tap water in the Madrid region (Spain). *Environmental Science and Pollution Research*.
- Merz, B., et al. (2021). Perspectives on flood hazard and risk assessments. *EGUsphere*.
- Nuissl, H., et al. (2009). Urban climate change and flood risk management. *Urban Climate*.
- Pazwash, M. (2011). Assessment of flood risk in urban areas. *Journal of Flood Risk Management*.
- Portney, P. R., & Weyant, J. P. (2013). *Discounting and intergenerational equity*. Routledge.
- Rahman, M. A., et al. (2021). Assessing urban flood vulnerability. *Journal of Environmental Management*.
- Reddy, A. (2010). Flood risk management in India. *Climate Change and Urban Planning*.
- Saaty, T. L. (2008). *The analytic hierarchy process: Planning, priority setting, resource allocation*. RWS Publications.
- Schanze, J., et al. (Eds.). (2007). *Flood risk management: Hazards, vulnerability and mitigation measures*. Springer.
- Smith, A. (2021). *Urban flooding: Challenges and solutions*. Urban Studies.

- Smith, J. (2020). Flood risk and climate change adaptation. *Journal of Environmental Science*.
- Smith, R. (2017). Innovations in flood risk management. *Journal of Water Resources*.
- Smith, R. (2022). Climate adaptation strategies in urban areas. *Journal of Urban Planning*.
- Tehrany, M. S., et al. (2014). Flood risk assessment using GIS and remote sensing. *Remote Sensing*.
- Tramblay, Y., et al. (2020). Challenges for drought assessment in the Mediterranean region. *Earth-Science Reviews*, 210, 103348.
- Triantaphyllou, E. (2000). Multi-criteria decision-making methods: A comparative study. *European Journal of Operational Research*.
- U.S. Environmental Protection Agency. (2017). National water quality assessment program. EPA Report.
- U.S. EPA. (2011). Floodplain management: A comprehensive approach. EPA Report.
- Van Der Meulen, F., et al. (2016). Flood risk and urban planning. *Water Resources Management*.
- Voter, C. B., & Loheide, S. P. (2018). Urban residential surface water inundation modeling using a high-resolution coupled hydrologic and hydraulic model. *Water Resources Research*.

- Watson, A., et al. (2009). The evolution of international society: A comparative historical analysis. Routledge.
- Winsemius, H., et al. (2016). Flood risk assessment and management strategies. *Nature Climate Change*.
- Wodnimu, M. A., et al. (2022). Flood vulnerability assessment: A review of methods and applications. *Natural Hazards*.
- Yu, G., et al. (2019). Atmospheric nitrogen deposition stabilization in China. *Nature Geoscience*, 12(6), 424-429.
- Zhang, Y., et al. (2018). Impact of urbanization on flood risk. *Journal of Environmental Management*.

Annex-1 House-to-house visits

As a postgraduate student at Adama Science and Technology University, I am researching seasonal flood dangers and mitigation techniques in Adama Town, specifically Kebele 09. This questionnaire seeks information about the causes and consequences of floods on the local environment, society, and economy, as well as the community's coping mechanisms. Your real comments are critical to the success of this study, which is being conducted in partial fulfillment of my Master's program requirements. The information you give will be used strictly to achieve the goals of this study and will be kept confidential. I plan to collect data through both Google Forms and house-to-house visits. Please feel free to share honest criticism on the questions below.

Research Information

Research Title: "Assessing Seasonal Flood Hazards And Its Mitigation Strategies: The Case Of Adama City"

University: Adama science and technology university ASTU (Adama Ethiopia).

Chair: Urban planning and design.

Prepared By: Ayinaddis Alemu

Supervised By: Sileshi Azagew (PhD)

Note: - Mark only one square for close question

Section 1 Primary data

Part 1: Demographic Information

1. Your age?

☐ Under 18 years	☐ 18-24 years	☐ 25-34 years	☐ 35-44 years
☐ 45-54 years	☐ 55-64 years	☐ 65 years and older	

2. You're Sex?

Male ☐ woman ☐

3. What is the highest level of education you have completed?

☐ Basic ☐ Primary School ☐ Secondary school

☐ First-degree ☐ Secondary degree ☐ Doctor and above

4. How many members are there in your family?

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 and above ☐

5. How long have you lived in Adama?

☐ Under 1 year ☐ 1-5 years ☐ 6-10 years

☐ 11-20 years ☐ More than 20 years

6. What is your current employment status?

Employed ☐ Unemployed ☐ Student ☐ Retired ☐

Other (please specify) ☐

7. What is your primary source of income?

Salary/wages ☐ Self-employed ☐ Agriculture ☐ Business ☐

Other (please specify) ☐

8. What is your average monthly household income?

Less than 1,000 ETB ☐ 1,000 - 5,000 ETB ☐ 5,001 - 10,000 ETB ☐

More than 10,000 ETB ☐

Section 2: Awareness and Preparedness

9. Do you know about the flood risk in Adama city?

☐

Yes

☐

No

10. If yes to question 6, please briefly explain the causes of flooding in the city.

.....
.....
.....

11. Have you received any information or training on flood preparedness?

☐

Yes

☐

No

Section 3: Drainage Facility Assessment

12. How do you rate the effectiveness of the drainage infrastructure in Adama city?
Please rate on a scale of 1 to 5, 1 being ineffective and 5 being very effective.

☐

If 1 is ineffective

☐

5 if effective

13. Are there certain areas or neighborhoods where drainage problems are common?

☐

Yes

☐

No

14. If the answer to question 2 is "yes", please describe the areas or neighborhoods.

.....
.....
.....

15. Have you noticed blockages or maintenance problems in the drainage systems (garbage, debris, etc.)?

☐

Yes

☐

No

Section 4: Sustainable Pavement Systems

16. Do you know sustainable sidewalks?

☐

Yes

☐

No

17. Do you think implementing sustainable sidewalks will help reduce flood risks?

☐

Yes

☐

No

18. What are your opinions on using permeable pavements or other environmentally friendly materials in Adama City?

.....
.....
.....

Section 5: Impact of Floods

19. How did the flood affect your family?

.....
.....
.....

20. What kind of damage or loss did you experience as a result of the flood?

☐

Property damage

☐

Loss of personal property

☐

Interruption of utilities (water, electricity).

☐

Health problems (wounds, waterborne diseases)

☐

Displaced from home

☐

Other (please specify)

21. How does flooding affect your daily life and activities?

.....
.....
.....

22. Did the flooding affect essential services such as health, education and

transportation?

☐

Yes

☐

No

Section 6: Mitigation Strategies

23. Do you know of any flood prevention measures implemented? Government or local authorities?

☐

Yes

☐

No

24. If yes, please describe the steps taken.

.....

.....

.....

.....

25. Is there anything else you would like to share about floods and their impact on your family or mitigation ideas?

☐

Yes

☐

No

26. If yes, please describe the steps you have taken

.....

.....

.....

Section 7: Quality of Life

27. How do you evaluate the overall quality of your life in Adama City in terms of floods?

☐

Excellent

☐

Good

☐

Average

☐

Poor

28. Do you feel that the flooding in your area has affected your lifestyle?

☐

Yes

☐

No

29. If yes, please explain how the flooding affected your quality of life.

.....
.....
.....

Section 8: Additional Comments

30. Is there anything else you would like to share about floods and their impact on your family or mitigation ideas?

.....
.....
.....

Section 8: Flood Preparedness and Awareness

31. Have you received any information or training on flood preparation and response?

☐ Yes ☐ No

32. If yes, please describe the sources of information or training received.

.....
.....
.....

33. How confident do you feel that you will respond effectively during a flood?

☐ Very confident
☐ Somewhat confident
☐ No confidence

34. Have you ever taken an emergency evacuation plan or precaution for your family during a flood?

☐ Yes ☐ No

35. If yes, please briefly describe your discharge plan.

.....
.....
.....

Section 9: Government Response and Support

36. How satisfied are you with the government's response to the flood disaster in Adama?

- ☐ I am very satisfied
☐ I am somewhat satisfied
☐ Independent
☐ Slightly dissatisfied.
☐ Very dissatisfied.

37. What specific measures or reforms would you like to see from the government to address flood risks?

.....
.....
.....

Section 10: Flood Warning Systems

38. Do you know there are flood warning systems in Adama city?

☐ Yes ☐ No

39. If yes, how effective do you find the existing flood warning systems?

☐ Very effective ☐ It is not effective

40. Have you received timely flood warnings through these systems?

☐ Yes ☐ No

41. If yes, how did you receive flood warnings?

.....
.....
.....

Annex-2 Key Informant Interview

Name of the respondent _____

Age_____ SEX_____ Occupation _____

How long have you lived in the area? _____

Residential Areas:

1. What kinds of extensive damage to homes, personal belongings, and important documents have the residents reported?
2. How have the recurring floods led to loss of life and injuries, especially for vulnerable populations in the residential areas?
3. In what ways have the floods disrupted to daily life and activities due to water logging and inaccessibility in the residential areas?
4. What significant financial losses and costs for repair/replacement have the residents faced due to the flood impacts?

Schools:

1. What types of destruction to educational materials, documents, and equipment have been reported in the schools?
2. How have the school facilities been contaminated and rendered unsafe for learning environments due to the floods?
3. In what ways have the teaching and learning schedules been disrupted because of the recurring floods?
4. What are the main challenges with student and staff safety and access to schools during flood events?

Commercial/Industrial Areas:

1. What kinds of damage have been caused to the small businesses, workshops, and stores in the commercial/industrial areas?
2. How have the inventory/stock losses and financial setbacks impacted these commercial entities?
3. In what ways have the business operations and supply chains been disrupted due to the floods?
4. What drainage and infrastructure issues have hampered the flood mitigation efforts in the commercial/industrial areas?

Service Providers:

1. What challenges have the local service providers faced in maintaining operations and accessibility for customers during floods?
2. What kinds of financial losses have they incurred from damaged facilities and disrupted service?
3. How have they struggled to restore services after the flooding events?

Transport/Mobility:

1. What damage has been caused to the roads, bridges, and other transport infrastructure due to the recurring floods?
2. How have the floods disrupted the local mobility and connectivity in the area?
3. What challenges have the floods posed for emergency response and relief efforts?

Annex-3 Expert respondents on the AHP Analytical Hierarchy Process

Objective: Application of the GIS-based multi-criteria decision analysis and analytical hierarchy process (AHP) in flood susceptibility mapping

Only input data in the light green fields!

Please compare the importance of the elements about the objective and fill in the table:

Which element of each pair is more important, A or B, and how much more on a scale of 1-9 as given below?

Once completed, you might adjust highlighted comparisons 1 or 3 to improve consistency.

The Analytical Hierarchy Process (AHP) is a multi-criteria decision-making method developed by Thomas L. Saaty [1]. The general AHP formula can be expressed as follows:

$$Aw = \lambda_{\max} * w$$

n=10

input=0

n	criteria	comment	RGMM	+0r -
1	TWI		10	
2	Elevation		10	
3	Slope		10	
4	Precipitation		10	
5	LULC		10	
6	NDVI		10	
7	Distance from river		10	
8	Distance from road		10	
9	Drainage density		10	
10	Soil type		10	

participant
.....

$\alpha=0.1$

CR=0

name

weight

date

		Criteria		More important?	Scale
i	j	A	B	A or B	(1-9)
1	2	TWI	Elevation		
1	3		Slope		
1	4		Precipitation		
1	5		LULC		
1	6		NDVI		
1	7		Distance the from river		
1	8		Distance from road		
2	3	Elevation	Slope		
2	4		Precipitation		
2	5		LULC		
2	6		NDVI		
2	7		Distance the from river		
2	8		Distance from road		
3	4	Slope	Precipitation		
3	5		LULC		
3	6		NDVI		
3	7		Distance the from river		
3	8		Distance from road		
4	5	Precipitation	LULC		
4	6		NDVI		
4	7		Distance the from river		
4	8		Distance from road		
5	6	LULC	NDVI		
5	7		Distance the from river		
5	8		Distance from road		
6	7	NDVI	Distance the from river		
6	8		Distance from road		
7	8	Distance from river	Distance from road		

Intensity	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	strong importance	Experience and judgment strongly favor one element over another
7	very strong importance	One element is favored very strongly over another, its dominance is demonstrated in practice
9	extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8 can be used to express intermediate values		

Pairwise Comparison Matrix (A):

$A = [a_{ij}]$, where a_{ij} represents the relative importance of criterion i over criterion j , with $a_{ij} > 0$ and $a_{ii} = 1$.

Priority Weights (w):

$$Aw = \lambda_{\max} * w$$

where w is the priority weights vector, and $\lambda_{\max}$ is the principal eigenvalue of the matrix A . To calculate the priority weights, we can use the following steps:

- Normalize the columns of the pairwise comparison matrix A .
- Calculate the row averages to obtain the priority weights w .

Consistency Ratio (CR):

$$CR = CI / RI$$

Where CI is the Consistency Index and RI is the Random Index. The Consistency Index (CI) is calculated as:

$CI = (\lambda_{\max} - n) / (n - 1)$ The Random Index (RI) is a lookup value based on the number of criteria (n).

Alternatives Evaluation:

For each alternative, we calculate the local priority weights for each criterion using the same pairwise comparison and priority weights calculation.

Synthesis:

The global priority weight of an alternative is the weighted sum of its local priority weights, where the weights are the priority weights of the criteria.