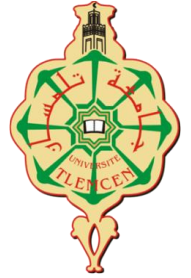




**Institute for Water
and Energy Sciences
(incl. Climate Change)**



**PAN-AFRICAN UNIVERSITY
INSTITUTE FOR WATER AND ENERGY SCIENCES
(including CLIMATE CHANGE)**

Master Dissertation

Submitted in partial fulfillment of the requirements for the Master degree in
Climate Change Engineering

Presented by

Yahya, Ali WABERI

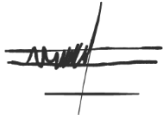
Climate Change and Flood Risk Mapping in Djibouti: A Web-GIS Approach

Defended on 16/04/2025 Before the Following Committee:

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DECLARATION

I Yahya Ali Waberi affirm the originality of my thesis "Climate Change and Flood Risk Mapping in Djibouti: A Web-GIS Approach" which was developed through strict adherence to academic intellectual conduct and moral research principles. Every source of information together with data and scholarly contributions has received proper acknowledgment. This research project exists as an original work and has not received complete or partial submission to graduate that would qualify someone at any educational institution. My independent work produced the analyses and findings which aim to enhance knowledge of flood risk mapping along with climate change adaptation strategies in Djibouti.



Yahya Ali Waberi

PAUWES/2023/MCCE18

MSc Climate Change Engineering

This thesis has been submitted for examination with my approval as supervisor.



Supervisor

Prof. Mohamed Saber

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I owe the sincerest appreciation to my family, who provided unconditional backing together with patience and trust in my abilities. The support I receive from them serves as my main inspirational force, motivating me through each stage of this journey. The journey to complete this work was possible because of the moral backing I received from my friends, who shared this experience together with me, offering support in times of need.

I extend my appreciation to all institutions and organizations for offering valuable, resources, and technical help that led to the successful research outcome. Without their contribution, this project would not have been possible. The chance to make contributions in Geographic Information Systems while adapting to climate change brings me immense pride and appreciation. I believe this research will significantly help Djibouti manage its flood risks, contributing to the region's climate resilience.

LIST OF ACRONYMS

GIS: Geographic Information System

WebGIS: Web-based Geographic Information System

SRTM: Shuttle Radar Topography Mission

HTML: HyperText Markup Language

CSS: Cascading Style Sheets

WEB: World Wide Web

LULC: Land Use and Land Cover

TWI: Topographic Wetness Index

HAND: Height Above Nearest Drainage

NMA: National Agency of Meteorology

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CHAPTER ONE

1. INTRODUCTION

1.1. Background

Flooding is one the most detrimental, recurrent and prevalent natural disasters in the world which has affected economies, environment and human life greatly with severe interruption of income sources(Armah et al., 2010). Research as established that floods account for forty percent of weather-related disasters, with weathers and climate-related disasters amounting to over billions of dollars every year(Eckstein et al., 2021). In past few decades floods have caused death of many people and displaced billions of people globally(Jonkman, 2005). Flooded rivers only have affected millions of people while putting literally innumerable other people at risk every year(Postel & Richter, 2012). Inability to control population and growth of infrastructure also leads to increased vulnerability to natural disasters and climate change because changes in temperature and patterns of rainfall affect these impacts and make flood more frequent and more intense(Baker, 2012).

This paper has established that the African continent; and indeed, areas such as Djibouti are the most sensitive to the impacts of climate change through their limited Socioeconomic characteristics, growing Urbanization and dependence on natural resources(Baker, 2012). Despite the increasing number of extreme events, Djibouti does not have well-developed flood-risk management systems and the intensity and rarity of rainfall events have led to increased flash floods. Such a situation was observed in November 2019 when the floods brought the amount of rainfall 300 mm, which is the annual average, for two consecutive days only and affected hundreds of thousands of people and offered great losses in terms of lives and property(Idyle Mousse Iye, 2019). Likewise, Cyclonic Storm Sagar that was experienced in May 2018 brought one year rain in one day; the cyclone displaced scores of people and destroyed some vital structures(Maity & Gonekar, 2023). These events underpin the need to carry out better assessment of flood risks and develop specific flood risk management frameworks for the geographic and climatic setting of Djibouti.

Flooding disaster risk and its evaluation and mitigation continues to be a complicated process given the climatology and physiography of the area and the socio-economic structures of the population(Maity & Gonekar, 2023). Due to flood occurrence uncertainty important factors like, land use, terrain elevation, rainfall's intensity and the capacity of the drainage system is

an important factor. To manage flood risk there must be some preventive measures for the flood, to recognize the areas that are more vulnerable, the measures of early warning, and the climate change scenarios integrated in the practice(Zhang et al., 2024). Remote sensing using Geographic Information Systems (GIS) has become a critical solution for understanding and mapping flood hazard to formulate relevant responses(Abid et al., 2020).

Although GIS and remote sensing technologies have been actively implemented in flood risk mapping, advanced decision-support systems to integrate with such technologies are seldom employed in developing countries such as Djibouti(Ali, 2022). A range of problems including inadequate and often fragmented spatial databases, and the absence of dedicated and accessible information platforms, increases the limitations in the current flood risk management concepts(Munawar, 2020). These gaps have been filled by undertakings of this research which created a Web-GIS platform well suited for Djibouti built with the use of multiple datasets, climate projections and cooperation with other stakeholders for improved flood risk modeling and management.

Through the use of sophisticated Geospatial technology this research seeks to minimize flood impacts, enhance socio economic susceptibility and develop sustainable strategies within Djibouti territory due to the climate change. The Web-GIS platform models a novel form of flood risk mapping that offers timely information for decision making processes of individuals and other residents(Daud et al., 2024). Remote sensing using Geographic Information Systems (GIS) has become a critical solution for understanding and mapping flood hazard to formulate relevant responses.

1.2. Problem Statement

In the realm of flood risk mapping, GIS applications encompass a broad range of tasks, such as the storage and management of hydrological data, as well as the generation of flood inundation and hazard maps, all of which are crucial for effective flood risk management. In recent years, there has been a significant accumulation of knowledge and expertise in utilizing GIS for flood risk mapping, particularly over the past decade(Evans et al., 2023). Djibouti, a nation covering an area of 23,200 square kilometers, is divided into five districts: Ali-Sabieh, Dikhil, Djibouti, Obock, and Tadjourah. The estimated population is around 500,000 individuals, with over two-thirds residing in the capital city of Djibouti(WHO/Djibouti, 2004).

As per the Meteorological Institute of Djibouti, a period of heavy rainfall occurred from November 21 to 23, 2019, resulting in a remarkable precipitation of over 295mm. This exceeded Djibouti's average annual rainfall of 127mm and was equivalent to two years' worth of rainfall. Tragically, eleven individuals, including seven children, lost their lives due to flooding and landslides. A Government-led Interagency Rapid Assessment conducted on November 27 and 28 revealed that more than 250,000 people were affected countrywide: Affected locations in Djibouti in 2019 (source government of Djibouti) Figure 1. The city of Djibouti experienced the most severe impact, with an estimated 200,000 people (21% of the country's total population) being affected. The localities of Arta, Damerjog, Goubeto, and Tadjourah were also affected. Furthermore, subsequent rains between December 7 and 10, 2020, further hindered access to the affected areas(IFRC, 2020).

This natural event is mostly caused by global warming, which increases the rate and intensity of rainfall, leading in intense rains that cause dams to break, oceans to flood, and streams to overflow. Following that, they cause catastrophic floods in a specified location for a set amount of time, resulting in socioeconomic losses, deaths, and property damage. Today, flood assessment and management are of interest to professionals from all around the world, including hydrologists, hydrogeologists, and planners. They are looking for an effective and dependable method to lessen the risk of floods. Indeed, flood risk management and assessment are critical for decreasing risk and guaranteeing long-term socioeconomic progress(Osman & Das, 2023).

GIS has proven to be highly effective in visualizing the extent of flooding and analyzing flood maps to generate flood damage estimation maps and flood risk maps(Demir & Kisi, 2016). Also, GIS technology has become the industry standard for producing and presenting risk information since risk is a spatially variable phenomenon(UNCTAD, 2012). And let's not forget that we live in the internet era, and there's no better way to share information with decision-makers than through it. In addition to making, it accessible to the general public and all parties involved in the flooding problem. As can be seen from the title of my thesis above, a GIS Mapping was desperately needed for Djibouti context in order to map the areas that are vulnerable to flooding and deal with it successfully.

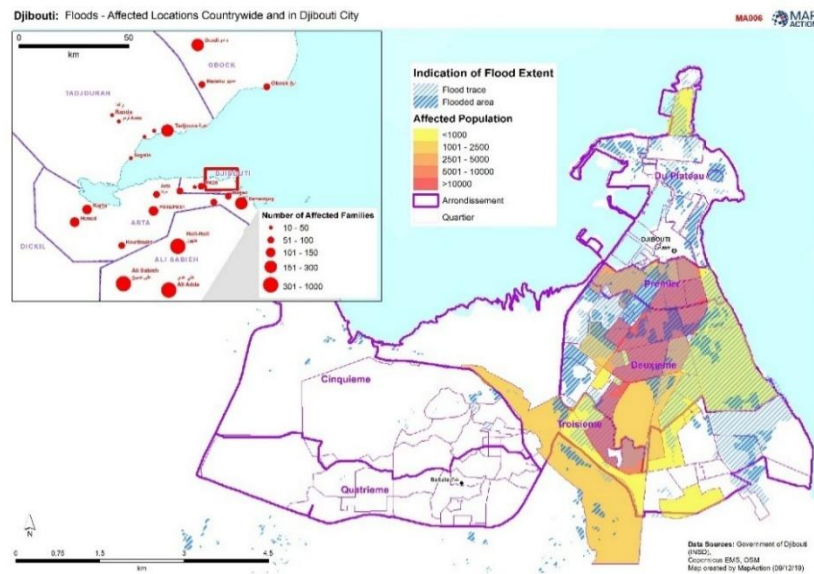


Figure 1 : Affected locations in Djibouti in 2019 (source government of Djibouti)

1.3. Research Objectives

1.3.1. Research aim

The research evaluation of climate change-induced flood risk simultaneously develops an operationally available Web-GIS platform for flood risk management. Users of the platform will experience integrated climate change data utilization for flood risk assessments that present flood-prone domains while allowing flooding report submission which facilitates better decisions for improved disaster mitigation and response in Djibouti.

1.3.2. Specific Objectives

- Construct a Web-GIS platform with interactive mapping features to unite projected climate changes with flood hazard assessments for applying information about risk sectors plus water bodies and infrastructure and landscape aspects and climate elements for the area of Djibouti.
- Users should have access to interactive flood maps which demonstrate live flood hazards alongside risk level assessments coupled with insights about flood patterns caused by climate change.
- The system should accept user-generated flood reports and stakeholder-submitted information because this practice leads to better disaster responses and more precise data.

- An accessible Web-GIS system within the system helps different stakeholders including government departments and emergency teams and policymakers to work together for flood risk assessment and adaptation strategy development.

1.3.3. Research Questions

1. How effectively does the developed Web-GIS platform integrate projected climate change data with flood hazard assessments to identify flood-prone areas in Djibouti?
2. To what extent does the Web-GIS platform provide users with access to interactive flood maps that display live flood hazards, risk level assessments, and climate change-induced flood patterns?
3. How does the Web-GIS platform facilitate the input of user-generated flood reports and stakeholder-submitted information, and what impact does this have on the accuracy and effectiveness of disaster response?

1.4. Relevance of study

Djibouti has faced the challenge of diverse categories of floods and even larger proportion of the country's population has been residing in high-risk areas. Climate change is likely to increase the occurrence of these threats in fact, the country's economy and infrastructure may be at risk. The thesis leading to design a Web GIS platform for flood risk mapping in Djibouti is clearly related to upgrading of flood risk management activities in the country. Through the generation of a fully-fledged spatial database and the implementation of an appropriate flood risk evaluation and mapping method, the study aims at furnishing policymakers and other stakeholders with relevant information that would assist them in better understanding flood risks and putting mitigation measures in place. This is why we need data and information so that decisions can be made in a way that is more informed; we can target mitigation actions, and we can prepare better for emergencies.

1.5. Limitation of the Study

The main problem which a Web-based GIS will face in design is data availability and its timeliness and adequacy. Provision of inclusive and credible data of risk areas, waterways, infrastructure and geographical characteristics may necessitate communication with multiple stakeholders and agencies. Data scarcity or lack of data might be problematic also, concerning

the creation of a spatial database as well as its correctness. Ensuring the quality and compatibility of the gathered data can be a substantial challenge. Information from distinct data sources maybe has some diverse grades of accuracy, resolution and format. Data integration and cleaning protocols may be long and detailed works that may need thorough rereading in order to have the database reliable and consistent. Lately, limited or unreliable internet access in some parts of Djibouti could hinder user access to the Web-GIS platform.

1.6. Thesis Outline

The study commences by introducing essential background knowledge about worldwide flood impacts that damage economies as well as environments and human existence. The introduction establishes two key components: first it presents the problem of insufficient flood risk mapping and management in Djibouti but also acknowledges how climate change worsens this situation. The research identifies its major targets for development while concentrating on Web-GIS platform creation to support flood risk management tasks along with examining both theoretical and practical constraints.

Chapter two includes a literature review focusing on climate change effects in flood patterns together with methods that evaluate flood risk and utilize Web-GIS in flood management operations. The paper examines both the flood risk-risk relation to climate change developments and the role of stakeholder participation and challenges in mapping Flood risks and potential advancements for future Flooding risk mapping technologies in Djibouti.

The research utilizes the third chapter to exhibit all materials and methods employed. The study area receives evaluation through geographical information presenting hydrological features together with topographical elements and climatic characteristics and rainfall statistics from Djibouti. The chapter describes all software technologies used together with data acquisition approaches and resources and explain methodologies before discussing flood risk mapping and Web-GIS development alongside field observation method validation along with methodology restrictions before exploring potential future applications of advanced technologies.

Chapter four shows the research outcomes together with their discussion sections. An analysis evaluates elevation, slope, HAND, precipitation patterns, population counts, aspect, hillshade mapping, land uses, distance from rivers and TWI and Stream Power Index data.

The conclusion of this research presents final recommendations that stem from the gathered research outcomes.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Overview of climate change and flooding

Global warming which is exhibited by increase in global temperatures, changes in rainfall and an increase in occurrences of rigorous weather situations has taken the shape of one of the biggest challenges the world is facing today. One of these effects is the increased probability of floods, or in sensitive areas like Djibouti(Patz et al., 2014). While emissions of greenhouse gases increase the global temperature, the water cycle becomes much irregular with irregular rains, frequent storms and long droughts(Loaiciga et al., 1996). In Djibouti, a land of low and variable precipitation rate mostly arid and semi-arid, these climatic fluctuations worsen existing risks such as flash floods, river flooding and coastal flooding(Omar et al., 2023b). Due to its flat terrains, sparse vegetation cover, and location along the Red Sea, flood occurrences in the country are always extraordinarily disastrous. Higher temperatures produce variable rainfall regimes that overtax natural antecedent conveyance systems; sea level rise from thermal expansion and the melting of glaciers leads to coastal storm surge and tidal inundation(Iskandar et al., n.d.). Further, it also indicates that due to low vegetation cover and concrete pavements there is high surface runoff when there is intense precipitation. These are some of the challenges that need to be met by new ways and more specifically by the use of new technologies such as GIS(Sahay, 1998). Integrated with climate change information, GIS enables definition of the spatial distribution of flood risks by superposing climate forecasts, elevation, water bodies, and facilities(Eniolorunda, 2019). Through this technology, it is easy to determine which regions are frequently flooded and which policymakers and stakeholders can help organize the hazard mitigation.

In addition, the use of Web-GIS builds on these functions by offering real-time flood risk information as well as improving cooperation with government agencies as well as other communities and organizations. This study highlights, GIS-based flood modelling and risk assessments should be considered in Djibouti for the purpose of reinforcing flood mitigation measures like mapping the future risks and designing the adaptation measures. Through the utilization of technological support and active involvement of stakeholders, Djibouti is in a position to mitigate existing climate boosted flood impact hazards and lower socio-economic susceptibilities. Such an approach points towards use of scientific instruments and techniques

to protect communities as well as facilitate sustainable development whenever climate risks are involved.

2.2. Flood Risk Assessment and Mapping

The evaluation of flood risks along with their geographic representation play fundamental roles in flood risk management systems which protect communities suffering from climate change intensifying floods(Kundzewicz et al., 2014). The process of flood risk assessment determines both the harmful impact potential from flood hazards and the exposed risk and vulnerable state of population groups as well as infrastructure systems(Karmakar et al., 2010). The visual spatial presentations delivered by mapping systems allow decision-makers to picture risk priorities for intervention purposes(Andrienko et al., 2007). Geographic Information Systems (GIS) introduced a transformational change to how organizations study and manage flood risks through their integration for assessment purposes. Better flood risk assessment happens through GIS because this technology enables multiple data layers to be stacked for seeing a complete picture(Macchione et al., 2019). Topography and land use and rainfall patterns and infrastructure can be layered to create these maps(Pielke Sr et al., 2007). These types of mapping systems present critical information about how flood risks distribute across space so authorities can develop proper mitigation strategies. Through GIS-based flood risk mapping Djibouti will gain improved abilities to anticipate and manage flood events stemming from both flash floods and riverine flooding. These maps gain enhanced predictive power when climate change projections are incorporated because stakeholders can use them to create strategies that minimize predicted impacts.

2.3. Web-Gis in Flood Management

Web-GIS technology serves as an essential tool for flood management systems within developing countries such as Djibouti which lacks sufficient traditional flood management systems. By using Web-GIS platforms users get easy considerate access to real-time data sharing and analysis of flood-related information through an intuitive platform(Sánchez, 2013). Web-GIS platforms create a framework which enables government agencies and NGOs and local communities to unite their efforts in flood risk management operations. Web-GIS stands out because it provides the capability to automatically incorporate actual weather data in order to generate immediate flood alert notices. The need for quick response becomes crucial when rapid flash floods strike Djibouti since they create major destruction in a brief timespan. The

sharing capabilities of Web-GIS platforms make it possible to distribute flood risk maps and supporting information to diverse user groups including emergency teams and all members of the wider public and governmental officials(Albano et al., 2015). The increased accessibility of flood risk information provided by Web-GIS contributes to building public preparation capabilities which helps minimize flooding's economic impacts in the community(Daud et al., 2024). The Web-GIS platform mentioned in this research represents an essential move for Djibouti because it creates targeted solutions to improve flood risk management throughout the country.

2.4. Methodologies in flood Risk Mapping

Flood risk mapping techniques exist in various forms yet maintain separate capabilities and disadvantages in their applications. The prediction of flood risks depends primarily on historical flood data along with hydrological models through traditional examination approaches(Daud et al., 2024). The techniques lack complete accuracy in assessing flood risks because climate change affects rainfall behavior and produces more severe flood occurrences. Contemporary analytical methods that use GIS and remote sensing technologies present a complete system for identifying flood risk dangers(Adjei-Darko, 2017). Multiple data sources that encompass satellite images and digital elevation models (DEMs) and climate projection data can produce dynamic and improved flood risk maps through these methods. GIS-based methodologies supplement inadequate data conditions in Djibouti by creating an advanced framework that improves flood risk assessment. The use of stakeholder participation during mapping procedures with participatory mapping methods helps improve both accuracy and applicability of flood risk maps(Maskrey et al., 2022). This research adopts multiple methods to create an effective flood risk mapping system that works for Djibouti's specific environmental conditions.

2.5. Climate Change and Flood Risk

The vulnerability of Djibouti to extreme weather events increases further because climate change represents a major risk element for floods(Aden, 2014). World temperature increases produce irregular and powerful rainfall patterns that exceed the capacity of existing drainage systems and cause torrential flooding(Douglas, 2017). The arid terrain of Djibouti becomes susceptible to severe flash floods following minor rainfall increases because the landscape remains almost entirely flat(East & AFRICA, 2024). Effective flood risk mitigation strategies require the incorporation of climate change projections because of their critical role(Wilby &

Keenan, 2012). Stakeholders can protect against future flood threats through proactive risk reduction measures after they utilize climate models to forecast rainfall and sea level changes. The study finds climate change data must be included in flood risk assessments because it enables effective durable solutions for risk reduction.

2.6. Stakeholder Involvement in Flood Risk Management

Accomplished flood risk management depends heavily on stakeholder engagement (Geaves & Penning-Rowsell, 2016). The development of useful flood risk mitigation strategies in Djibouti requires constant collaboration between government agencies, local communities and NGOs because resources remain scarce while flooding damages expand widely. The contributions of stakeholders create opportunities to combine their experienced perspectives regarding vulnerable areas and necessary intervention choices (Greenhalgh et al., 2016). The inclusion of stakeholders during flood risk mapping enhances the chances that society will both accept and perform flood mitigation operations within their protective territories (Begg, 2018). The study demonstrates why stakeholder involvement proves essential in developing the Web-GIS platform because it guarantees the platform matches Djibouti's particular requirements. The platform establishes valuable flood risk management resources for the country through communication and collaboration of stakeholders.

2.7. Challenges in Flood Risk Mapping in Djibouti

Several implementation hurdles still exist for flood risk mapping in Djibouti despite the promising advantages of GIS and Web-GIS technologies. Several obstacles exist because there is an insufficient foundation of accurate data collection in remote locations and rural settings. Flood risk maps become less precise when there is insufficient information about topographical features and land usage together with infrastructure details resulting in restricted effective strategy development (Council et al., 2009). The country faces barriers because some parts lack sufficient Web-GIS platform developers and maintainers who possess required technical abilities especially in areas which restrict access to training opportunities. Shattered internet access throughout rural areas acts as a barrier which limits users' platform access and reduces the Web-GIS system's performance as a flood risk monitoring platform. This study tackles the current difficulties through a collaborative technique which brings stakeholders from different parts of the nation together to create an accurate and accessible Web-GIS platform.

2.8. Future Directions in Flood Risk Mapping

The development of superior flood risk mapping tools remains essential because climate change intensifies flood hazards in Djibouti and similar vulnerable areas. Future research needs to work on enhancing the precision and detail of flood risk charts by processing complex information on location features and environmental planning as well as climate change models (Wilby et al., 2009). Web-GIS platforms will get enhanced capabilities through the development of automated flood risk assessment tools which use artificial intelligence and machine learning technologies (Tengtrairat et al., 2021). These evaluation tools enable real-time flood risk inspections coupled with warning systems that lower harmful effects on exposed populations. The process of area cooperation for information sharing presents one possible solution to fight data shortage problems that affect resource-limited regions. Countries in the Horn of Africa together with their neighboring nations can construct enhanced flood risk management systems which protect people from climate change effects.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Study Area

3.1.1. Geographical Overview of the Study Area

The Horn of African country Djibouti occupies an area of 23,200 square kilometers which makes it one of the smallest territories in Africa (James, n.d.). Due North to Eritrea and South to Ethiopia continue to West separates the country from Somalia in the Southeast while the Gulf of Aden together with the Red Sea define the eastern boundaries of Djibouti (Figure 2). The climate of Djibouti features arid and semi-arid conditions across most regions because the country suffers from scant water supplies and depends heavily on seasonal precipitation. As the economic political and administrative center of the country Djibouti City functions as the largest urban area in the entire nation. Flooding poses significant threats to the city because urban development has surged too fast and the drainage systems need improvement while the city exists at an exposed coastal elevation (El Raey, 2010).

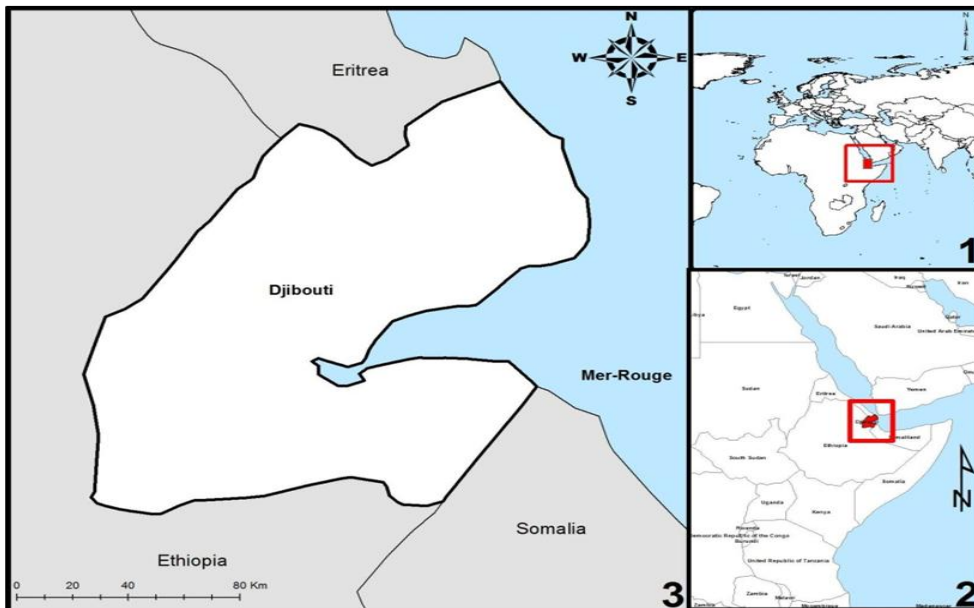


Figure 2 : The geographical position of Djibouti in the Horn of Africa (source: NMA).

3.1.2. Hydrology and Topography

Djibouti receives its main hydrological system from two seasonal rainfall patterns during March to May (spring rains) and September to November (autumn rains). Djibouti City contains the

Ambouli River which represents its largest hydrological feature(Omar et al., 2023a). The river makes its start in the hill region then carries water through Djibouti City before reaching the Gulf of Tadjourah. The river exists in its dry state most times yet severe rainfall triggers sudden flooding conditions. Climate change has intensified the unpredictability of rain amounts while making heavy weather events occur more frequently as well as intensify thus escalating the possibility of flooding.

The landscape of Djibouti consists of three primary terrain features which are volcanic plateaus together with coastal plains and separated mountain chains. The topographical features determine how water flows and affects flooding risks in an area. The areas of the Godas and Mabla mountain ranges north of the country exceed 1,500 meters in elevation but the central and southern parts of the region feature plateaus with the low-lying Grand Bara and Petit Bara basins that contain substantial flash flood risks.

Djibouti City occupies mostly flat regions extending from sea level at 200 meters above(El Raey, 2010). Due to its low elevation position the city faces increased flood risk because it rapidly collects rainfall water runoff (Figure 3). The city has multiple seasonal rivers as the Ambouli River stands as the most prominent since it originates in the highlands before reaching the Gulf of Tadjourah. The Ambouli River generally dries up yet heavy rainfall results in its quick flooding which struck the city during 2004 when floods submerged wide urban areas while forcing massive resident migration while causing extensive infrastructure destruction.

The absence of permanent rivers in the country creates excessive dependence on periodic rains because they remain its only water resource. The main water supply in Djibouti relies on underground reservoirs together with short-lived streams that cannot supply steady freshwater throughout extended dry months. The nation exists with two simultaneous risk factors which are drought and flooding disasters.

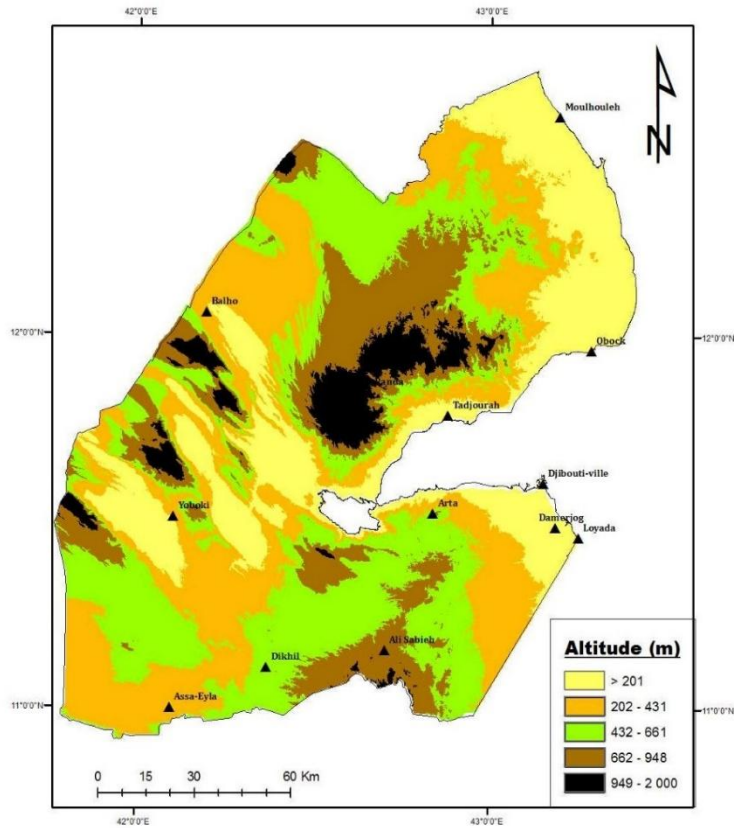


Figure 3 : The Relief of the Republic of Djibouti

3.1.3. Climatic Conditions and Flood Hazards in Djibouti

The climate of Djibouti shows characteristics of aridity and semi-aridity along with temperatures which remain high throughout the year and scarce rainfall patterns. The average rainfall across the country totals approximately 150 millimeters per year while meteorological patterns remain highly inconsistent from one year to the next (Waberi et al., 2023). Short bursts of irregular rainfall occur in disordered patterns which generate substantial hydrological obstacles for the country. Djibouti's position in the Horn of Africa makes it exposed to dramatic climatic changes that produce both long dry periods and unexpected water-related disasters. Data from climate observation revealed decreasing rain totals while registering growing occurrences of violent weather phenomena. The national temperature average has increased by 1.7 degrees Celsius since 1950 while heatwaves became both stronger and more regular and rainfall patterns underwent significant seasonal changes. Climate change has worsened the threat from droughts and flash floods so Djibouti faces increased challenges regarding water shortages and degraded infrastructure.

3.1.4. Rainfall Patterns and Seasonal Variability

Djibouti receives most of its annual rainfall during two main periods from March to May and September to November. Springtime precipitation in Djibouti remains at moderate levels so that it helps restore both groundwater reserves along with minimal agricultural output. During either light rain or heavy rainfalls significant flooding occurs primarily in drainage-deficient areas. Autumn rains in Djibouti deliver stronger and less foreseeable rainfall patterns that bring about frequent torrential downpours resulting in flash floods. Natural water infiltration is limited at Djibouti due to its soil aridity and scarcity of vegetation leading to massive surface water movement.

The dry season prevails throughout most of the year in Djibouti which intensifies water shortages because of the extreme heat (Aden, 2014). Less common than summer rains are convective storms which generate brief precipitation bursts that may trigger quick flood events in the area. Seasonal rainfall patterns in the country have undergone changes because of unpredictable precipitation along with the increase in temperatures. In the upcoming years the region can anticipate an increase in severe climate events such as continuous drought or stronger storm systems according to climate prediction models. The present climate trends present major obstacles to the management of water resources together with agricultural activities while demanding changes to municipal infrastructure systems.

3.2. Materials Used in This Study

3.2.1. Software Technologies Used

Advanced software tools supported the analysis of data alongside flood risk modeling and performance of real-time data dissemination within this research project. The project employed ArcGIS as its main utility which provided essential capabilities for spatial analyses and combined all relevant data to create flood risk maps. Multiple datasets including satellite imagery and hydrological records and socioeconomic data could be accurately combined through its features to determine effective flood-prone areas assessments. DEMs could be built through ArcGIS software for essential topographical assessments needed to do proper flood modeling work.

Web-GIS functions as a primary tool in this study because it delivers interactive services to conduct instant flood risk evaluations. Through this technology anyone from policymakers

down to the general public gained ability to view current flood data and examine hazard areas together with potential solutions for mitigation. The essential need for flood response development achieved success through Web-GIS's capability to link data in one system and facilitate partnerships among stakeholders. The study achieved better forecasting by uniting climate data and remote sensing technologies through Web-GIS integration. The research employed advanced geospatial technologies to create a data-based and effective strategy for flood risk management throughout Djibouti.

3.2.2. Data Acquisition and Resources

A complete assessment of flood risks in Djibouti was achieved by utilizing multiple data sources that include meteorological records, hydrological data and satellite imagery as well as socioeconomic information. Major surface observations were taken from Landsat and Sentinel-2 satellite images to visualize both surface expansions and flooded regions which enabled clear assessments of coated territories. Satellite-based data systems delivered essential information about environmental modifications along with urban sprawl effects on flood dangers.

Modern climate data and projected forecasts were acquired from meteorological agencies and global climate models which provided essential insights regarding rain patterns alongside temperature changes and extreme weather patterns. Water measurement information together with details about rivers and watersheds enabled scientists to demonstrate precipitation into runoff behavior along with predictions for flood patterns. Digital Elevation Models (DEMs) at high resolutions were used to determine terrain variations for the purpose of accurate flood modeling.

Flood vulnerability assessment of communities relied on socioeconomic data consisting of population density statistics along with infrastructure distribution patterns along with land-use information. Both field data acquisition and interacting with stakeholders added value to the research as they confirmed GIS outputs using site observations and included regional expert insights. Various datasets used in synchronization allow Djibouti to conduct comprehensive flood risk assessment which helped decision-makers develop flood mitigation protocols while preparing for disasters.

3.2.3. Methodology

The research implements a methodology that analyzes flood risks in Djibouti through integration of Geographic Information Systems (GIS) and Web-GIS technologies. The approach unites processes for data acquisition with data preparation (AHP) and flood risk maps before creating a Web-GIS system that performs real-time decision support. This methodology provides an organized method for both understanding how to deal with floods and making flood risk management transparent in climates that adapt due to changes in weather.

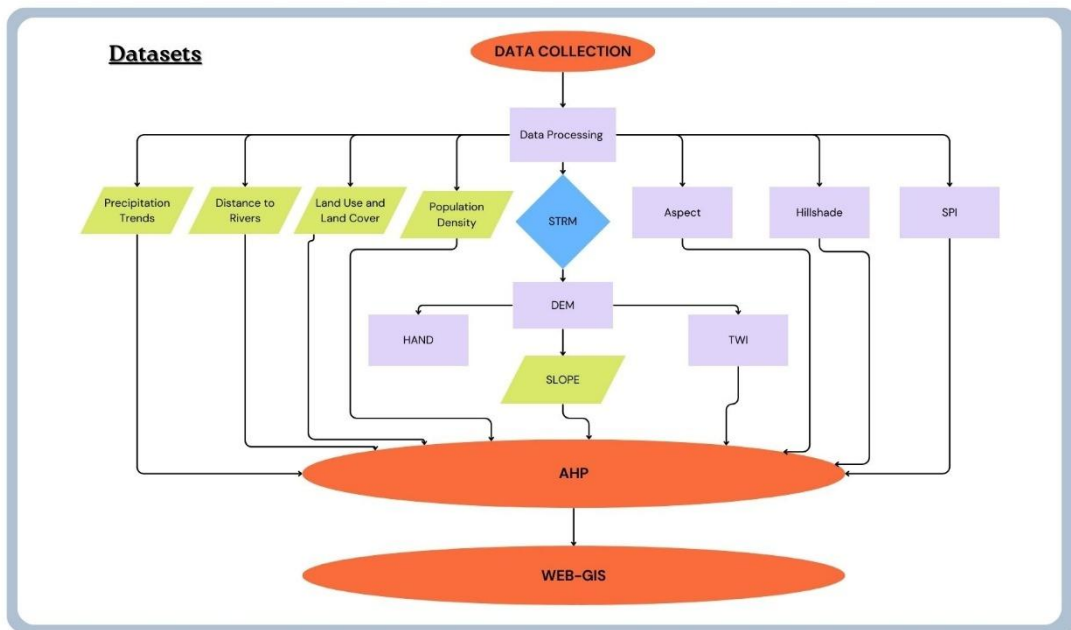


Figure 4 : Datasets used in the Study

3.2.4. Data Preprocessing

The methodology started with gathering satellite imagery together with hydrological records climate data and socioeconomic information as well as satellite images. Both Landsat and Sentinel-2 satellite data served for land cover mapping and flood extent mapping while historical and future rainfall data came from meteorological sources alongside global climate modeling. Researchers obtained hydrological records about river discharges along with watershed characteristics to track water flow patterns. A thorough analysis of vulnerability required the acquisition of socioeconomic information regarding population density together with infrastructure distribution. The team conducted some field surveys together for validating the GIS output while integrating local knowledge. A specific set of procedures adjusted the

collected data to establish both precision and uniformity. The preprocessing stage required cleaning data to fix inconsistencies and errors while performing georeferencing to link spatial data to a standard coordinate system and applying standardization to guarantee dataset interoperability. The preprocessing step established a reliable basis which enabled successful flood risk modeling together with analysis procedures.

3.2.5. Analytic Hierarchy Process (AHP) Application

3.2.5.1. Defining the Goal and Criteria

The Analytic Hierarchy Process (AHP) starts by clearly defining the main objective. For instance, in flood risk mapping, the goal might be to identify and classify areas prone to flooding. Once the goal is defined, relevant criteria are selected, such as slope, rainfall, land use, soil, elevation, and distance to water bodies.

These criteria influence the probability and impact of flooding in an area.

3.2.5.2. Constructing the Pairwise Comparison Matrix

| Relative Importance | Definition |
|---------------------|-------------------------------------|
| 1 | Equal importance |
| 2 | Equal to moderate importance |
| 3 | Moderate importance |
| 4 | Moderate to strong importance |
| 5 | Strong importance |
| 6 | Strong to very strong importance |
| 7 | Very strong importance |
| 8 | Very to extremely strong importance |
| 9 | Extreme importance |

Figure 5 : Saaty's Criteria Weight Scale

Each criterion is compared with the others in terms of its importance relative to the goal. The comparisons are expressed using Saaty's scale, ranging from 1 (equal importance) to 9 (extremely more important). These comparisons are filled in a square matrix, with reciprocal values for lower importance.

Rainfall is considered strongly more important than slope (value = 5), then the reverse comparison (slope vs rainfall) gets a value of 1/5.

3.2.5.3. Normalizing the Matrix and Calculating Weights

The matrix is normalized by dividing each value by the sum of its column. After normalization, the average of each row is calculated to get the relative weight or priority of each criterion. These weights represent the influence of each factor in determining flood risk.

3.2.5.4. Consistency Check

λ_{max} (maximum eigenvalue)

Consistency Index (CI) :

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

Consistency Ratio (CR) :

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

Where:

n = number of criteria

RI = Random Index (based on n)

If **CR** < 0.1, the pairwise comparisons are consistent.

AHP includes a built-in mechanism to check the consistency of the judgments made in the pairwise comparisons. This is done by calculating the Consistency Index (CI) and the Consistency Ratio (CR). The CR is compared to a Random Index (RI) value depending on the number of criteria. If CR < 0.1, the level of consistency is acceptable. If not, the matrix should be revised.

3.2.5.5. Applying Weights in GIS

After obtaining consistent weights, each raster layer representing a criterion in GIS is reclassified and assigned its respective weight. These weighted layers are then combined using tools such as Weighted Overlay or Raster Calculator to produce a final flood hazard map. The map classifies areas into different flood risk levels (e.g., low, moderate, high).

3.2.6. Flood Risk Mapping

An evaluation of Digital Elevation Model (DEM) data produced slope and elevation measurements and watershed characteristics for analysis. The analysis of DEM data enabled experts to discover flood-prone areas by identifying both low-lying locations and river basins through their knowledge of water flow movements. The DEM data allowed detection of drainage networks and rainfall water accumulation patterns in Djibouti City particularly because urbanization has raised flood risks at that location.

The hazard mapping operation included placing multiple data layers of hydrology, infrastructure, land use, and socioeconomic elements before performing a flood hazard evaluation. The high-risk areas were located where drainage conditions were poor and population density was high and where ground surfaces were impervious to water flow. The visualization step identified flood-prone areas which required immediate intervention because unplanned construction throughout Djibouti City had intensified flood dangers in populated urban regions.

Vulnerability assessment included population density as well as distribution of infrastructure and land-use patterns when building the flood risk model. Areas designated as informal settlements and low-income neighborhoods faced high vulnerability because their residents had subpar housing construction and inadequate supporting resources. At this stage the process identified vulnerable human populations to guarantee their proper inclusion within the risk assessment framework.

3.2.7. Web-GIS Development

The Web-GIS platform serves as a platform which delivers both interactive user-friendly functions for flood risk assessments along with decision-making capabilities. HTML and CSS built the frontend platform framework that established a responsive user interface along with attractive visual elements. The application uses Leaflet.js GIS libraries together with JavaScript to develop its backend functions and provide interactive mapping features. Users could utilize the platform to view flood risk maps while gaining access to current flood risk data about

different areas. The developed submission page allows flooding event reporting by sending instant email notifications directly to me. The Web-GIS platform receives this data directly for from users and store through which it ensures management and storage operations take place instantly. Multiple tests during development aimed to validate correct behavior of all components alongside a user-friendly interface which operated with optimal response times. The publication of the website concluded and this stage is ongoing.

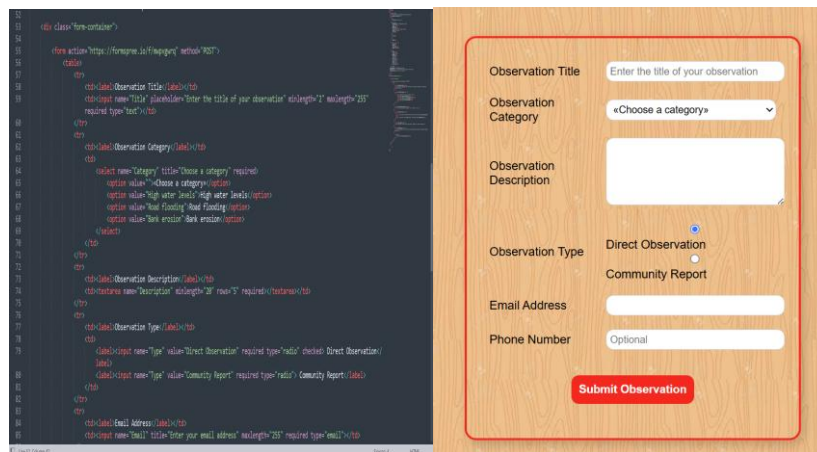


Figure 6 : Scripts Codes

3.2.8. Validation and Field Observation

The validation of flood risk maps and Web-GIS platform incorporated both historical flood data analysis and physical site checks. The evaluated accuracy of flood risk zone models relied on historical flood document comparisons. The flood risk model received verification by conducting field investigations across primary flood vulnerable regions including both Djibouti City and the Ambouli River watershed. During site inspections researchers collected data to confirm that the generated flood risk maps showed accurate measurements of actual field locations.

Participants in field observations gathered direct knowledge from local communities about historical flood occurrences and their consequences during their survey work. Local citizens contributed their flood experience data to improve the validity of the risk maps through integration during the validation process. The flood risk maps obtained scientific validity through historical data and practical relevancy through field observations to serve the needs of the flood risk management system in Djibouti.

3.2.9. Limitations of the Methodology

Several obstacles affected the methodology due to insufficient data availability while facing technical obstacles along with accuracy issues. The limited supply of high-quality data created substantial barriers because it mostly affected locations that were remote and rural. The study encountered two main limitations because of technical difficulties in data consolidation and the expensive requirements of flood simulation algorithms. The analysis became more difficult because different datasets showed inconsistent accuracy and resolution levels. Some parts of Djibouti encountered reduced Web-GIS platform effectiveness because of limited internet connectivity. The research positioned itself successfully toward establishing an entire flood risk assessment framework for Djibouti while dealing with various challenges. Future research should focus on addressing these limitations by improving data collection methods and computational capabilities while expanding internet access in underserved regions.

3.2.10. Future Directions with Advanced Technologies

Future research needs to enhance flood risk maps by uniting improved climate models with detailed high-resolution data. Web-GIS platform capabilities would increase substantially through artificial intelligence and machine learning tools which provide automatic flood risk assessment thus enabling better and faster flood warning delivery to communities. A regional collaboration between Horn of Africa countries that involves data sharing would enable them to establish improved flood risk management plans which benefit entire populations.

Community readiness and disaster response time can improve when Web-GIS platforms merge real-time weather data and early warning systems. Through adoption of modern technologies combined with improved international collaboration Djibouti would create pathways toward better sustainable flood control management. Destruction from floods needs to be minimized through these critical steps that enhance resilience against climate change developments. Safety measures aim to defend both human existence and occupational sustainability as a way to establish a safer world for everyone.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1. Introduction

The environmental problem of flooding affects Djibouti frequently because of changing climate patterns alongside fast-paced urban expansion. Effectively managing risks depends on detailed knowledge about how flood hazards and vulnerabilities spread across different locations because extreme weather conditions now appear with increasing frequency. A comprehensive study regarding flood risk map creation in Djibouti through Web-GIS analytics combined geospatial information with vulnerability assessments of flood hazards.

The initial step of the analysis requires researchers to identify crucial flood hazard indicators by examining elevation and slope and evaluating rainfall intensity as well as water bodies accessibility. GIS technological processes and remote sensing methods evaluate these elements to produce detailed flood hazard mapping of vulnerable locations.

The evaluation of flood vulnerability occurs after hazard assessment through an investigation of population data alongside assessment of land structure and infrastructure capabilities. Both hazard and vulnerability assessments produce a joint flood risk map that displays detailed geographical locations of flood hazard areas throughout Djibouti.

The findings present a complete framework of climate adaptation as well as flood management systems. The discussion examines flood danger effects based on comparative data analysis from studies as well as records of historic flood occurrences to evaluate their influence on city planning and readiness and policymaking strategies. Existing flood control measures will be assessed by identifying their strong points along with their weaknesses along with future potential for development.

The chapter delivers strategic recommendations for enhancing flood resilience in Djibouti by spotlighting Web-GIS technology as a vital tool for decision-making support. Geospatial analysis integrated with risk management strategies provides information to establish risk-reducing flood mitigation policies that are sustainable and proactive in nature.

4.2. Elevation

Elevation stands as the key determinant of flood vulnerability since this factor regulates how flood water vectors and amasses across terrain (Anvar, 2023). Lower areas near the water tend

to flood more often because their poor drainage capacity falls short of managing elevated water levels. Areas elevated above flood plains run water away rapidly reducing their flood exposure. Coastal areas and riverine locations that have nearly flat topography face worsened flood danger because flood waters stay stagnant longer before causing major infrastructure damage and affecting communities.

Digital Elevation Model analysis of Djibouti reveals how elevation alters the spatial distribution of risk zones susceptible to floods. Djibouti City and the adjacent zones beneath 10 meters above sea level face maximum flood vulnerability. These flood-prone areas are chiefly susceptible to floods from the blended effects of natural elements and human-caused sources which comprise:

Relatively low coastal elevations increase vulnerability to tidal wave surges together with rising ocean levels because it raises the risk of coastal flooding during storm events. The speed of sea level elevation resulting from climate change will heighten both frequency and intensity of coastal floods in Djibouti.

The drainage systems in urban areas with limited elevation cannot adequately manage intense rainfall which results in street and space and residential area water accumulation. Roles of poorly maintained drainage infrastructure intensify flood susceptibility of these areas.

The flood susceptibility of inland water bodies and seasonal watercourses increases because these locations naturally serve to store water. Areas prone to heavy rainfall turn into inundated locations resulting in flash floods.

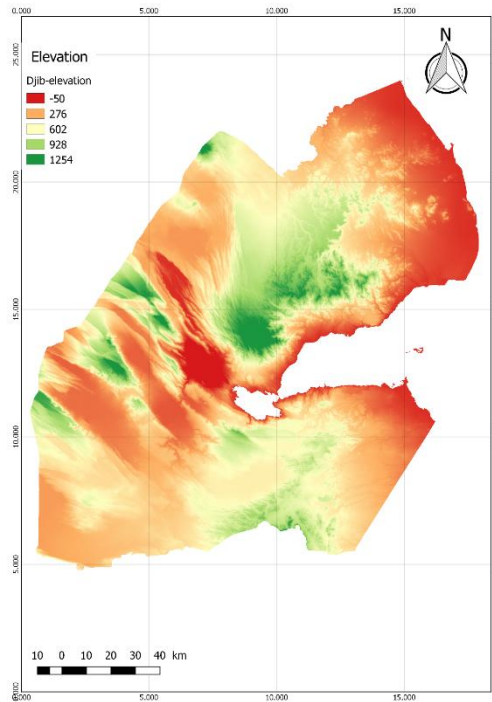


Figure 7 : Elevation Map of the Republic of Djibouti

Elevation represents the bedrock feature that strongly determines the traits of climate patterns as well as hydrological processes and territorial use patterns (Bonada & Resh, 2013). The elevation map for Djibouti displays elevation variations which extend from the lowest points at -50 meters below sea level up to 1,254 meters above sea level. The elevation levels appear as a color spectrum which uses red shades for lower areas while showing green for elevated regions. Elevation conditions of Djibouti differ between its central and western sections because these areas feature elevated mountain faces while its eastern and coastal regions maintain lower elevations. Different elevation levels create substantial consequences for the management of natural environments as well as urban development practices and catastrophe risk evaluation procedures.

The Western and Central regions of Djibouti hold elevated terrain that comprises volcanic geology and mountainous formations thus limiting human settlement capabilities but serving essential purposes for biodiversity conservation and watershed quality maintenance. The eastern coastal lands experience the most risk from sea-level rise and flooding especially in regions adjacent to the Gulf of Aden. The proper understanding of elevation patterns serves as a foundation for establishing infrastructure plans alongside efforts for flood protection and

strategies for climate adaptation. The implementation of elevation data through GIS-based decision systems assists stakeholders to maximize land usage and develop sustainable development strategies as well as enhance disaster preparedness in Djibouti.

4.3. Slope

The geomorphological studies along with hydrological research heavily depend on slope measurements because this factor defines runoff speed and land erosion and stability conditions. Djibouti's wide range of topography requires slope pattern evaluation to conduct flood risk assessments and urban planning and environmental management activities (Mouhoumed et al., 2023). The provided slope map shows how slope gradients change throughout the entire spatial extent of Djibouti. The slope gradient values stretch between flat 0 degrees slopes and steep 67.77 degrees slopes. A slope color gradient extends from dark blue which signifies low slopes to yellow and red scales indicating increasing slope steepness.

The western sections along with central regions show primarily rugged geographical features because steep slopes dominate the region. The volcanic nature of Djibouti proves itself through its highlands as well as its escarpments that make up its geological features. The eastern coastal section alongside the low slope areas provides ideal conditions for development infrastructure and residential settlement constructions. Rapid surface runoff forms when slopes are steep thus increasing chances of flash floods in low-lying zones. Water accumulation risks increase during heavy rainfall mostly in level regions adjacent to water bodies.

Soil erosion together with landslides become major problems in high-slope regions because they create unfavorable conditions for agricultural cultivation. The development of sustainable areas demands planners to evaluate slopes because they need to prevent building things where landslides or flooding is likely to occur. Djibouti requires slope distribution knowledge to develop effective land use plans and protect its environment from natural disasters. Analyzing slope data alongside GIS-enabled research enables authorities to create plans that reduce natural disaster risks and build better resilient communities.

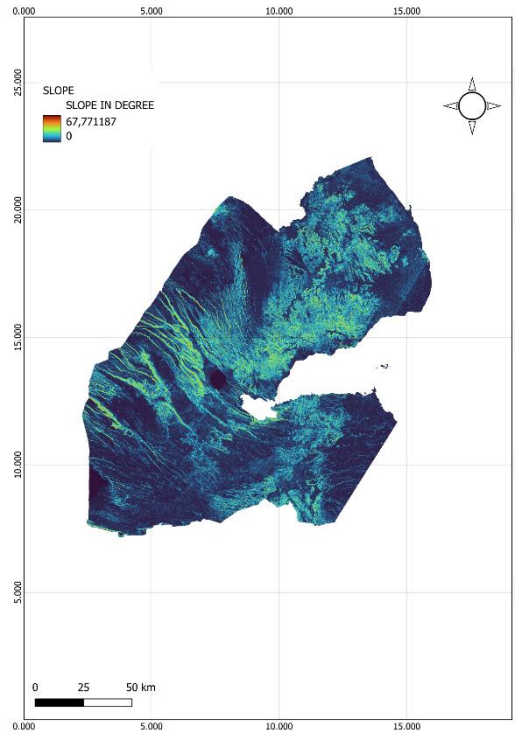


Figure 8 : Slope Map of the Republic of Djibouti

4.4. Height Above Nearest Drainage (HAND)

A Djibouti Height Above Nearest Drainage (HAND) map demonstrates its worth as a flood risk evaluation instrument by showing elevation differences near drainage channels. Danger zones for flooding begin at areas where HAND values approach zero because these places lie closest to drainage channels. The arid terrain of Djibouti makes low-lying zones more susceptible to flooding because water flows rapidly through wadis which are ephemeral riverbeds after sudden rainwater occurs. The color scheme of the map uses grayscale intensity gradients to display HAND values where darker zones show positions at higher risk of flooding including towns and farms besides valuable infrastructure situated close to drainage systems.

The identified HAND values extending to 25 meters demonstrate that the elevation changes across the area are substantial. Areas colored with higher HAND values tend to be detected as elevated plateaus and mountainous territory and have less risk for flooding conditions. The exceptional HAND value of 605,278 remains an experimental or statistical error which renders it unfit for practical use in flood risk assessments. The mapping scale at 50 km magnitude shows that the map offers comprehensive coverage for regional flood risk assessment however it fails to deliver specific information necessary for site-level planning needs.

The topographical map enables authorities to pinpoint zones that merit first attention for flood control mitigation efforts including warning systems together with drainage enhancements and land usage regulations. The areas located in the Low HAND category need extra attention for monitoring because they contain human settlements together with economic activities. The map functions as a tool to facilitate hydrological modeling because it displays natural water flow patterns together with areas that may experience flooding. Incorporating more detailed elevation data together with extreme values assessment would boost the accuracy and practicality of such decision-making solutions in regions prone to flooding in Djibouti.

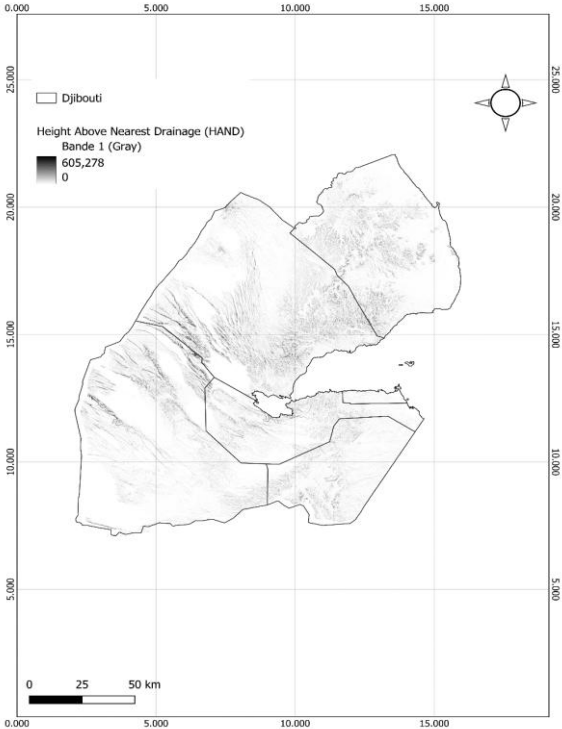


Figure 9 : Height Above Nearest Drainage Map

4.5. Precipitation Trends in Djibouti (1954–2007)

The provided precipitation maps display rainfall distribution throughout Djibouti between 1954-1961, 1962-1969, 1970-1977, 2000-2007 and 2008-2015. Annual precipitation rates across the region correspond to specific color categories starting from black for extremely wet areas with more than 200 mm of rainfall and ending with yellow for regions receiving less than 50 mm.

During the period of 1954-1977 significant high rainfall events occurred throughout most areas in Djibouti. Dark blue and black coloring covers extensive parts of the maps which indicate that

precipitation reaches levels exceeding 150 mm annually. Precipitation levels were higher throughout most of Djibouti during these twenty years. Significant changes manifest in the rainfall patterns between 2000 and 2015 when compared to earlier time periods. The western portion of Djibouti recorded substantial precipitation decline which becomes evident through the spread of yellow-colored areas in central and southern parts of the region. Accumulated evidence shows how the climate has become increasingly arid throughout recent periods.

The maps demonstrate how rainfall amounts differ greatly between Djibouti's several geographical areas. Northwestern areas together with highland regions receive more rainfall than Djibouti-ville and Loyada as well as other lowland coastal zones including Randa and Tadjourah. Topography determines precipitation distribution in the territory since elevated regions accumulate greater amounts of precipitation because of orographic influences.

The systematic rainfall decrease demonstrates a definite relationship with planetary climate transformation which enhances the dryness conditions and water shortages in Djibouti. The changing precipitation patterns affect key economic sections including farming systems along with groundwater refreshment resources and societal water provision.

An increase in rainfall during the earlier periods potentially raised flooding risks for flood-prone low spots that experienced surface runoff. The ongoing reduction in rainfall patterns creates critical water scarcity issues because it demands immediate adoption of adaptive measures in water resource management to overcome this dryness problem.

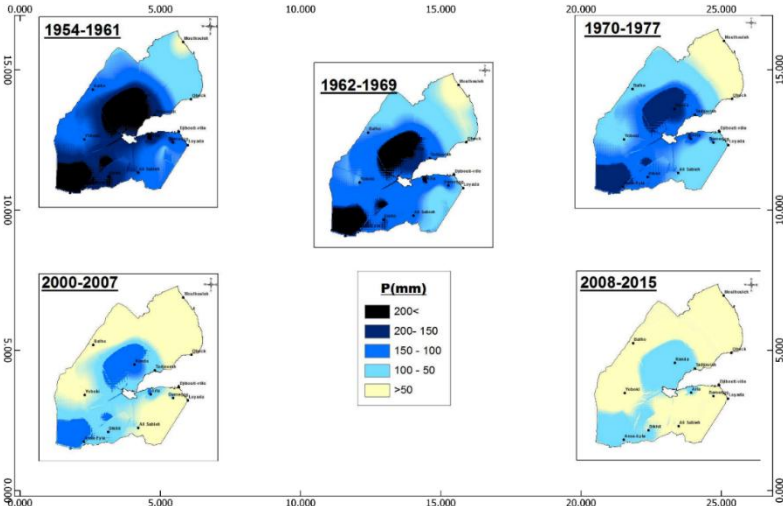


Figure 10 : Precipitation Trends in Djibouti Map

4.6. Population Density

A 2024 Population Density Map of Djibouti presents vital information about how Djiboutians distribute themselves across the nation that supports flood risk assessment and climate change impact understanding. Population density stands as an essential element in extreme weather vulnerability evaluation because dense people areas face increased risks during floods and experience heatwaves and water-related shortages. This distribution appears on the map through a color system that shows dense and thin population areas.

Djibouti City together with its neighboring zone exhibits the most active human settlement where people densify up to 3962 individuals per square kilometer. The economic and administrative hub of this country appears in the darkest zone. Djibouti City lies at a low elevation by the coastline making it extremely susceptible to the effects of rising sea levels as well as storm surges and intense rainfall events. The expansion of people living in flood-prone locations results in elevated displacement numbers and increased damage to infrastructure and elevated waterborne disease rates. Flood risk management requires immediate focus because poor drainage systems along with informal settlements combine to enhance these vulnerabilities.

The population density in Arta and Ali Sabieh reaches from 18 up to 676 persons per square kilometer classifies them as moderate to high-density locations. The deep red colored areas are witnessing urban expansion and infrastructure development activities which enhance their exposure to climate-related risks. These areas will encounter flash floods together with droughts and soil erosion because of changing precipitation patterns and increasing frequency of extreme weather events. The risks these areas face can be minimized by carrying out suitable urban planning alongside climate adaptive development of infrastructure coupled with early warning systems.

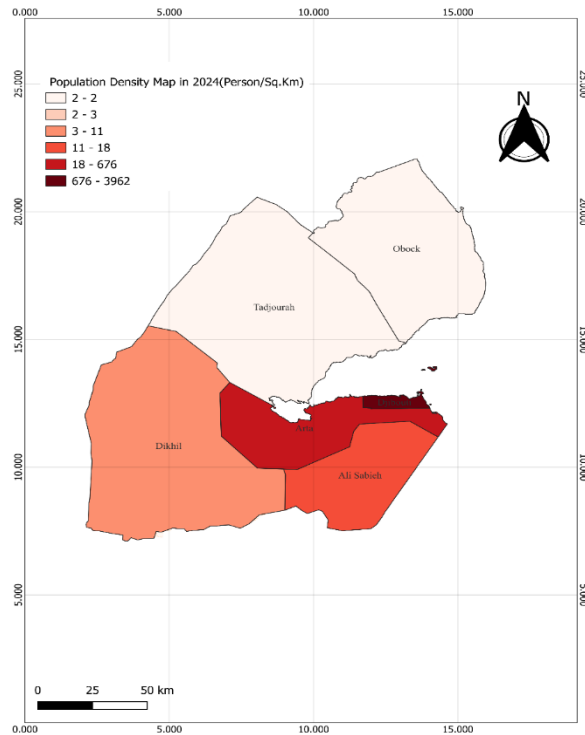


Figure 11 : Population Density Map

4.7. Aspect Analysis

The aspect map of Djibouti allows essential insight into how climate change can affect flood risks by using the "Bande 1 (Gray)" raster layer information. Slope direction known as aspect determines the facing direction of hills that affects both solar exposure and soil water content and runoff quantity. Climatic conditions in the arid to semi-arid region of Djibouti make this analysis beneficial because slight changes in these key elements directly influence both hydrological processes and flood exposure.

The majority of the landscape extends from south to south-eastward directions as shown through the abundance of yellow tones (143-288 degrees) in the legend. Large parts of Djibouti experience high solar radiation levels that result in greater evapotranspiration and possibly drier ground conditions. Environmental changes related to climate change will likely worsen dry conditions while simultaneously speeding up water flow patterns during heavy rainfall incidents because of elevated temperatures. Soil moisture tends to be elevated in areas having northerly aspects identified through dark blue tones (≤ 143 degrees) because these zones receive less

direct solar exposure. The specific areas respond differently to rainfall because saturated soil will lead to increased surface runoff.

The different aspects across the study area do not appear evenly dispersed. The southwesterly direction predominates in both the central and southwestern parts of the area probably because these regions stand under the influence of particular geological structures and land contours. Historical flood risk evaluations need to account for aspect-specific local effects because aspect distributions throughout the study area show spatial variation. Rapid runoff effects flash floods more intensely within regions with steep southerly slopes after droughts cause the soil surface to become hardened.

The influence of aspect on vegetation cover stands as an essential factor. Djibouti experiences low vegetation cover so modifications in microclimates caused by aspect variations could transform the natural vegetation distribution which will affect soil stability and soil infiltration rates. The modification of flood events depends on aspect-related climate changes. Using these direct and indirect relationships the thesis requires to build precise flood risk using Web-GIS.

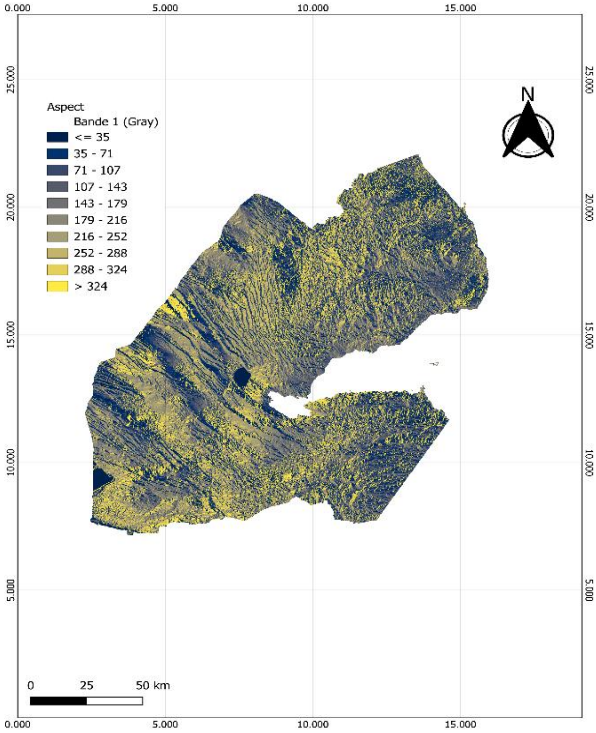


Figure 12 : Aspect map of Djibouti

4.8. Hillshade Map of Djibouti

Elaborating on sustainable flood risk assessments requires an understanding of the diverse topography in Djibouti where the hillshade map presents multiple terrain illumination patterns using blue to orange gradients. Terrain illumination variations emerge through a gradient spanning from dark blue to yellow-orange on the map thus it emphasizes both the slopes and shadows within the region. The northern section together with the western section of Djibouti feature a densely patterned design which results from multiple darker and lighter color combinations. The rugged appearance reveals mountains with steep inclines together with deep valleys thus indicating that runoff moves quickly during heavy rainfall. Those elevations create shadows that expose natural channels and depressions which function as water pathways leading to flash floods in those areas.

The coastal regions spanning the Gulf of Tadjourah and the Bab-El-Mandeb Strait appear smooth in the surface modeling due to their lower textured appearance. Such flat landscape features aspect a reduced potential for flash flooding although they introduce different types of threats. The flat regions located near sea level face two potential threats including rising sea levels and drainage system overflows that can flood their territory. The central region particularly Lake Assal shows a basin shape which defines its particular low relief terrain. This location functions naturally to collect excess water from the higher terrain thus making itself a potential flood zone especially during intense rainfall.

Through its visual representation the hillshade map acts as a substitute for following the solar radiation distribution across different areas of land. The south-facing slopes stand out through their bright yellow-orange coloring which indicates they receive greater direct sunlight exposure that increases soil evapotranspiration rates. Nearing north at the landscape receives little direct solar exposure through its dark blue coloration so moisture may stay on the surface longer.

Soil stability along with vegetation coverage respond to variations in soil moisture that result in modified runoff and flood vulnerabilities. The informative map demonstrates that topographic situations need to be taken into account when evaluating flood damage potential in Djibouti. Hydrological processes are significantly influenced by the complex interactions

between slopes, shadows, and drainage patterns shown through the hillshade map thus these processes must be included in a complete flood risk evaluation under climate change conditions.

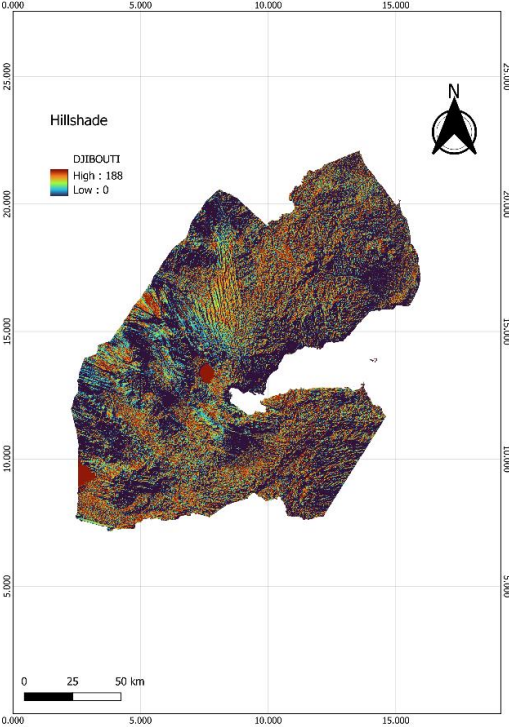


Figure 13 : Hillshade Map

4.9. Land Use and Land Cover Classification

Environmental processes like flooding receive substantial impact from land use and land cover (LULC) since they act as fundamental elements for spatial surface distribution understanding. The study area contains six main classes based on land use and land cover (Figure 14) which summarize the region as urban regions along with water bodies and forests and drylands and mountain areas and other land types. The six categories of the classification system present unique geographical features that impact hydrological processes and both surface runoff patterns and the degree of flood exposure.

Urban areas as depicted in blue occupy the northeastern corner of the study area. The northern segment of Djibouti City exists in this designated area because it represents the capital city. The expansion of cities changes the natural water cycle because urban developers convert a large amount of land into non-permeable roads and buildings and paved areas. Water cannot penetrate

these flooded surface types so runoff quantity increases which makes cities vulnerable to overwhelming flooding when heavy rains occur.

The light blue markings indicate water bodies which occur scattered throughout different locations of the region. The area contains a combination of man-made and organic water structures ranging from lakes to reservoirs and coastal seawater locations. These water areas function as vital water sources but experience flood dangers whenever heavy precipitation exceeds their capacity to drain or deplete surrounding lower land areas.

The study area displays scattered forest cover which is marked with green. Forest areas perform essential functions by retaining water and stabilizing soil while reducing flood damage across the landscape. The vegetation in these flood-prone zones takes in precipitation thus slowing flood water flow and reducing flooding danger. Declining forest areas through deforestation or land degradation will create conditions that enhance soil erosion and produce flooding in lower regions.

The yellow-colored dryland territories occupy broad regions throughout the area and include semi-arid territories with little vegetation. The regions become highly vulnerable to soil degradation together with erosion issues when vegetation cover disappears. Drylands may lead to quick flood formation during heavy rainfalls based on soil properties since dense and minimally absorbing soils will generate these events.

Purple-colored mountainous regions cover vast areas within the inland parts of the territory. The elevated zones act as critical drainage systems because their runoff becomes the source for surface waters in lower geographic regions. Although most flooding occurs less frequently in mountains their sloping terrain generates rapid runoff and erosion that affects settlements and infrastructure in the lower areas.

The brown/olive-colored portion shows a collection of land types which include bare lands together with grasslands and transitional zones. The distinct vegetative cover along with different soil features within these zones determines how runoff is generated and flood vulnerability becomes apparent. Among the regions there exist buffer areas which generate less severe flooding effects but those which consist of bare lands demonstrate increased surface water volume and soil destruction.

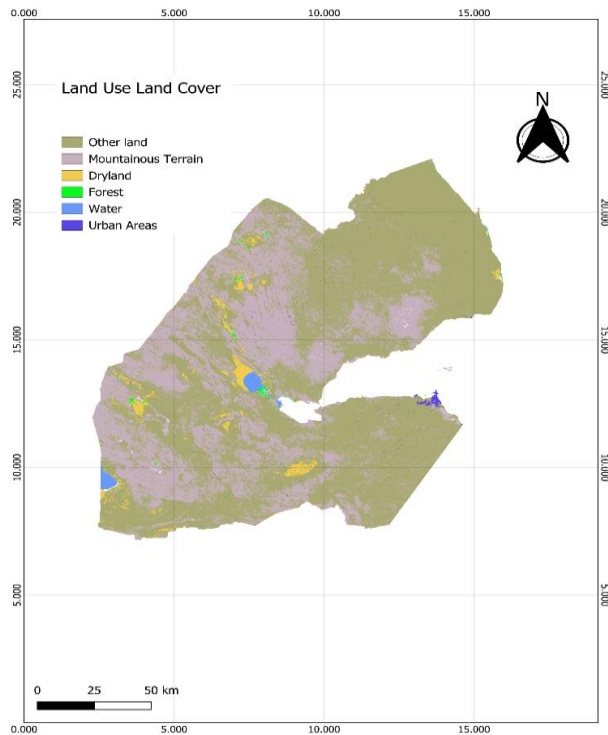


Figure 14 : Land Use and Land Cover Map

4.10. Distance to Rivers

The flood risk assessment heavily depends on river proximity due to riverbank areas facing elevated flooding danger from water overflow incidents and surface runoff accumulation. The Flow Distance map of Djibouti (Figure 15) divides the study area into five categories of flood hazard zones through its assessment of river network distances. Mobile application users can easily monitor flood hazards which distribute from very high hazard zones (0–9 km) to very low hazard zones (>138 km").

The high flood vulnerability spans from 0–9 km surrounding rivers (marked by red) because this range of the study area faces maximum flood hazards from river water movement. The country's dry climate as well as unpredictable severe storms generates conditions that lead to the formation of flash floods in previously chosen zones. Similarly, areas within 9–30 km (yellow) still experience a high flood hazard, especially in low-lying terrains or locations with poor drainage infrastructure. Proper strategic planning should be implemented for these areas to reduce their exposure to expected flood risks.

Flood susceptibility in regions located within the moderate hazard zone (30–66 km, green) is low even though localized flooding can occur because of surface runoff and land topographical features. The brown-colored part from 66–138 km shows low riverine flood risk yet localized flash floods and poor drainage operations might result from severe weather conditions or inadequate urban drainage practices. Floods caused by river systems have minimal impact on the very low hazard zone areas beyond 138 km distance due to their remote location from watercourses. Nevertheless, this area remains vulnerable to localized flooding from factors such as urban development and soil drainage properties and weather-related extremes.

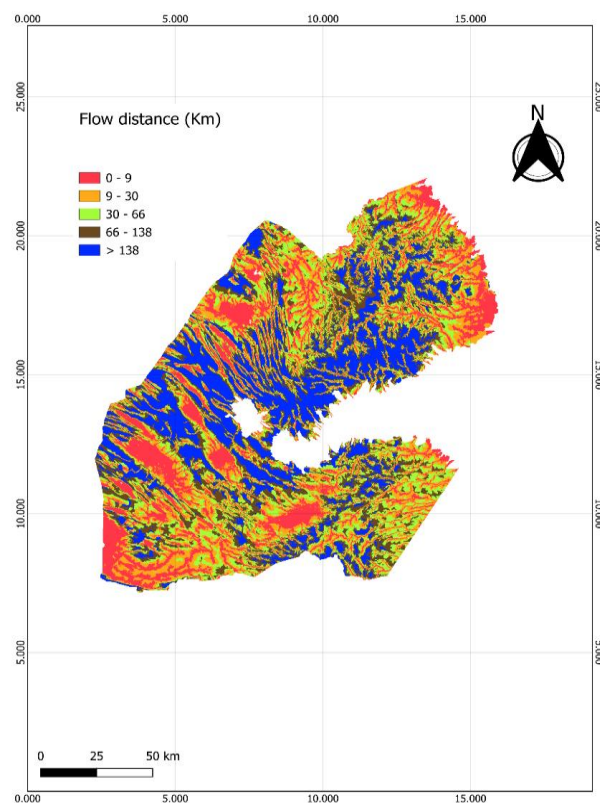


Figure 15 : Flow Distance Map

4.11. Topographic Wetness Index (TWI) Analysis for Djibouti

The Topographic Wetness Index (TWI) functions as an essential hydrological parameter to evaluate how water accumulates and how soil moisture distributes across various topographic areas. A TWI map of Djibouti utilizes the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) to generate data that has been processed in ArcGIS 10.8 with a north orientated view according to the compass rose. On the lowest map segment, a 25-kilometer

distance equals [screen measure value amount] centimeters. The TWI index serves a vital function because it enables users to assess flood-prone zones together with soil moisture content and water movement patterns to help administrators reduce natural disasters and protect the environment better.

The TWI values across Djibouti fall within five distinctive groups starting from low at 0–7 and proceeding through 7–11, 11–15, 15–19 and finally exceeding 19 which indicates high values. Water drainage in steep mountainous regions leads to minimum moisture retention thus creating dark purple areas with TWI values between 0 and 7. These areas are located in the northern and central parts of the study area. The moist content and flood risk are lowest in these geologic areas.

The blue to green color scheme shows moderate water retention capacity in areas which fit into both the 7–11 TWI class and the 11–15 TWI class. Transition areas located between runoff zones at mountain elevations and flood zones in lower elevations show gentler slopes which form these transitional regions. Numerous wadis that originate in the mountains and travel towards the coast form an obvious direct pattern of increased TWI on the TWI map.

Water accumulation naturally occurs in low-lying areas and valleys or depressions of western and southern Djibouti which display TWI values between 15–19 and above 19. This data is depicted in the map through yellow and brown colors. During heavy rainfall such areas experience high levels of flooding risk due to their elevated vulnerability. TWI measurements reach elevated heights across the coastal regions as well as in other strategic low-lying parts.

The TWI values spread across Djibouti territory show different flood risk levels throughout its regions. The arid meteorological climate of Djibouti supports the appearance of high TWI values within low coastal areas and depressions. The resulting analysis demonstrates that TWI data should be used together with land-use planning procedures and hydrological assessments along with climate models to create effective flood prevention systems.

The TWI distribution patterns of Djibouti provide fundamental information that enables better planning of cities and disaster prevention and climate response strategies. Policymakers and research teams can enhance drainage systems as well as flood prediction systems by analyzing these data sets to create better sustainable management practices. The findings from TWI

analysis will support designing resilient infrastructure that promotes the sustainable growth of urban and rural communities in Djibouti.

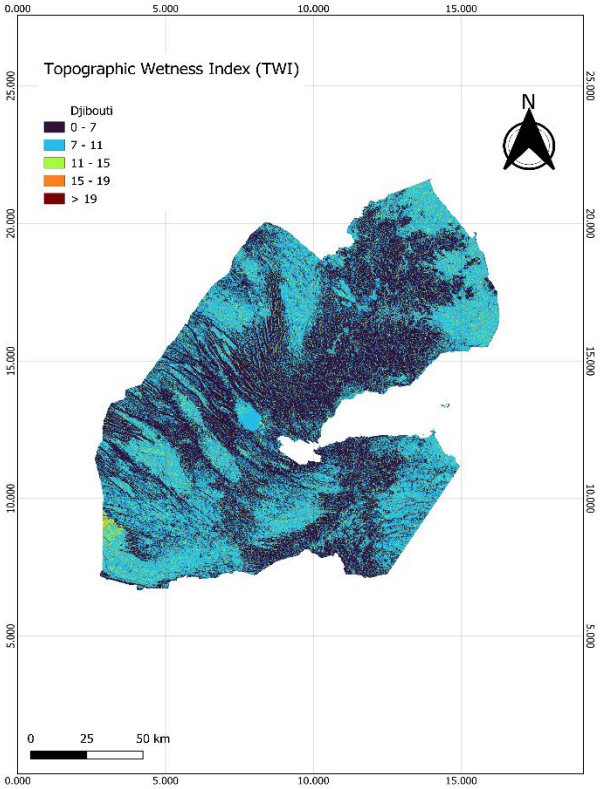


Figure 16 : Topographic Wetness Index Map

4.12. Stream Power Index in the Context of Flood Risk

The Stream Power Index (SPI) tool for assessing flood risks showcases different zones of erosive water patterns throughout the entire nation of Djibouti. The SPI values are displayed through colored raster cells which distribute stream power data from zero to 4 (green) towards stream power exceeding 67 (dark red). The map presents water flow dynamics through a directional north-up orientation backed by a compass rose and it displays a 25-kilometer measurement scale. The southwestern area displays generally low stream power characteristics because its SPI values indicate reduced power rates and sluggish water movement.

The flat areas along with depressions in the landscape indicate regions where water accumulation would be possible which increases flood exposure. The northern part of the area together with central areas show high SPI measurements that are primarily located across discernible drainage systems. Fast-moving water occurs mainly in this terrain which contains

sharp inclines and runs with intense flow speed indicating limited flood risk yet high potential for torrential flow during heavy precipitation.

The central and eastern areas display widespread yellow to orange colors indicating that moderate water flow exists along with water risks that correspond to those areas. The SPI map serves as a vital resource for flood risk management since data shows climate change will boost rainfall intensity. The areas showing low SPI need specific efforts for implementing flood control measures since the regions with high SPI require regular flash flood monitoring. The combination of SPI data with additional relevant datasets into a Web-GIS platform will support superior flood risk evaluations and intelligent choices for land management sustainability in Djibouti.

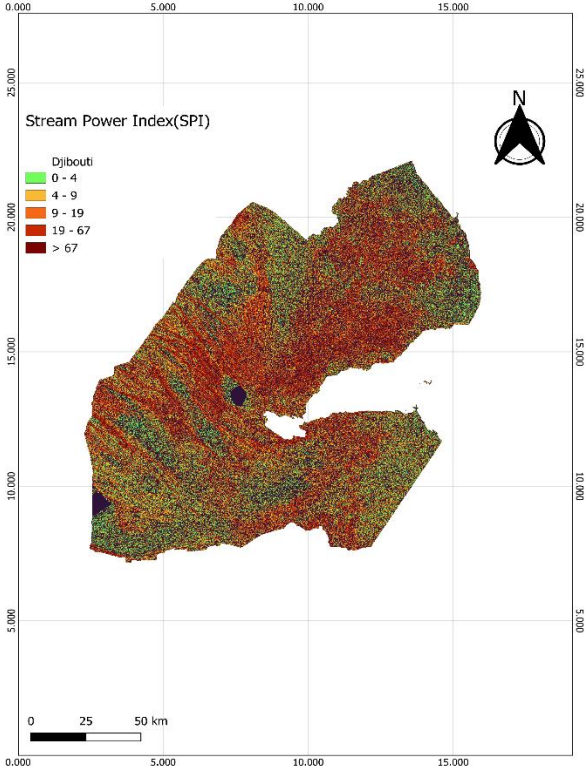


Figure 17 : Stream Power Index Map

4.13. Flood Risk Map

Decision-makers use flood risk maps to determine which areas experience the highest flood risks for effective flood risk mitigation purposes. Detailed spatial visualizations through these maps help governments make better decisions regarding planning alongside infrastructure

implementations for decreasing disaster risks. Figure X displays the flood risk map of the study area which shows different degrees of flood potential throughout its territories.

The black areas on the map represent regions with a very low flood risk. The mountainous territories possess steep slopes that efficiently drain water to prevent flooding. Nationwide these high-altitude areas with natural drainage operations show minimal flood exposure which makes them the safest areas according to the map. Rocks inside these areas and permeable soils work together to allow water to move deeper into the ground which stops water from running across the surface.

Low flood risk classifications appear in gray-colored sections on the map. These areas consist of low-lying and elevated terrain which experience short-term waterlogging because natural drainage operations stop flooding from becoming severe. These regions face less flood danger except when heavy rainfall triggers flooding because poor soil permeability prevents water absorption as well as bare terrains obscure water drainage.

White-colored regions show moderate positions regarding the risk of flooding. Water collection occurs at these regions because they function as connections between elevated and bottom terrain which create areas where water collects because of smooth hillsides and limited drainage capability. Areas designated as moderately susceptible to flooding receive water only periodically but especially during heavy rainfall events. Waterlogging together with temporary inundation grows worse as a result of faulty drainage systems in these regions. Proper land-use planning with improved stormwater management systems acts as the fundamental solution for reducing flood risks in these zones.

The high flood risk occurs within areas marked in orange. Alluvial plains together with river valleys as well as low topographic relief regions mark the typical areas where these regions exist. These regions maintain high flood vulnerability because of their geographical features which make them vulnerable to floods during heavy rainfall and extreme weather conditions. Flood vulnerability rises through human-caused deforestation and urbanization because these activities diminish groundwater intake and produce additional water runoff on the surface. Strategic flood management techniques for these areas must include better drainage infrastructure as well as sustainable land-use policies together with tree planting initiatives.

The red-colored areas demonstrate an extreme flood hazard. These vulnerable areas exist in coastal plains together with riverbanks together with low-lying urban districts where frequent prolonged water aggregation is normal. Poor drainage capacity alongside low elevations and

stressful weather events results in the most severe flooding conditions for these areas. The high flood risk in Djibouti results from expanding urban areas together with poor drainage infrastructure located in high-risk areas which causes multiple flooding events that endanger both populated areas and built infrastructure. The situation becomes worse as both sea-level rises together with rainfall intensity increase due to climate change. High-risk flood areas must benefit from flood-resistant infrastructure which must be accompanied by improved early warning systems along with adapted climate management measures.

The flood risk map generates beneficial knowledge about how flood hazards spread throughout the investigation area. Strategic flood mitigation programs can be developed to protect vulnerable areas after decision-makers identify regions with elevated flood risk. The gathered data stands essential for both damage reduction and community safeguarding in addition to supporting sustainable flood-prone area development.

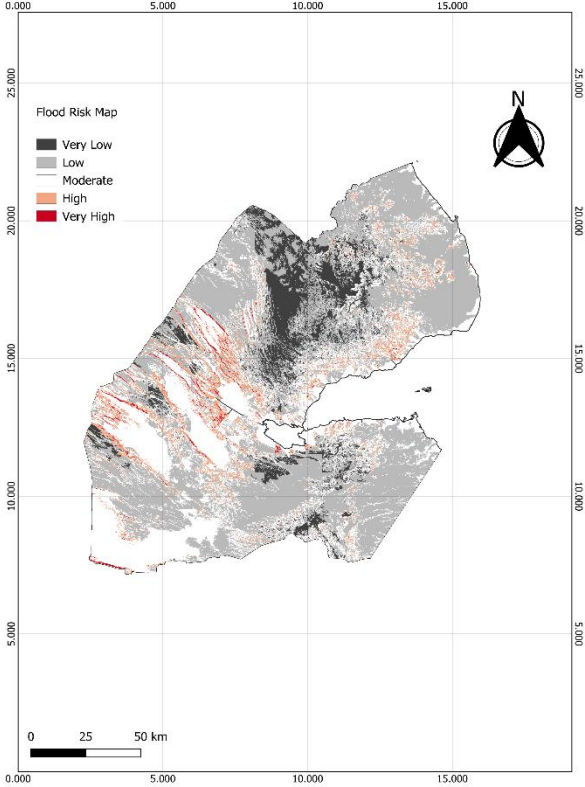


Figure 18 : Flood Risk Map

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

The developed Web-GIS platform provides solutions to enhance flood risk management in Djibouti while addressing local challenges. The study brought together data about climate change alongside spatial technologies along with public participation to develop an interactive framework that supports flood risk measurements and reduction efforts.

The analysis of elevation, slope, precipitation trends, population density and hydrological and topographical features demonstrated that Djibouti faces major flood risks in its lowlands especially surrounding the urban center of Djibouti City. Studied data demonstrates how flood threats rise from intensified urbanization together with climate change shifts and this calls for instant adaptive management practices.

Users can easily visualize flood hazards through this Web-GIS platform as it helps them assess risk levels by sharing real-time data between stakeholders effectively. The platform incorporates climate change projections to deliver assessments which allow people to take proactive measures in flood risk management and make better decisions. The validation methods that combined field verification with historical flood records authentication established that the platform-generated flood risk maps remain precise and steadfast.

The research confirms that advanced technology systems such as GIS and Web-GIS remain essential for improving flood resistance measures in Djibouti. The study exhibits the requirement for government agencies to unite with local communities and international partners to solve urbanization and climate change difficulties. The developed Web-GIS platform serves as a basic instrument that supports regional flood risk management and assessment through collaborative initiatives.

5.2. Recommendations

The following suggestions aim to improve flood risk management in Djibouti based on research conclusions:

Enhance Data Collection and Integration:

The acquisition of high-resolution remote sensing devices and extensive field investigation will complete data coverage especially in distant regions. The creation of an improved and precise flood risk management database will be ensured through these recommendations.

Creating a single database for hydrological, meteorological and socio-economic data will establish consistency and promote stakeholder data sharing while improving accessibility to the built database system.

Strengthen the Web-GIS Platform:

The system should implement an integration of live meteorological data and warning systems to boost predictive abilities so that crucial alerts reach vulnerable populations in a timely manner.

The platform should receive additional capabilities through AI and ML and automated flood risk assessment and alert functions to make flood management processes more efficient and precise.

Community Engagement and Capacity Building

Conduct flood preparedness training for local authorities and residents.

Promote participatory mapping to incorporate indigenous knowledge into risk assessments.

Use mobile applications linked to the Web-GIS platform for real-time flood reporting.

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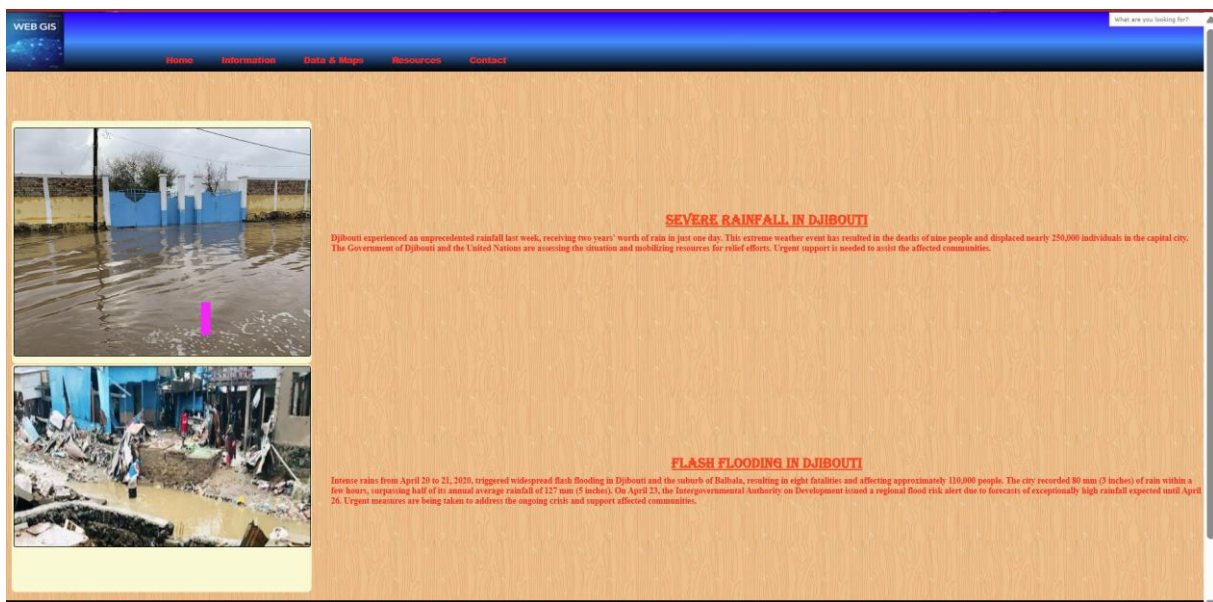
APPENDICES

Web-GIS Platform Presentation Images (Home Page)

Study Area



Impacts of flooding



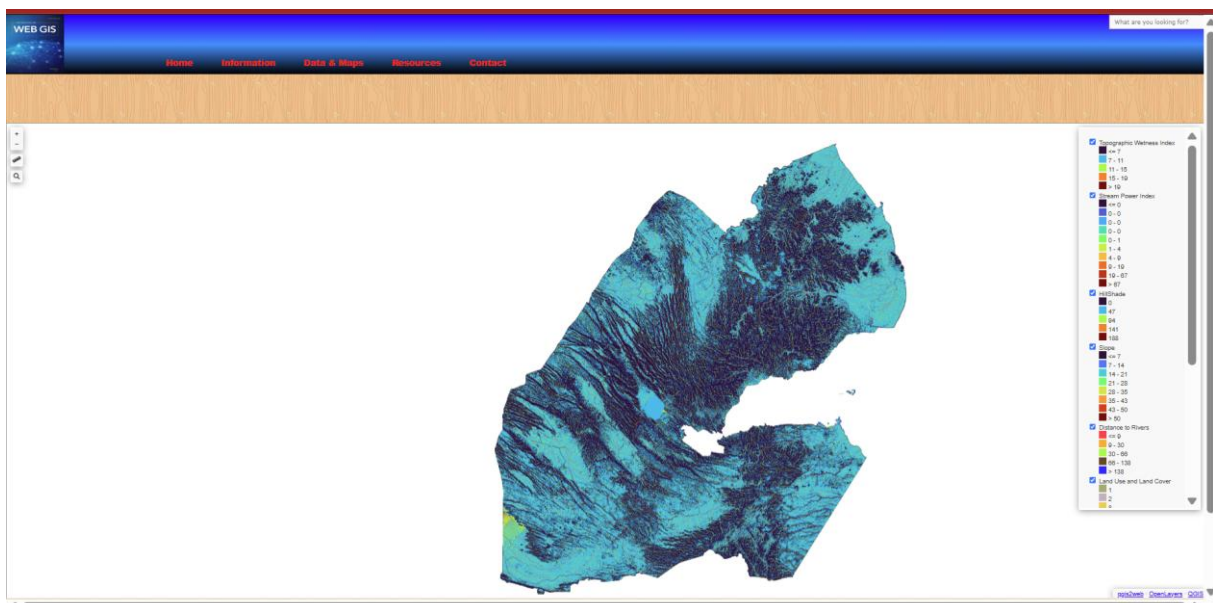
Submission Directly for flood reports

The image shows a web form for submitting flood observations, set against a light wood-grain background. The form is enclosed in a red rectangular border and contains the following fields and options:

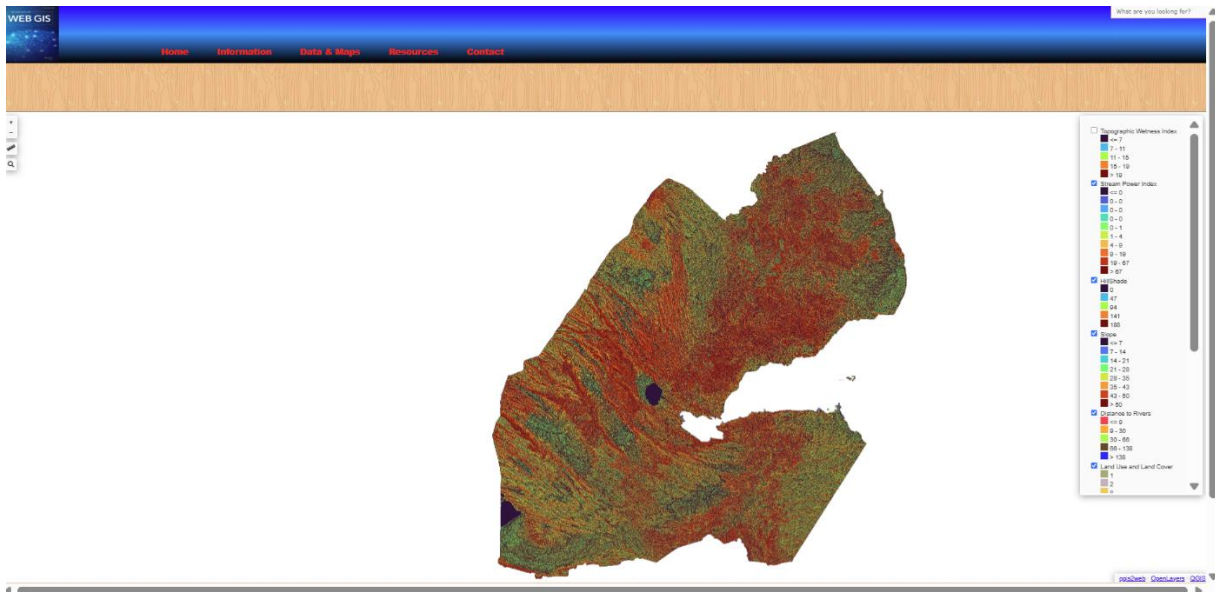
- Observation Title:** A text input field with the placeholder text "Enter the title of your observation".
- Observation Category:** A dropdown menu with the selected option "«Choose a category»".
- Observation Description:** A large text area for entering details.
- Observation Type:** Two radio button options: "Direct Observation" (which is selected) and "Community Report".
- Email Address:** A text input field.
- Phone Number:** A text input field with the placeholder text "Optional".
- Submit Observation:** A red button at the bottom of the form.

Mapping Page

TWI



SPI



Mapping Codes

```
1
2 <!DOCTYPE html>
3 <html>
4   <head>
5     <title>Flooding Information Portal</title>
6     <meta charset="utf-8">
7     <link rel="stylesheet" type="text/css" href="CSS/style.css">
8   </head>
9   <body background="IMAGE/images (35).jpg">
10    <div id="global" style="border: 0px solid yellow;width: 100%;height: 100%">
11      <div id="header">
12        <input id="recherche" name="q" class="input-search" placeholder="What are you looking for?"
13          type="search">
14        <a href="index.html"></a>
15        <ul>
16          <li><a href="index.html">Home</a></li>
17          <li><a href="">Information</a>
18        <ul id="ans">
19          <li><a href="Causes.html">Causes</a></li>
20          <li><a href="Impact.html">Impact</a></li>
21        </ul>
22        <li><a href="">Data & Maps</a>
23        <ul id="ans">
24          <li><a href="Recent-Floods.html">Recent Floods</a></li>
25          <li><a href="Mapping.html">Mapping</a></li>
26        </ul>
27        <li><a href="">
28        <ul id="ans">
29          <li><a href="Inscripton.html">Resources</a></li>
30          <li><a href="Connectez-vous.html">Contact</a></li>
31        </ul>
32      </div>
33    </div>
34    <iframe src="Maps/index.html" style="width: 100%; height: 1000px; margin-top: 100px;"></iframe>
35
```

Line 29, Column 97

Tab Size: 8