Building Coastal City Resilience and Extreme Heat Action in Zanzibar, Tanzania through Multi-Hazard Risk Assessment (MHRA)

Red Cross Red Crescent Climate Centre

by

Anushka Shahdadpuri

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Authored by: Anushka Shahdadpuri
Department of Urban Studies and Planning
15 May 2024

Certified by: Brent D. Ryan
Vice Provost, Professor of Urban Design and Public Policy
Department of Urban Studies and Planning
Thesis supervisor

Accepted by: J. Phillip Thompson
Professor of Political Science and Urban Planning, MCP Committee Chair
Department of Urban Studies and Planning

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Abstract

The Coastal City Resilience and Extreme Heat Action Project (CoCHAP) is an ongoing initiative of the Red Cross Red Crescent Climate Center that aims to build climate resilience in urban areas, particularly addressing extreme heat and coastal threats in Southeast Asia, Latin America, and East Africa. This project is conducted in collaboration with the International Federation of Red Cross and Red Crescent Societies (IFRC), American Red Cross (Am. RC), Global Disaster Preparedness Center, and the National Red Cross Societies. As part of CoCHAP, this thesis investigates the spatial vulnerabilities of compound risks related to heatwaves and flooding in Zanzibar, East Africa, in partnership with the Tanzania Red Cross Society (TRCS). Recent increase in temperature and precipitation have heightened Zanzibar's vulnerability. With one of the highest population densities in Africa, the region's economy heavily relies on climate-sensitive activities such as agriculture, tourism, and fishing, making it the most climate-vulnerable small island region. To understand the region's dichotomous predicament, I analyze the location-dependent climatic, socio-economic, physiological, and environmental parameters using a Multi-Hazard Risk Assessment (MHRA). The assessment evaluates three latent variables — exposure, vulnerability, and hazard — derived from remote sensing and household census survey (HCS) data. Principal component analysis and spatial analysis techniques were employed to assess the weighted vulnerability of over 100 wards (the smallest administrative zones) to both heat and flood risk. I find that while the hazard factor itself, does not pose a major risk in Zanzibar, the socio-economic conditions, coupled with inflexible planning under neoliberal frameworks, exacerbate risks, particularly in urban wards. This is evident in the distribution of flood and heat risk, which is random throughout the island city, although high land surface temperatures and precipitation are concentrated around existing built-up coastal areas. 20 wards were identified as highly vulnerable to heatwaves and coastal flooding, revealing nuanced variations in multi-risk distribution across urban, suburban, and agrarian areas, influenced by gradients from coastal low-elevation to high-elevation inland zones. Notably, tourism-dependent wards emerge as potential areas for synergistic ecological and economic gains. These findings offer crucial insights for the TRCS, informing tailored adaptation plans as part of the Zanzibar Climate Change Alliance: City Wide Risk Assessment (CWRA).

Thesis supervisor: Brent D. Ryan
Title: Vice Provost, Professor of Urban Design and Public Policy Department of Urban Studies and Planning, Massachusetts Institute of Technology

Thesis Co-advisor: Sumeeta Srinivasan
Assistant Professor, Urban & Environmental Policy & Planning, Tufts University

Thesis Reader: Norhan Bayomi
Research Scientist, Massachusetts Institute of Technology

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Acronyms

AM CROSS: American Red Cross
COCHAP: Coastal City Resilience and Extreme Heat Action Project
CWRA: City Wide Risk Assessment
DOE: Department of Environment
DoLR: Department of Land and Resources
EIA: Environmental Impact Assessment
IFRC: International Federation of Red Cross Red Crescent
LCLU: Land Cover and Land Use
LST: Land Surface Temperature
MHRA: Multi Hazard Risk Assessment
MHRI: Multi Hazard Risk Index
MMR: Mjini Magharibi Region
NDBI: Normalized Difference Built-up Index
NDVI: Normalized Difference Vegetation Index
OLI: Operational Land Imager
RCRCC: Red Cross Red Crescent Climate Center
TIRS: Thermal Infrared Sensor
TRSC: Tanzania Red Cross Service Center
URT: United Republic of Tanzania
UNDRR: United Nations Office for Disaster Risk Reduction
UNFCCC: United Nations Framework Convention on Climate Change
ZACCA: Zanzibar Climate Change Alliance
ZCCS: Zanzibar Climate Change Strategy
ZEMA: Zanzibar Environmental Management Authority

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1. Introduction

Coastal City Resilience and Extreme Heat Action Project (CoCHAP) and Red Cross Red Crescent Climate Center

The Global Disaster Preparedness Center (GDPC) in collaboration with Red Cross Red Crescent Climate Center, American Red Cross International Services (AmCross ISD), Red Cross Red Crescent (RCRC) National Societies Bangladesh, Honduras, Indonesia, and Tanzania is working on the Coastal City Resilience and Extreme Heat Action Project (CoCHAP). Funded by USAID. The Coast City Resilience project aims to build climate resilience of urban communities, particularly to extreme heat and coastal threats through expanding risk knowledge and strengthening local action in Southeast Asia, Latin America, and East Africa regions in nine secondary cities. Under this project, the RCRC National Societies will use its convening power to engage relevant partner organizations in lasting coalitions to focus city-wide expertise, capabilities, and resources on priority risks facing vulnerable communities in the city. The coalitions will complement existing urban governance processes led by local government and draw wider support from the private sector, universities, civil society organizations, and other stakeholders into city-wide civic engagement for community resilience. CoCHAP is a response to the call for increasing frequency and severity of extreme heat and coastal hazard events in the projected cities *(nine cities in Bangladesh, Indonesia, Honduras, and Tanzania)* for heightened collaboration between the National Societies and the RCRC Climate center to implement more strategic adaptation solutions that contribute to reduced disaster risk resilience.

Over the last few years, there has been growing recognition of the need to study the interrelationships between multiple hazards and their socio-economic dimensions, especially in the regions of East Africa, South America, and Asia Pacific. These regions have faced significant exposure to one or more hazards, with a predominant occurrence of both geophysical and hydro-meteorological-driven events. This vulnerability is exacerbated by the fact that a considerable portion of the population resides in areas prone to seismic activity and coastal hazards, such as fault lines and coastal zones. For instance, in Tanzania, the population has grappled with recurring droughts and floods, as evidenced by the events of 2021 (Pavur & Lakshmi, 2023). Similarly, Honduras has faced multiple climate-related hazards, including hurricanes, tropical storms, floods, droughts, and landslides. Between 1970 and 2019, the country experienced 82 disasters linked to natural phenomena, with the majority attributed to hydro-meteorological causes, according to the International Federation of Red Cross and Red Crescent Societies (IFRC).

Further, these regions, characterized by high exposure to climate hazards, are often more densely populated and less developed than average, posing significant risks of human and economic losses. For example, metropolitan regions in East Asia & Pacific (excluding high-income areas) exhibit a population density of 133 people per square kilometer, significantly higher than the 19.12 people per square kilometer observed in North American cities as of 2021(*World Bank Open Data*, 2022). The rapid urbanization in East Asia, particularly in cities like

Dhaka and Jakarta, has led to a staggering 2-3% increase in population within a single year from 2022 to 2023 (*Bangladesh Bureau of Statistics,* 2022). Which means the region absorbs 2 million new urban residents every month and are projected to triple their built-up areas in the coming two decades – exposure is increasing and will translate into heavy loss of life and property unless proactive measures are mainstreamed into urban planning processes. In East Africa, there has been a fourfold increase in the number of annual natural disasters over the past two decades (*East African Community, Disaster Risk Reduction and Management*, 2024). These disasters, which include coastal landslides triggered by storms, have the potential to damage critical infrastructure such as dams and reservoirs, exacerbating flood risks in the region. The complex interactions between various hazards further underscore the need for comprehensive risk assessment and proactive mitigation strategies to safeguard communities and infrastructure.

Different regions face varying levels of exposure to natural hazards due to their unique geographical and geological characteristics. For instance, some cities may confront only one type of hazard, like typhoons, yet the devastation caused by such an event can be overwhelming, as seen in the case of the Philippines. On the other hand, certain cities may be susceptible to a range of hazards, but these occurrences are rare, resulting in minimal impact, as evidenced in Alice Springs, Central Australia. While it may be susceptible to various hazards such as heatwaves, bushfires, and flash floods, these occurrences are relatively rare, leading to minimal impact on the town. Conversely, there are areas exposed to numerous hazards occurring frequently and with high intensity, such as Mumbai, India where annual monsoons and cyclones pose significant threats to the city's infrastructure and population. Even cities with currently low exposure to climate hazards, like coastal floods, may face escalating risks due to factors like sea-level rise induced by climate change, as observed in Tanzania, where coastal communities are increasingly vulnerable to the impacts of rising sea levels and coastal erosion. The consequences in terms of mortality, illness, and property damage may be more severe in cities experiencing frequent but relatively low-impact disasters cumulatively, compared to cities facing a single catastrophic event with a 500-year recurrence period.

Considerable work has been conducted around the world to assess risk to individual cities from individual hazards. Many cities have modeled seismic or flood risks, and advanced tools are available to support such efforts. However, assessing the theoretically and epistemically cumulative impacts of multiple hazards has not entered the mainstream of urban management practice around the world. The United Nations Office for Disaster Risk Reduction (UNDRR) : Sendai Framework Terminology on Disaster Risk Reduction (*Sendai Framework Terminology on Disaster Risk Reduction | UNDRR*, 2015) defines multi-hazards as “the selection of multiple major hazards that the country faces, and the specific contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects. A better understanding of the impacts of multiple hazards – including future hazards arising from climate change – can support more focused engagement and policy actions by various stakeholders, ranging from multilateral agencies to local governments. Understanding multi-hazard risk could help to prioritize interventions; it could also form the basis for major institutional, operational and policy adjustments that improve government and citizens capacities to better manage overall risk to hydro-meteorological hazards and compounding risks.

CoCHAP, through City-Wide Risk Assessments (CWRA) and Coalition Building (CB), aims to provide governments with insights into the concepts and interactions between climate change adaptation and urban vulnerabilities. The project comprises three key components aimed at addressing the complex challenges posed by multi-hazard events in urban environments.

a. **Epistemological** : This aspect of the project involves the creation of comprehensive factsheets focused on defying multi-hazard. These factsheets would be subdivided into six parts, provides guidance to local governments in the regions on the concepts of climate change and disaster risk reduction; how climate change consequences contribute to urban vulnerabilities; and what is being done by city governments around the world to actively engage in capacity building and capital investment programs for building resilience.

b. **Technical**: The purpose of this project is to develop a methodology for measuring multiple risks at the city level from natural hazards. The methodology will be tested and refined in applications of Tanzania, Africa. Assessing the impact of multi-hazards based on the framework defined in the study with the intention to aggregate effects of multiple hazards and highlight the differences in potential risks facing cities, particularly in African metropolitan regions. Historical data depicts that metropolitan regions in Africa have historically been exposed to at least four natural hazards (Lukamba, 2010) to a far higher degree than elsewhere in the world.

c. **Institutional and Regulatory:** Building on the insights gleaned from the factsheets and risk assessments, this component aims to develop training modules and guidelines to empower governments and communities in addressing multi-hazard challenges. Specifically, it seeks to support policymakers and planners in East African cities by providing decision support tools for assessing, mitigating, and benchmarking urban risks arising from natural hazards and climate change; (ii) national governments with tools to guide intergovernmental fiscal transfers geared toward translating national policy on disaster risk reduction and climate adaptation into local action; and (iii) international development partners with a standardized and rapid risk assessment at the city level that can help identify areas of greatest need as well as capacity to effectively utilize funding support.

1.1 CoCHAP in Tanzania, Zanzibar

While the CoCHAP project addresses multiple components, the thesis specifically explores the part b) technical aspect of risk related to coastal and heat vulnerability within the context of Tanzania, specifically Zanzibar. This focus is driven by two primary factors:

a) **In Tanzania the prevailing focus has been directed towards mitigating multi-hazard vulnerabilities to heatwaves and floods.**
Situated in East Africa, Tanzania's heavy reliance on rainfed agriculture for sustenance and income renders it highly susceptible to shifts in precipitation patterns, temperature fluctuations, and changes in atmospheric CO2 concentration. Recognizing these interconnected risks, the Red Cross Red Crescent and the Tanzania National Red Cross Society have worked to develop comprehensive city-wide risk assessments (CWRA) aimed at building climate resilience of urban communities.

b) **Existing City-Wide Risk Assessment (CWRA) and the Zanzibar Climate Change Alliance:** The Tanzania Red Cross (TRCS) with support from the American Red Cross (Am Cross) and International Federation of Red Cross Red Crescent (IFRC) with implementation of the Coastal City Resilience and Extreme Heat Action (CoCHAP) Project that funded by USAID Bureau for Humanitarian Assistance (BHA) in two cities of (Tanga-Mainland and Unguja-Zanzibar Island of Tanzania). The Project aims to build climate resilience of urban communities, particularly to extreme heat and coastal threats through expanding risk knowledge and strengthening local action. TRCS to ensure the achievement of this project conducted City Wide Risk assessment September-October month with close support from IFRC, Local government, Universities, and different stakeholders for both cities of Tanga and Unguja. The assessment was to assess impacts on different city systems related with environmental science, engineering, economics, social sciences, and community engagement. It covered various aspects of its social, economic, environmental, and infrastructure components in playing a crucial role in guiding urban development and governance through providing a comprehensive understanding of a city's strengths and weaknesses, enabling informed decisions and policies that can enhance the overall well-being and sustainability of the community. To complement the achievement of this CWRA report, TRCS recruited ZACCA- Zanzibar Climate Change Alliance to develop GIS-based mapping of the Unguja cities.

Despite efforts to assess CWRAs in Tanga and Unguja, led by the (TRCS) several gaps persist. While these assessments highlight vulnerability factors such as inadequate drainage systems, runoff, and lack of waste disposal facilities contributing to the overall vulnerability of wards in tackling flooding and extreme temperature risks, they fall short in two key areas. Firstly, they do not spatially map the risks and damages associated with the two hazards, which is crucial for targeted intervention and resource allocation. Secondly, they overlook the cumulative impact of heat risk and flooding hazards, failing to recognize the compounded vulnerabilities that communities may face when confronted with simultaneous occurrences of these hazards. Addressing these gaps is essential for developing more effective risk management strategies and enhancing the resilience of urban communities in Tanzania, particularly in small island regions like Zanzibar.

1.2 Hypothesis

Given the diverse climatic conditions and socio-economic vulnerabilities in Zanzibar, exacerbated by climate change impacts, this study hypothesizes that a comprehensive response framework integrating multi-criteria analysis and composite indicators can offer an evidence-based approach to address the multi-hazard risks posed by current climate variability and future climate change in archipelago. Through questions addressing the manifestation of social vulnerabilities, environmental exposure and hazards, the study aims to highlight the dichotomy of climate anthropocene in Zanzibar through three intersecting frames of *economic development v/s environmental conservation*, *Urban social cohesion v/s rural self-sufficiency* and *changing housing policies*. It particularly aims to address three main questions:

How do heat and coastal vulnerabilities manifest in Zanzibar, a small island nation in the Indian Ocean with a concentrated population density heavily dependent on climate-sensitive activities such as tourism and agriculture?

Within this archipelago, what are the implications of 'development' for different human settlements, particularly urban and agrarian communities?

How do associated risks and socio-economic vulnerabilities and exposure intersect with these environmental challenges to address the very paradox of development?

To address these inquiries, the thesis employs remote sensing and satellite data, to spatially analyze and quantify the combined impacts of both heat and flood risk.

2. The Archipelago of Zanzibar and Regional disparities

Zanzibar is a semi-autonomous region within the United Republic of Tanzania that was established through a union in 1964. Being part of the United Republic means that Zanzibar falls under the same constitution as the Tanzania mainland and while there are some areas of government that are the sole responsibility of the federal government such as defense, currency, foreign affairs etc., all other matters concerning Zanzibar (e.g. environmental management) are within the exclusive jurisdiction of the Zanzibar Revolutionary Council and its legislative body, the House of Representatives.

Figure 1 Location of the Study, Zanzibar

Currently, it comprises two principal islands, Unguja (1,666 km2) and Pemba (795 km2), along with several smaller inhabited and uninhabited islets. Zanzibar is situated in the Western Indian Ocean at coordinates ranging from 39°05'E to 39°55'E and 4°45'S to 6°30'S. Collectively, these islands span a total area of 2460 km^2, positioned approximately 40 km off the East African mainland coast. They are separated by the 700-meter-deep Pemba channel and are approximately 50 km apart. In the context of this study, the term "Zanzibar "primarily refers to the island of Unguja due to its larger population and the presence of Zanzibar city. Administratively, Zanzibar Island (Ungula) is divided into three regions (Mjini Magharibi Region, Kusini Region and Kaskazini Region) and six districts (Mjini and Magharibi, Kati and Kusini, Kaskazini A, B). According to the National Bureau of Statistics (NBS)'s 2022 Population and Housing Census (PHC), the current population of Zanzibar Island (Ungula) in 2022 is 1.34 million. This marks a significant twofold increase from the recorded population of 0.8 million in 2012 over the span of a decade, representing an annual population growth rate of average 3.7% growth rate (Table 1). While natural population growth remains a major contributor to this increase, factors such as the migration, growth of the tourism industry and economic development have also played a significant role. These factors have attracted substantial migration from mainland Tanzania and other parts of East Africa, resulting in a very densely populated island with a density of 546 inhabitants per square kilometer (Figure 3). This rapid growth has led to high rates of urbanization, particularly in the Mjini Magharibi Region (MMR), which has alone witnessed an expansion of 40% from 2004 to 2013. The MMR houses the largest population of 0.89 million accounting for 47.3% of the total population in Zanzibar (Figure 3).

Region	Population			Population Increase (Number)	Average Annual Intercensal Population Growth Rate (Percent)	
	2012 Census	2022 Projections	2022 Census	2012 - 2022	2002-2012	2012-2022
Tanzania Zanzibar	**1,303,569**	**1,762,989**	**1,889,773**	**586,204**	**2.8**	**3.7**
Kaskazini Unguja	187,455	242,314	257,290	69,835	3.2	3.2
Kusini Unguja	115,588	142,935	195,873	80,285	2.0	5.3
Mjini Magharibi	593,678	765,686	893,169	299,491	4.2	4.1

Table 1 Population, Population Increase and Average Annual Intercensal Population Growth Rate by Region, Tanzania Zanzibar; 2012 and 2022 PHCs. Source (National Bureau of Statistics, Tanzania)

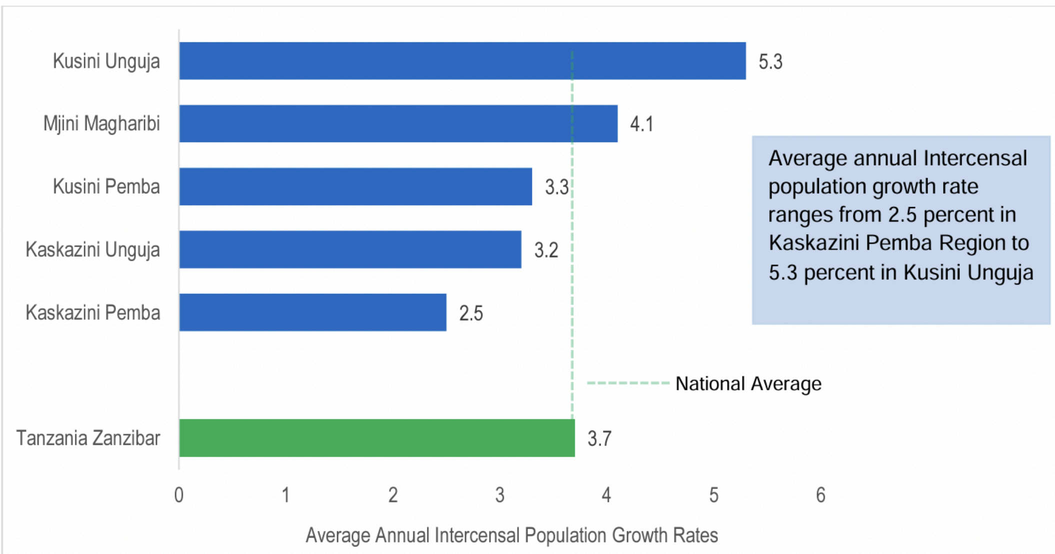


Figure 2 Average Annual Intercensal Population Growth Rate by Region, Tanzania Zanzibar; 2012-2022 PHCs

Another one-third of the population is located within the West district. The remaining 63% are distributed among the four other districts, occupying 86% of the land area. The Mjini and Magharibi districts are the most developed districts, and have problems related to urbanization. The four other districts can be characterized as more rural and primary production based, with less population pressure and lower development status. The lower incomes are compensated with domestic food and natural resource production, but still poverty and incapability are more present here than in the urban areas. Fishing is an important source of livelihoods in Kaskazini, Kusini and Urban districts of Mjini and Magharibi, while the people in Kusini are less engaged in agricultural actions.

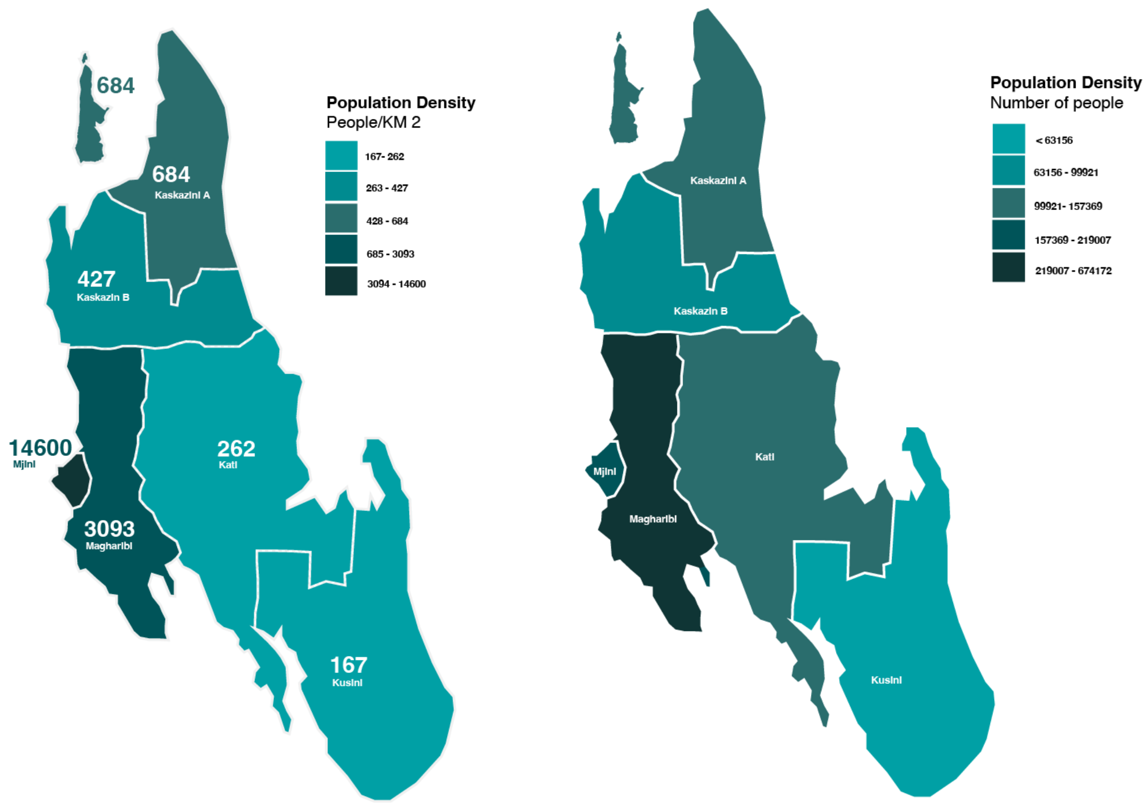


Figure 3 District-wise population and population density, Zanzibar, 2022

2.1 Climate of Zanzibar

The climate in the Zanzibar is diverse because of proximity of the ocean; wide altitudinal range, which governs temperature; and latitude. It is characterized by four distinct seasons namely the long rains, the short rains, the hot season, and the cold season. The rainy season is associated with the southward and northward movement of the Inter-Tropical Convergence Zone. The long rains (Masika) begin in the mid of March and end at the end May, while the short rains (Vuli) begin in the middle of October and continue to early December. "Kaskazi" (the hot season, which is between December and February and associated with either little or no rains), "Kipupwe" (the cold season, with strong winds between June and September. The annual rainfall of the island ranges from 1600 mm for Unguja and 1900 mm. The temperature ranges between 29 °C and 30 °C on average. The temperature in the island is increasingly changing which is driven by various pressures such as population growth, human habitation expansion, and the overarching influence of climate change. These factors have collectively contributed to a notable clearing of the island's forests and vegetation cover (Kukkonen & Käyhkö, 2014). As human activities intensify and the population expands, the natural landscape is being transformed, leading to alterations in local climate patterns. The loss of forest cover has implications for temperature regulation, biodiversity conservation, and ecosystem stability, further exacerbating the challenges posed by climate change.

2.2 Coastal Hazard and Extreme Heat Vulnerability in Zanzibar

The region suffers periodically from the extremes associated with El Niño and La Niña years, which leads to heavy precipitation (floods) and dry spells (droughts). These extreme events have major economic costs on the islands, which are significant at the macro-economic level, as well as affecting many livelihoods. In recent decades, the region has experienced rising temperatures, unpredictable rainfall patterns, intensified wind speeds and excessive high-tide levels. The changes have significantly elevated Zanzibar's vulnerability making it one of the most climate-vulnerable small island regions. According to a study by the World Bank on Zanzibar's disaster risk profile, the average loss from flooding constitutes nearly 90 percent of the average loss per year amounting to $1.9 Million (World Bank, 2016). The analysis of historic meteorological data indicates that temperatures have increased strongly over the last 40 years in Zanzibar (TMA ZCCS, 2013). The monthly temperatures compared to the 40-year climate mean (1980-2020) (figure 5) show a consistent trend of increasing warmer months (more red bars) since the year 2010. The island recorded its highest-ever recorded temperature, exceeding 39°C between December to May. There is evidence suggesting that extreme weather events are becoming more frequent and intense, with indications of increased variability in rainfall patterns and higher-intensity rainfall events causing significant flooding, as observed in April 2016 and November 2023 (figure 5). Rapid change in LCLU patterns and conversion of forest land to unplanned and uncontrolled built-up, urban sprawl, and anthropogenic activities are majorly causing this change in the local and micro-level climate of the region.

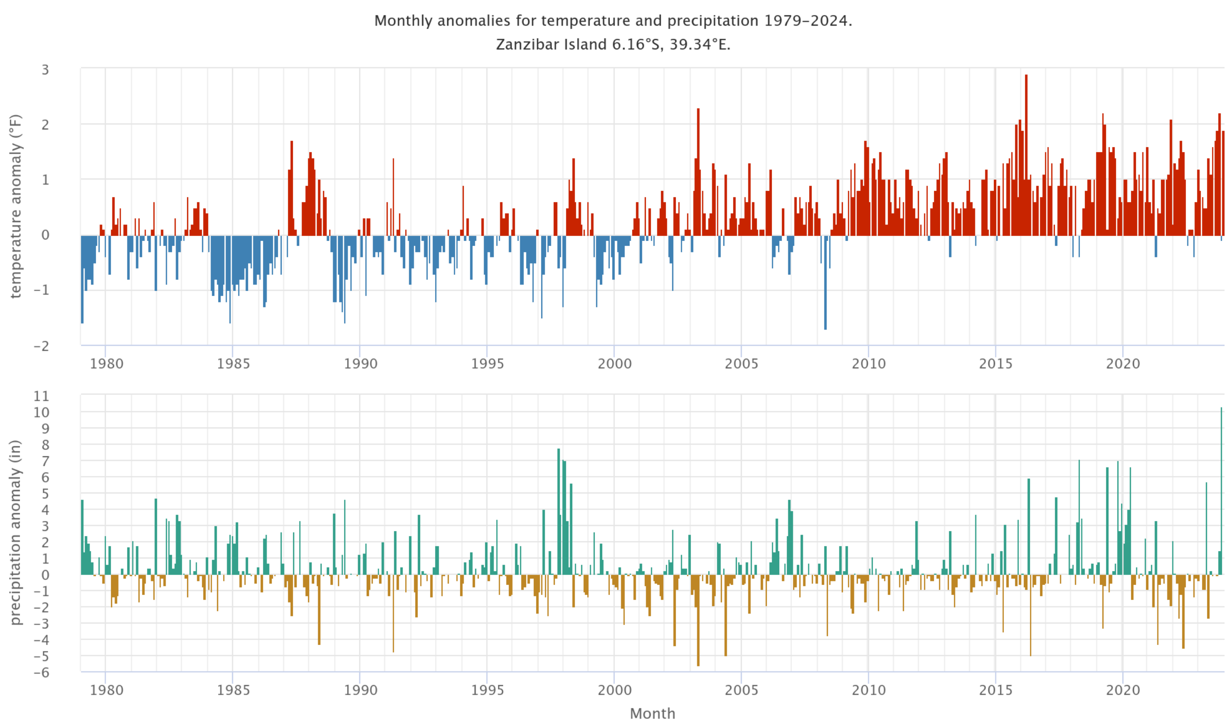


Figure 4 Monthly anomalies for temperature and precipitation in Zanzibar Island, 1979-2024, Source: Meteoblue.com

Another study on social construction of peri-urban places in Zanzibar highlights that the rapid land use changes in Zanzibar have imposed an intensive degradation on its ecosystems (Myers, 2010), Over a 15-year period from 2003 to 2018, the expansion of built-up areas on the island has resulted in a reduction in forest cover equivalent to a 42.6% increase in majorly construction land (Omar & Cabral, 2020). The main drivers (i.e., informal housing, high rate of casual farming, and improvised planning in the tourism sector) behind this intensive degradation are increasing, uncontrolled, and poorly managed. The vulnerability of Zanzibar is exacerbated by the fact that over 60% of its total population resides in the metropolitan region with heavy economic dependence on climate sensitive activities, either directly such as agriculture (crop production and fishing) and tourism, or indirectly for example from the use of natural resources.

Despite these challenges, the understanding of the environmental and anthropogenic impacts of extreme heat wave hazards and coastal flooding together in the context of the small island region is still in its infancy. Access to required data remains a significant challenge. To address these gaps in the existing literature, this study aimed to investigate the spatial pattern of the heat and coastal vulnerability in Zanzibar through remote sensing and satellite data by combining a multi criteria index of hazard, exposure, and vulnerability.

2.3 Regulatory Institutions and Governance of Climate Change in Zanzibar

Figure 5 Timeline of climate governance architecture in Zanzibar.

Zanzibar has had evolving climate change initiatives from the late twentieth century. The Revolutionary Government of Zanzibar launched the first environmental policy for Zanzibar in 1996. However, the policy did not include climate change issues, so in 2014, due to the serious impacts of climate change particularly related to the decline in the production of seaweed, the government launched climate change strategies. The strategies have also been useful in the context of Zanzibar as it is not adequately adapted to the current climate change impact like Tanzania. Thus, in parallel, it adopted its own climate change strategy in 2014, the Zanzibar Climate Change Strategy (ZCCS).

2.3.1 Zanzibar Climate Change Strategy, 2014

The ZCCS was developed to spearhead climate change interventions in Zanzibar. The strategy envisages building a climate-resilient and sustainable Zanzibar and provides strategic priorities for addressing climate change through building resilience and developing opportunities for carbon-relevant sustainable development.

It considers the key sectoral and cross-sectoral risks and opportunities as well as cross-cutting themes: 1. Building climate information and capacity, 2. Disaster risk management and resilient settlements, 3. Resilient coastal and marine areas, 4. Climate-smart agriculture 5. Sustainable forests and energy/electricity and Sustainable and low-carbon tourism.

The Vision has been to build a climate resilient and sustainable Zanzibar by 2030. The responsibility for climate change action implementation rests with the Environmental and Climate Change Units within each ministry. However, the ZCCS is still relatively new, and while some implementation is planned, there is still a significant need for further clarity regarding priority investments to improve Zanzibar's resilience and to assist in leveraging climate finance more strategically, to deliver results on the ground. Adding to the challenge, there has been no comprehensive analysis linking the strategic priorities outlined in the Tanzanian mainland's National Climate Change Strategy with those in the ZCCS. This lack of coordination makes it difficult to identify current financing for climate change activities and to pinpoint where activities are currently resourced and where financing gaps may exist (World Bank, 2016).

2.3.2 Zanzibar Environmental Policy, 2015

The Environmental Management Act of 1996 underwent review, leading to the establishment of the Zanzibar Environmental Management Act of 2015, which gave rise to the Zanzibar Environmental Management Authority (ZEMA) (*ZEMA-Zanzibar Environmental Management Authority – Zanzibar Environmental Management Authority-ZEMA*, 2015). This policy framework laid the groundwork for the protection, conservation, restoration, and management of Zanzibar's environmental resources. The aim is to ensure that these resources have the capacity to sustain development and preserve the rich environmental heritage for both present and future generations. This Act delineates the obligations of both the state and its citizens concerning the environment, as well as the fundamental principles that underpin the legislation. Every individual is mandated to safeguard the environment for the benefit of current and future generations. In return, the State grants every individual the right to a clean, safe, and healthy environment. The policy framework encompasses three major focal points:

- Promotion of the application of environmental impact assessment (EIA) and strategic environmental assessment (SEA).
- Strengthening public awareness regarding environmental issues.
- Enhancement of monitoring programs and assessments to evaluate the state of the environment accurately.

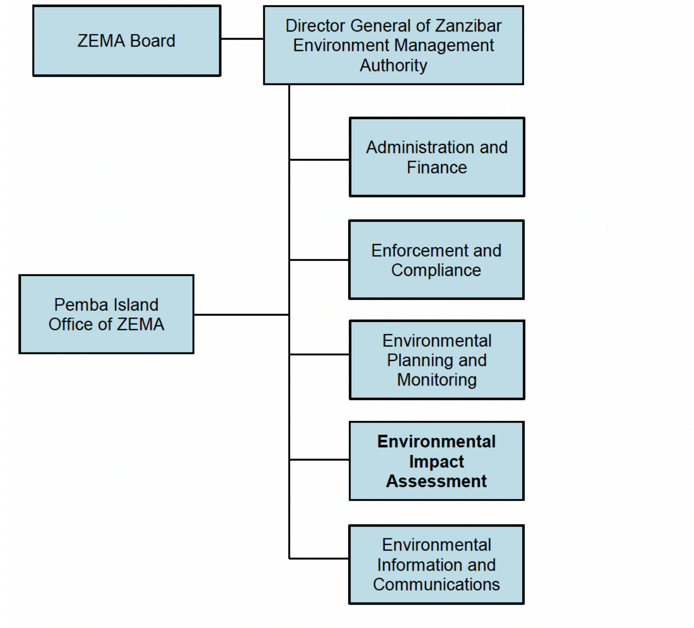


Figure 6 Organizational chart of the Zanzibar Environmental Management Authority

2.3.3 Zanzibar Environmental Management Authority, ZEMA

Under the Zanzibar Environmental Management Act, No. 3 of 2015, the ZEMA has been entrusted with a few functions to help safeguard the environment. These include a) *regulatory and administrative responsibilities* including permits and approvals, undertake environmental monitoring, enforcing regulations and standards, b) *promoting environmental awareness among citizens*.

However, challenges remain, including capacity gaps among policy makers and communities, resulting in low adaptive capacity to address climate change impacts. Being a data-starved region, it lacks evidence-based approaches that undermines the development and implementation of effective climate policies and interventions. International aid being the major source for Zanzibar to invest towards climate change action, the most critical limitation is the mismatch between climate financing and capacity in Zanzibar, as the United Republic of Tanzania (URT) serves as the focal point for the United Nations Framework Convention on Climate Change (UNFCCC), leaving Zanzibar without direct representation within the international climate change governance architecture. Hence, the data-driven approach examining multi-hazard risk assessment in Zanzibar can provide evidence-based insights into the most vulnerable communities and regions, aiding in prioritizing resource allocation and decision-making processes tailored to Zanzibar's development policy frameworks.

3. Gathering Data and Developing top-down and bottom-up strategies for Risk Assessment

The thesis investigates how the changing effects of climate affect Zanzibar through mixed methods approach leveraging both quantitative and qualitative methods. Quantitative method is used to conduct Multi-Hazard Risk Assessment (MHRA) to identify the communities at most risk. Semi-structured qualitative interviews were carried out post the qualitative assessment across selected sites with the Tanzania National Red Cross Society, and local community leaders to understand community perceptions of risk and resilience.

Data

Variables		**Description**	**Unit**	**Data source**
Latent	**Observed**			
Hazard	Land Surface Temperature	Pixel wise (30 m resolution) LST	°C	**United States Geological Survey (USGS), Landsat**
	Precipitation			**https://www.worldclim.org/data/worldclim21.html**
	Land Cover Classification Change	Percentage change in LCLU map based on the respective years	30 m resolution	**United States Geological Survey (USGS), Landsat**
Exposure	Vegetation	Represents trees, natural vegetation, mixed forest, gardens, parks and playgrounds, grassland, vegetated lands, agricultural lands, and crop fields. The area occupied by a vegetative cover of any given ward divided by respective ward's total area was considered.	Pixel ratio	**United States Geological Survey (USGS), Landsat**
	Access to electricity	Number of people per km2 having electricity connection in their houses.	p/km2	
	Built-Up			
	NDBI	Area occupied by built-up area by the total area of the respective ward.	sq.km	**United States Geological Survey (USGS), Landsat**
	Road	Area occupied by the road of any given ward divided by the total area of the	sq.km	**Tanzania National Bureau of Statistics**

		respective ward.		
	Population-density	Number of people living in per km2	p/km2	**Tanzania National Bureau of Statistics**
	Elderly Population	Number of old (>65 years) people per km2	p/km2	**Tanzania National Bureau of Statistics**
	Young Population	Number of children (<9 years) per km2	p/km2	**Tanzania National Bureau of Statistics**
	Illiteracy Rate	The number of illiterate people per km2 who cannot read or write a letter	p/km2	**Tanzania National Bureau of Statistics**
	Occupation/ unemployed	The number of people per km2 who were not involved in any work or were looking for work	p/km2	**Tanzania National Bureau of Statistics**
	Gini Coefficient	The income of people living within the ward	Income groups weighted	**Tanzania National Bureau of Statistics**
	Poverty	Number of people per km2 living below poverty line.	p/km2	**Tanzania National Bureau of Statistics**
Vulnerability	Land Use Land Cover	1. Forest, 2. Farmland 3. Swamp and flat land 4.Built-up	Land Uses weighted	**United States Geological Survey (USGS), Landsat**
Additional layer	Road	Calculate the road density		
	Ward Boundary	Calculate the total ward area		http://riskprofilesundrr.org/layers/geonode:tzwards
	Administrative Boundary			http://riskprofilesundrr.org/layers/geonode:tzwards
	Slope	Calculate the low-lying areas	30 M Resolution	SRTM-USGS
	DEM Elevation		31 M Resolution	SRTM-USGS
	Stream		32 M Resolution	SRTM-USGS

Table 2 Summary of data used in this study.

4. Quantitative Risk Assessment: MHRA, Zanzibar

For the quantitative assessment, the study adopts the Risk Triangle framework (Crichton1999) which suggests that risk or the likelihood of experiencing a loss depends on three indicators: hazard (inducing factors), exposure (inducing environment) and vulnerability (bearing body). The multi-hazard risk index (MHRI) was estimated as a function of hazard (H), exposure (E), and vulnerability (V) (UN/ISDR, 2004, p. 36). In general, the indicators used in the social vulnerability analysis depict socio-economic characteristics, properties of the built environment that influence to a greater or lesser extent the degree of vulnerability within a community. Following the literature review and available data sources, the variables were identified to measure the three latent variables which included both population housing census data with spatial and spectral remote sensing data (Table 1). The remote sensing variables acquired are from satellite imagery that encompass a wide range of information about the Earth's surface, atmosphere, and temperature for the hazard variable. Demographic and socio-economic variables were determined by Tanzania National Bureau of Statistics. Most of the variables were expressed in relative terms, i.e., per unit of surface (no/sq.km) to avoid the spatial bias induced by excessively large or very small administrative boundaries.

4.1 Indicator Selection

4.1.1 Hazard

In this study, focusing on two hazards—precipitation and flooding—they were represented by Land Surface Temperature (LST) and Precipitation Measurement. While LST traditionally signifies heat hazard (Mac and McCauley, 2017), recent research has argued its relevance in indicating the intensity of heat exposure as well (Inostroza et al., 2016). LST stands out as a significant variable reflecting heat wave vulnerability, as elevated LST levels correlate with increased occurrences of heat-related illnesses such as cardiovascular diseases, diarrhea, and respiratory issues (Basagaña et al., 2011; Ho et al., 2015; Rinner et al., 2010). Precipitation is a critical indicator for flood risk. The US Environmental Planning Agency (EPA) in its Climate Change Indicators, indicates an increase in flood risk due to heavy rains due to heavy precipitation (*Climate Change Indicators: Heavy Precipitation | US EPA*, 2023). Other literature (E. Bevacqua et al, 2019) shows extreme precipitation as a key contributor to the heightened probability of compound flooding in Europe. Their findings align with (Davenport, F. V., Burke, M., & Deffenbaugh, N. S., 2021), who demonstrate that the historical precipitation patterns have estimated one-third (36%) of the cost of flood damages in North America.

4.1.2 Exposure

Seven variables were identified to quantify the degree of exposure y to flood and heatwave hazards (Table 1). These are defined as hazard inducing environments which increase the likelihood of floods, such as Low-lying regions, defined as areas below 5 meters, are particularly susceptible to floods due to their geographical disposition(Veerappan & Sayed, 2020). Historical flood accumulation distance, runoff, and road distance play crucial roles in determining flood vulnerability (Eini et al., 2020). Additionally, vegetation quality, as indicated by the Normalized Difference Vegetation Index (NDVI), influences both heat stress and flood risk, with poor vegetation quality potentially exacerbating these hazards. High population density areas are identified as particularly vulnerable to both heat and floods due to increased exposure as rapid population growth leads to the expansion of built-up areas, which often occurs in flood-prone areas, as the spatial planning strategies are not adapted for rapid growth (Rahman et al., 2021; Botezan et al., 2021). Zanzibar, although sparsely populated with 768 persons per square kilometer, the Mjini Magharibi Region is densely populated with 14600 people/km2. The land cover classification- Land Cover database (European Environment Agency, 2022) was used to calculate the percentage of built-up areas, such as urban areas, that can further heighten flood susceptibility. Notably, vegetation quality can vary across different land-use types, with certain vegetated (used for agriculture purposes) areas potentially experiencing higher flood risks despite higher NDVI values.

4.1.3 Vulnerability

In case of hazard bearing features- population features were examined of communities. For instance, age is a critical factor influencing mobility during a disaster, the elderly and children being more vulnerable and increasing the difficulty of evacuation. The literature highlights that the population above the age of 60 is susceptible to flooding and heatwave due to their age and underlying medical problems like cardiovascular diseases (Aldrich and Benson, 2008). Similarly, populations below the age of 15 are also vulnerable to extreme heat events due to their susceptibility to different vector-borne diseases (Haines et al., 2006). Various socioeconomic conditions of people are also reportedly associated with extreme vulnerability to rising temperature and flooding such as illiteracy, unemployment, and poverty. Literature indicates that deaths caused by flooding and heat diseases are disproportionately high among these vulnerable populations (Cutter et al., 2003).

In Unguja island, the number of people living below the poverty line was 15-25% of the total population (NBS), while in the same region the unemployment rate ranges between 6-30% of the total population. In addition to economic factors, utility facilities of people living below the poverty line (population below $1.90 purchasing power parity/day according to the Asian Development Bank) make these groups sensitive to heatwave and flood vulnerability (McMichael et al., 2008). Hence, access to electricity was measured in Zanzibar, where Kaskazini B and Kusini consisted of 25-23% population with no access to electricity. In terms of the population distribution by age, 5% of the population is above 60, while 40% of the population is below the age of 14. The socio-economic data were obtained from the Tanzania National Bureau of Statistics (2022).

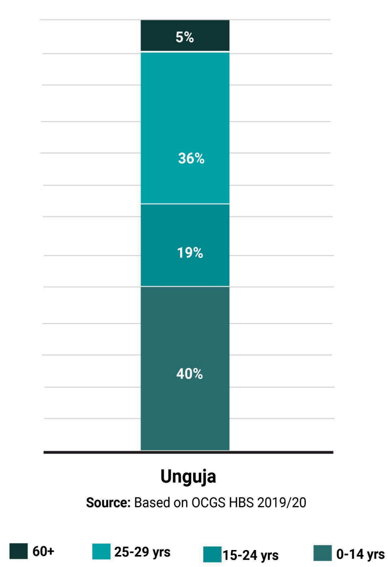


Figure 7 Population distribution of age groups in Unguja (%)

4.2 Satellite data processing

Given Zanzibar is a data starved region, it presents itself as an ideal use case for examining the potentials of remote sensing data, because the availability of other data sources is sparse. It applies image processing techniques to extract spatial and spectral information. In case of the study, surface temperature and land use land cover data along with the indexes for vegetation and built-up density were calculated.

4.2.1 LST and Precipitation

For heat and flooding hazard, the LST and precipitation data was derived using satellite image processing. LST was calculated from Harmonized Landsat Sentinel-2 - NASA- images of 30 m spectral resolution using the approach by He et al. (2019 for the year 2022. It retrieves LST using spectral bands of Thermal InfraRed Sensor (TIRS) 10. Precipitation was derived for the same year in the month of May (during the long rain period: Masika) from world climb data. In addition, land cover data was also calculated for the same year.

using the Landsat 8 — Operational Land Imager (OLI) — images of 30 m spectral resolution. The pixel-based estimates were distributed at ward scale.

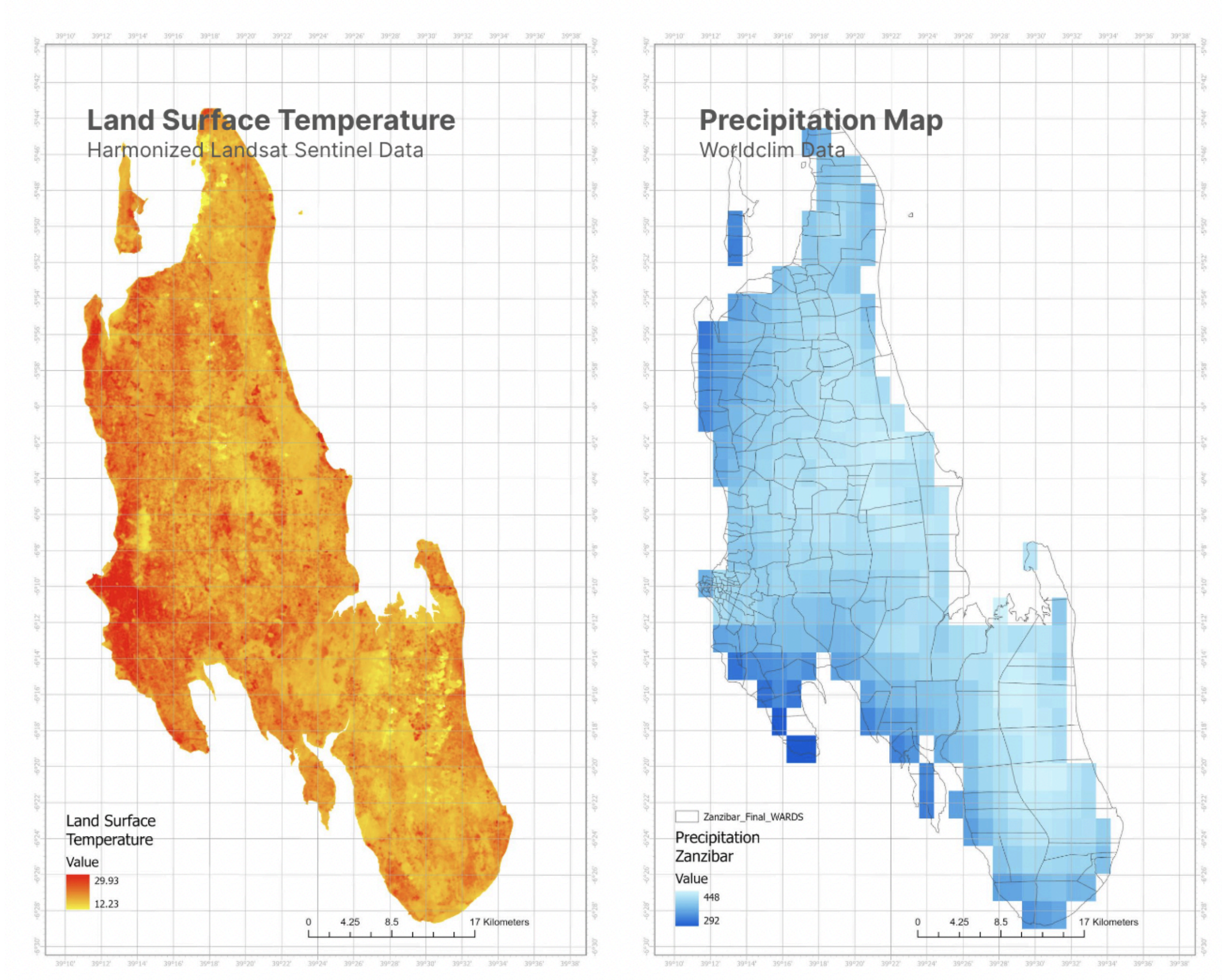
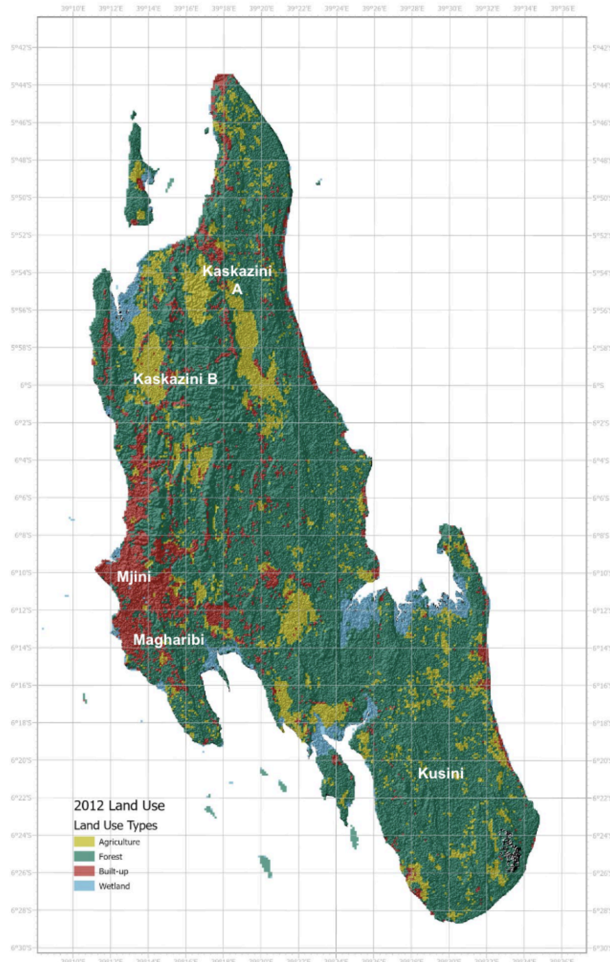
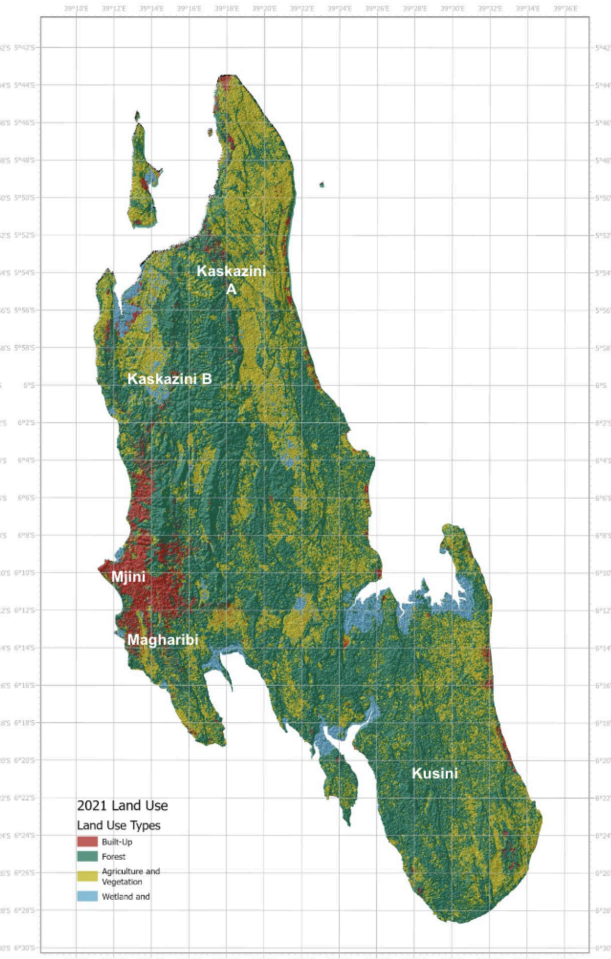


Figure 8 Land Surface Temperature and Precipitation in Zanzibar, 2021

4.2.2 Supervised Classification

The land cover classification was carried out using a widely used supervised classification technique to map decadal change between 2012 and 2021. The classification technique used was the maximum likelihood algorithm in GIS (Abdullah et al., 2019) due to its robustness and potentiality of producing precise land cover classes (Sisodia et al., 2014). Land cover data generated for the study area included four classes: Urban area, agriculture/vegetation, Wetland/Mangrove, and forest cover. There has been a significant change in the land use land cover pattern in Zanzibar in the last decade. For instance, 205.6 sq km (24.7%) of the forest cover has been lost. Of which 83% has been converted to agriculture, 17% to build up (Figure 9).





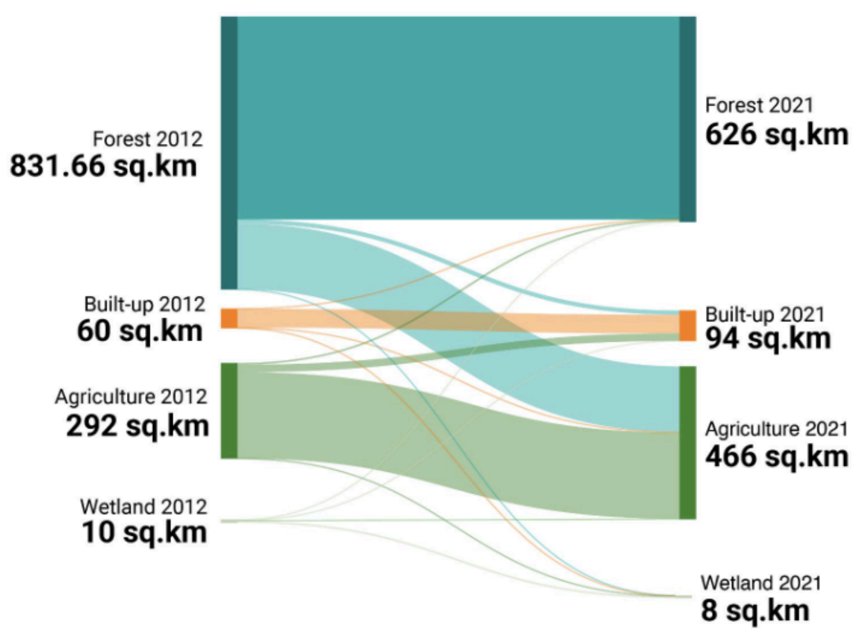


Figure 9 Land Cover Land Use Change, Zanzibar 2012-2021

4.2.3 NDVI and NDBI

Normalized Difference Vegetation Index (NDVI) is an index that describes the vegetation proportion by measuring the difference in the near-infrared portion of the electromagnetic spectrum which is strongly reflected by green vegetation and red portion of the spectrum which is absorbed by vegetation. NDVI was calculated by using NIR Band 5 and Red Band 4 of the Landsat-8 data by given below equation (1) in ArcGIS software. The calculation of the NDVI is important to understand the density and the quality of vegetation. On the other hand, the Normalized Difference Built-up Index (NDBI) serves to delineate urban built-up areas. It is calculated using the near-infrared (NIR) and short wave infrared (SWIR) to extract impervious surfaces from urban areas. NDVI and NDBI are both normalized indices that have an inverse relationship, meaning that high NDVI values indicate low NDBI values, and vice versa. Their values fall within the range of -1 to 1, where higher values signify built-up areas, while negative values indicate non-built-up regions. This inverse relationship facilitates the monitoring of changes in both vegetation cover and urban development over time. For instance, in the case of Zanzibar, the urban areas (Mjini region near the coast) have a low NDVI value of 0.2 but higher NDBI value of 0.8 suggesting greater degree of urbanization.

$$NDVI = (NIR+Red)/(NIR-Red) \quad \textit{(equation- 1)}$$

$$NDBI = (SWIR+NIR)/(SWIR-NIR) \quad \textit{(equation-2)}$$

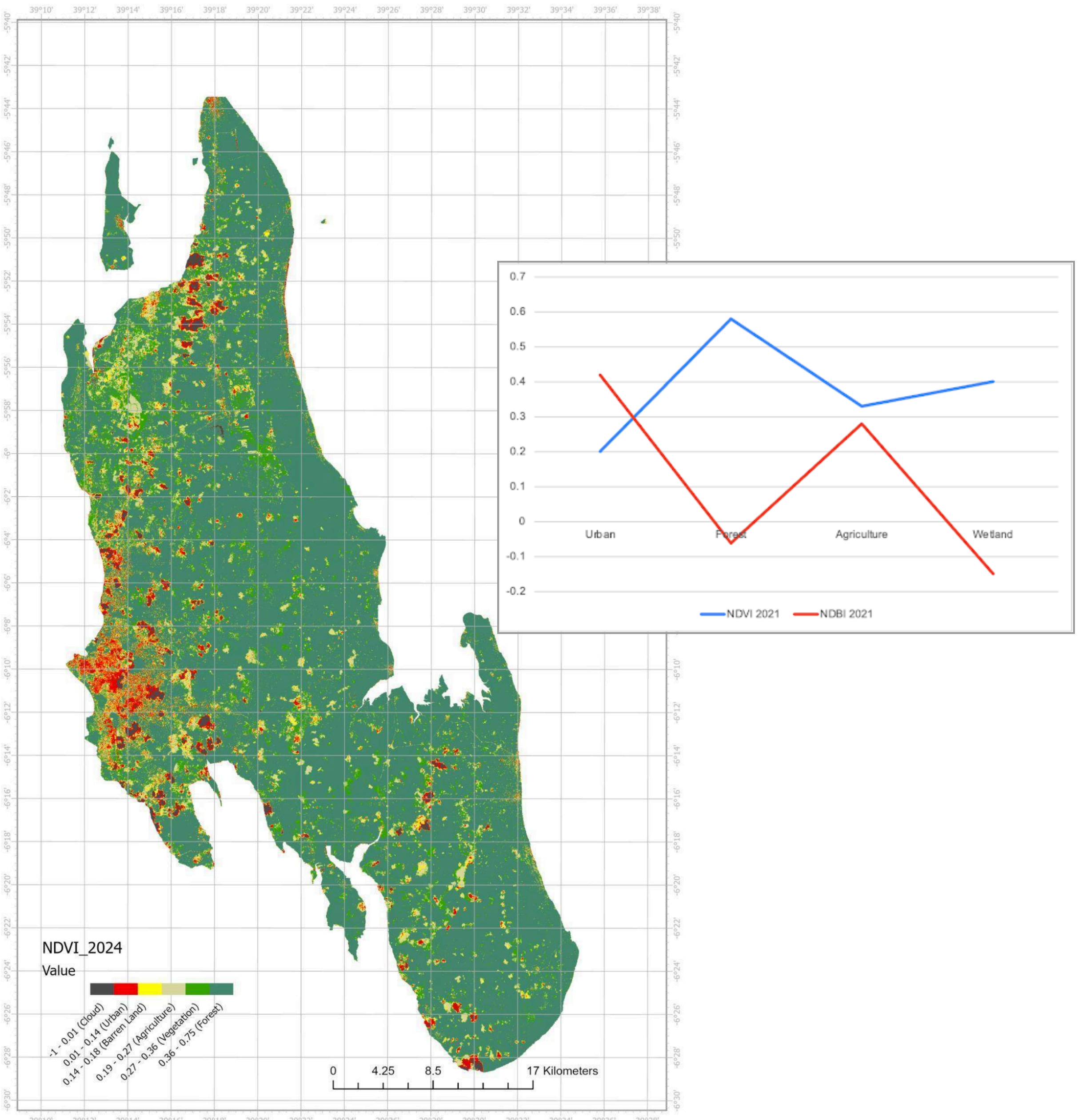


Figure 10 NDVI, 2021 and Relationship between NDVI - NDBI, 2021

4.3 Data processing and normalization

After the indicators, an overlay sum was calculated, and all latent variables were conducted individually.

The values of each latent feature- hazard, vulnerability and exposure were normalized to obtain comparable datasets. This is a standard procedure to ensure that the values that are represented at different scales will be included in the same domain (Swami and Parthasarathy, 2021; Tasc´on-Gonz´alez et al., 2020). The Min-Max method was used for normalization, which provides values between 0 and 1.

$$\beta = \left[\frac{x - x_{min}}{x_{max} - x_{min}} \right]$$

where β is the normalized MHRI value at each ward, x is the original MHRI value, xmin and xmax are the lowest and highest MHRI values, respectively.

Obtained normalized MHRI values were categorized into five classes — very low, low, moderate, high, and very high — applying the Jenks optimization method in GIS.

4.3.1 To calculate Multi-Hazard Risk Index using weights by PCA

The indicator weight assignment is one of the most important steps in multi-criteria decision-making, determining each indicator's importance and contribution to the social vulnerability index and affecting the ranking of the analyzed units. Moreover, the selection of the most appropriate approach to indicator weighing is still difficult since there isn't a standard weighting method. In the case of the study, PCA method to weigh the indicators and construct the risk index. The loadings of the indicators show how they are related to the principal components, and for an indicator to be included in one component, it should have a value higher than 0.5. Therefore, the indicators with the highest loadings (correlations) are grouped into one component (one dimension). The number of components is extracted based on the eigenvalue, which is generally considered to be > 1. Finally, the weights for each indicator were calculated using the factor loadings, which were squared and scaled to the unity sum. Moreover, to assign weights to each of the obtained dimensions, the percentage of the explained variance of each dimension was divided by the total variance explained (Eq. (3) (Chakraborty et al., 2020; Wu, 2021).

Wd = %Variance Explained/ *Total Variance explained* *(equation-3)*

The indicators were aggregated into three intermediate hazard, exposure, and vulnerability indices, according to the dimensions resulting from the PCA analysis, using Eq (4)

$$V_i = \sum_{i=1}^{N} \frac{w_i}{\sum_{i=1}^{N} w_i} \times I_{ni}$$ *(equation-4)*

- *where Intermediate Risk =*
- *Vi* represents the intermediate vulnerability index for a specific dimension resulting from PCA analysis.
- *wi=* is the weight assigned to the indicator *i* within the dimension/component.
- *N* is the total number of indicators within the dimension.

- *Ini* represents the normalized value of the indicator *i* within the dimension/component.

The multi-hazard risk index (MHRI) or the estimated risk was calculated by multiplying the value of each intermediate vulnerability, hazard and exposure index with its dimension weight and summing the results from all dimensions (Eq. 5)

$$\boldsymbol{MHRI} = Wd1Vi1 + Wd2Vi2 + Wd3Vi3 \qquad \textit{(equation-5)}$$

The values of the MHRI were grouped into 5 classes of vulnerability (very low, low, moderate, high, very high), each LAU falling into one of these classes, according to the vulnerability score obtained. The class division of the scores was done using the Natural Breaks (Jenks) function in QGIS, which tries to find natural groupings of data to create classes. The results will have a maximum variation between classes and a minimum variation within each class. The method aims to reduce within-class differences and maximize between-class differences. The scores were divided according to a ranking scale from 1 to 10, with the lowest value indicating low vulnerability and the highest value, high vulnerability (ArcGIS, 2023).

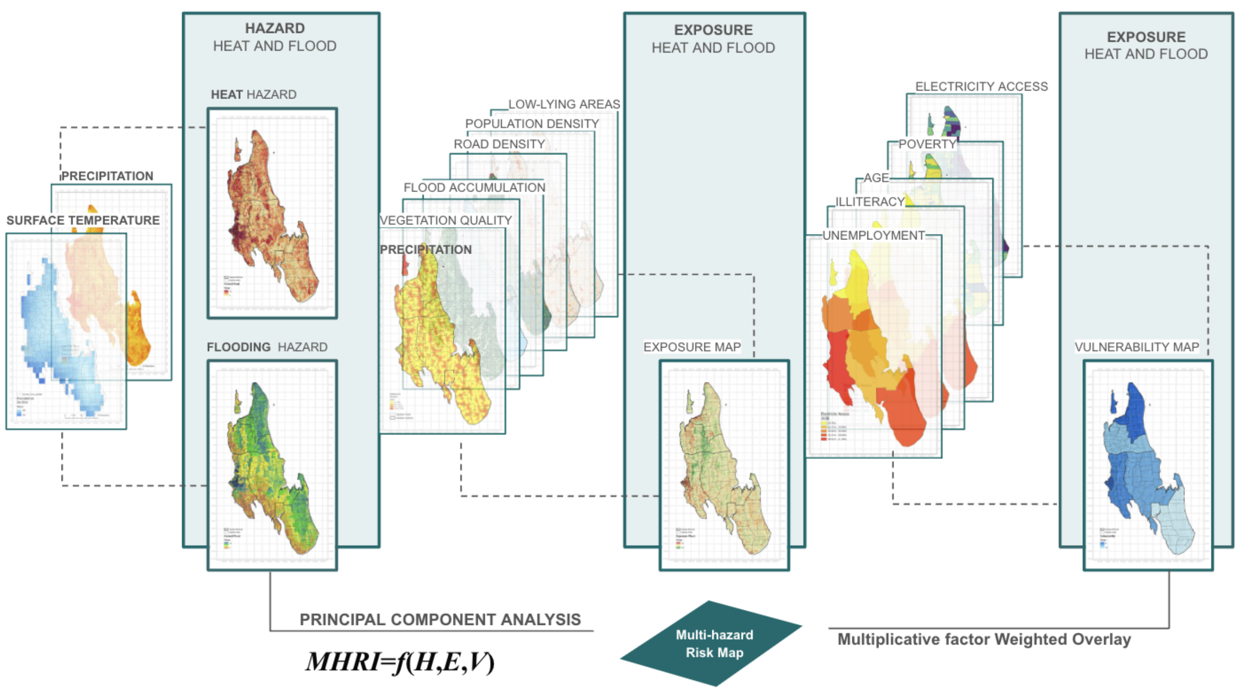


Figure 11 Methodology framework adopted in the study.

5. Advantages and limitations of the proposed methods

This study demonstrated how to use the composite indicator to measure vulnerability. The framework of MHRI is an objective and automatic model using PCA, data standardization, adequacy test, weighting, and statistical methods in the assessment process. This model is effective in integrating various indicators representing natural and human impacts for multi-hazard. Introducing sampling adequacy tests to determine the appropriate weighting approach makes the results more credible. In addition, the weighting approaches using PCA improved the credibility compared with equal weight evaluation or subjective experts weighting approaches. The improved weighting method shows the advantage of dealing with multidimensional indicators effectively based on their intrinsic features.

However, there are some limitations of this assessment method. The uncertainties attached to the preference of stakeholders are not usually considered; vulnerability indicators would need to be updated regularly, based on new research findings (Hinkel, 2011). Also, the weights of indicators identified by the PCA method may not necessarily reflect the actual importance of a specific indicator towards heat and flood vulnerability; and the effect direction of the indicators may vary. More appropriate and detailed approaches should be taken into consideration to rectify the difference between theory and reality in future studies.

Lastly, wards and census tracts are relatively large regions and not all factors of data were available at the same scale. Some features might be flattened when implementing average calculations, such as poverty, age and access to electricity etc. In this sense, the smaller the scale, the more accurate the assessment will be and the more reliable the decision making can be. Furthermore, vulnerability is a place-based and context-specific phenomenon (O'Brien et al., 2007, Cutter et al., 2003), and factors that create adaptive capacity are different. (Tol and Yohe, 2007) indicate that the weakest indicator may play an important role because other factors can compensate. Studies have also pointed out that vulnerability indicators should serve as high-level entry points to further detailed examination, since indicators reduce complexity; they can be interpreted in a variety of ways, and background information is necessary to prevent misinterpretation.

6. Principal Component Analysis for MHRA

6.1 The weight results using PCA

Through inputting 12 standardized factors and using the PCA tool of GIS, the study obtains the output of the Correlation coefficient matrix, as shown in Table 3. In this study, applying the PCA analysis, 5 principal components were extracted in case of heat and 4 in case of flooding, considering just the components with an eigenvalue higher than 1 (Table 3, Table 6). In case of heat, the results show that the extracted components explain 83% of the variation in the data, with the first component accounting for 44.42% of the variance, the second component for 12.60% and the third for 11.39%, the fourth component 8.16% and the fifth 6.78%.

PC Layer	EigenValue	Percent of EigenValues	Accumulative of EigenValues	
1.00	12.47	44.42	44.42	44.42
2.00	3.54	12.60	12.60	57.02
3.00	3.20	11.39	11.39	68.41
4.00	2.29	8.16	8.16	76.57
5.00	1.90	6.78	6.78	83.35
6.00	1.56	5.57	5.57	88.93
7.00	1.05	3.74	3.74	92.67
8.00	0.87	3.09	3.09	95.75
9.00	0.59	2.11	2.11	97.86
10.00	0.39	1.39	1.39	99.26
11.00	0.20	0.70	0.70	99.96
12.00	0.01	0.04	0.04	100.00

Table 3 Percent and Accumulative Eigenvalues (HEAT)

Flooding on the other hand showed 84% of the variance by the first four components. The first component accounted for 45.37% of the variance, the second 13.55%, the third 11.34% and the fourth 7.59%.

6.1.1 Heat Risk Factor: PCA

Furthermore, to identify the representative indicators for each component, the rotated component matrix was used, and the significant values were marked (Table 3). The indicators with the highest factor loadings (that must be > 0.5) in each component describe one dimension of risk. Analyzing how the indicators were grouped, the dimensions of risk associated with each principal component were named as follows: the vulnerability dimension(PC1 and PC2), containing social and demographic indicators as well as indicators related to the accessibility to resources; the hazard dimension (PC3), containing the indicator surface temperature- LST; the exposure dimension (PC4 and PC5), containing indicators related to social and built-up area development and growth (Table 4). Within each dimension, the weight of the indicators was assigned according to the squared factor loadings scaled to unity sum. Furthermore, the dimension weight was calculated using Eq. (4) (Table 4). Within the vulnerability dimension, the highest weights are access to electricity, unemployment, Illiteracy which can be explained by the fact that these indicators could have a direct impact on social vulnerability, being the principal factors that will influence the community's resilience and coping capacity. The age indicator has the lowest factor loading on the socio-economic dimension but is still part of this dimension. Within the hazard dimension, LST was the only factor considered, being the principal factor that will indicate the percentage of the area (and implicitly of the population) under the threat of extreme heat. Within the exposure dimension, the results showed that the land cover land use is the most important factor (factor loading of 0.66), this indicator of certain land types being more exposed to heat after NDVI and Road distance. The results of the PCA indicate that the exposure dimension is the most important in explaining the risk as it records the high factor loadings for most other indicators. As a result, the highest weight is assigned to the exposure dimension, showing that if the communities are exposed to low vegetation quality, changing land cover and land use the exposure to heat with urbanization markers influencing heat exposure.

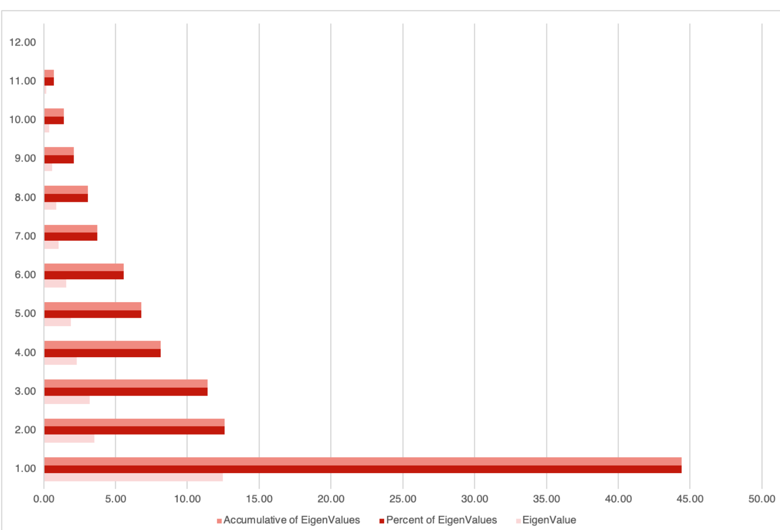


Figure 12 Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO): 0.813.

Layer	PC 1	PC 2	PC 3	PC 4	PC 5
LST	0.15812	-0.14695	**0.24619**	-0.12651	0.01487
NDVI	0.15381	-0.18452	**0.54923**	-0.14709	-0.48343
Slope	-0.0432	0.01167	0.0582	-0.0834	0.10179
Stream	0.00791	-0.09715	0.02345	-0.04708	-0.02177
Road Density	-0.10866	0.35087	0.0188	-0.20628	**0.64541**
LCLU	0.11602	0.01943	**0.66102**	-0.28661	0.38239
Population Density	0.02974	0.01742	0.09159	0.09616	-0.0004
Above 65	**0.41573**	0.40429	-0.10074	-0.29058	-0.17578
Below 10	**0.33911**	0.26074	-0.12392	-0.18443	-0.09788
Electricity Access	-0.0929	**0.73562**	0.16812	0.15974	-0.29364
Illiteracy	-0.39449	0.19293	0.361	**0.50522**	-0.01417
Unemployment	**0.68642**	-0.03468	0.06335	0.6481	0.25604

Table 4 Rotated component matrix from PCA and factor loadings after rotation. (HEAT)

Indicators	Extracted Components					Indicator Weight	Dimension Weights
PC Layer	**1**	**2**	**3**	**4**	**5**		
Hazard							
LST			**0.24619**			1	0.1
Exposure							
NDVI				**0.54923**		0.2611	
Road Density					**0.64541**	0.3604	
LCLU				**0.66102**		0.3785	0.5
Vulnerability							
Above 65	**0.41573**					0.111	
Below 10	**0.33911**					0.0739	
Electricity Access		**0.73562**				0.3479	
Illiteracy				**0.50522**		0.164	
Unemployment	**0.68642**					0.3033	0.4

Table 5 Weight calculation based on the rotated component matrix. (HEAT)

6.1.2 Flood Risk Factor: PCA

The indicators were grouped, the dimensions of flood risk associated with each principal component as follows: the vulnerability dimension (PC1), Above 65, Below 10, poverty population (PC2 and PC3): the exposure dimension containing the indicator containing highest for historic flood accumulation- 0.72: Road Density (Table 6). (PC4): the Hazard indicating Precipitation- 0.54. In case of flood risk, like that of Heat, the PCA of floods indicates that the highest loading (historic flood accumulation distance) and greatest exposure dimension is the most important in explaining the risk. As a result, the highest weight is assigned to the exposure dimension, showing that if the communities are near where flooding occurs, they are more likely to be at risk-coastal and low-lying areas with low vegetation quality.

PC Layer	EigenValue	Percent of EigenValues	Accumulative of EigenValues	
Precipitation	10.20049	45.3767	45.3767	45.3767
NDVI	3.0466	13.5527	13.5527	58.9294
Slope	2.55083	11.3473	11.3473	70.2767
Stream	1.70776	7.597	7.597	77.8737
Road Density	1.4533	6.465	6.4649	84.3386
LCLU	1.12841	5.0197	5.0198	89.3584
Population Density	0.92568	4.1179	4.1178	93.4762
Above 65	0.6133	2.7283	2.7283	96.2045
Below 10	0.4833	2.1499	2.1499	98.3544
Poverty Density	0.28532	1.2692	1.2693	99.6237
Illiteracy	0.08238	0.3665	0.3665	99.9902
Unemployment	0.00221	0.0098	0.0098	100

Table 6 Percent and Accumulative Eigenvalues (Flooding)

Indicators	Extracted Components					
PC Layer	**PC1**	**PC2**	**PC3**	**PC4**	**Indicator Weight**	**Dimension Weights**
Hazard						
Precipitation				0.54237	1	**0.1**
Exposure						
NDVI		0.68002			0.3185	
LCLU		0.67637			0.3148	
Road Density			0.72852		0.3667	**0.5**
Vulnerability						
Above 65	0.53321				0.3887	
Below 10	0.51138				0.2317	
Gini-povpop	0.52642				0.3796	**0.4**

Table 7 Weight calculation based on the rotated component matrix. (Flooding)

7. Evaluating Intermediate Risk of Hazard, Vulnerability and Exposure in Zanzibar

7.1 Hazard Index

The Hazard Index, a measure capturing the combined risks posed by floods and heat, reveals a significant correlation, particularly within densely populated urban areas. These regions particularly experience higher average temperature ranges between 20-30*C and the historic meteorological data reveals that temperature has been increasing. In the recent years, temperatures have been rising over the last 30 years with a strong increase in average increase of mean temperature from 1*F-3*F (Figure 5). The increases are highest in the years from 2015 when the island recorded the highest-ever temperature over 39°C (UNDP, 2019). The rainfall trends are more complex, although some important trends do converge with the year of 2015 and 2023 which recorded one of the worst floods in the history of Zanzibar killing over 47 people (Al Jazeera, 2023) and displacing over thousands. The areas of Nungwi and Zanzibar City in the Mjini area experience heightened vulnerability to both increased precipitation and elevated surface temperatures. Approximately 8% to 12% of Zanzibar's total area are classified as high-risk zones for heat and flooding, respectively, with coastal and wetland areas being especially susceptible. While forested regions exhibit comparatively lower heat hazard, they face a medium risk of flooding, impacting over a quarter of such areas. The depletion of vegetation and forest cover has contributed to approximately half of the region facing medium to high heat risk, indicative of the interplay between environmental degradation and heightened vulnerability to rising temperature.

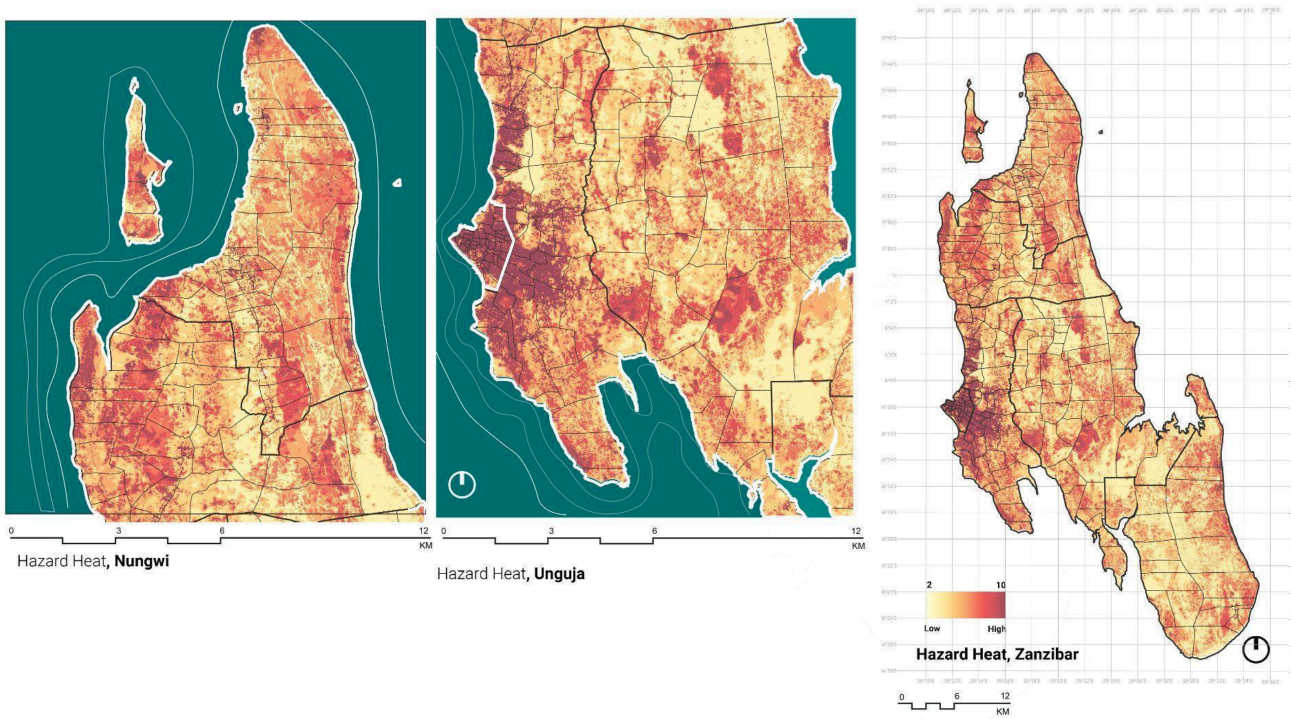


Figure 13 Spatial Distribution of Heat Hazard in Zanzibar, 2021

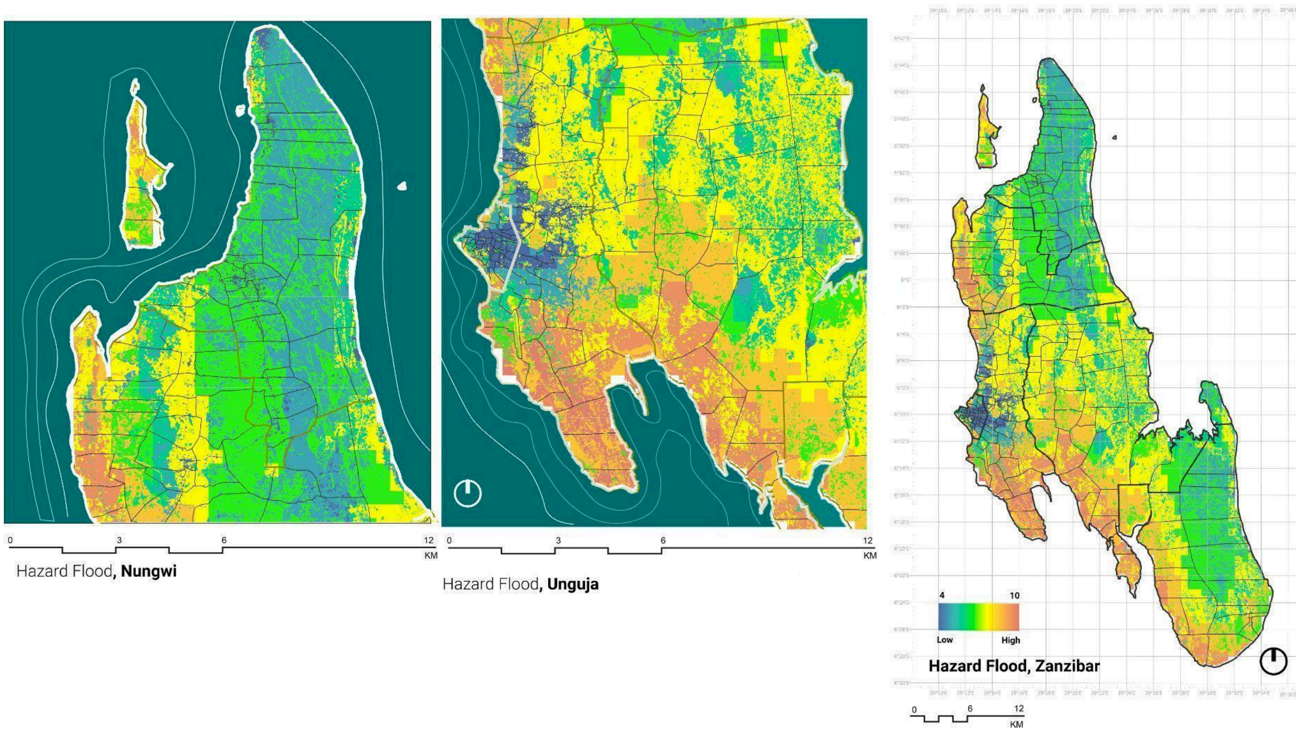


Figure 14 Spatial Distribution of Precipitation patterns across Zanzibar, 2021

7.2 Exposure Index

The exposure layer was obtained by combining the physical environmental features such as vegetation index-NDVI, elevation (areas below 5 m elevation), historic flood accumulation distance also referred cumulative historical flood extent, distance from major road proximity distance, the land use land cover. These components are classified to map the varying degrees of physical vulnerability within Zanzibar and, it can be observed that exposure is usually concentrated near the coastal and major urban regions unlike majorly distributed like the hazard indicator. Consequently, it has a positive correlation with NDVI. Which means, regions with lower NDVI values have a higher degree of exposure mapped. These are also regions which have a higher value of NDBI suggesting higher urban and coastal vulnerability. Certain regions around Dola with historic flood accumulation regions indicate a higher exposure score. Three major trends of exposure are mapped:

Relationship between Population Density and Historical flood extent, there is a positive relationship between the two variables which means that there is a higher exposure to flooding within densely populated areas. Population density hence is a significant factor of flooding and flooding is significantly caused by anthropogenic events/ man-made factors such as unplanned housing. The Zanzibar city has the highest population density, without proper drainage systems and city sewer systems which could contribute to urban flooding in dense regions. Moreover, the houses in the region are built very close to the coast due *(which are also low-lying regions)* to facilitate the tourism industry. Typical character of these neighborhoods is defined by narrow alleys, wide-independent bungalow houses with limited open spaces- so even if it rains a little, without an effective drainage system in place, water has nowhere to go. These regions flood irrespective of the amount of rain they receive. Secondly, the regions with *high population density have a lower NDVI value* (indicating an inverse relationship), exposing them to higher impacts of heat island effect. As a result, the wards with high population density are exposed to both flooding and extreme heat events.

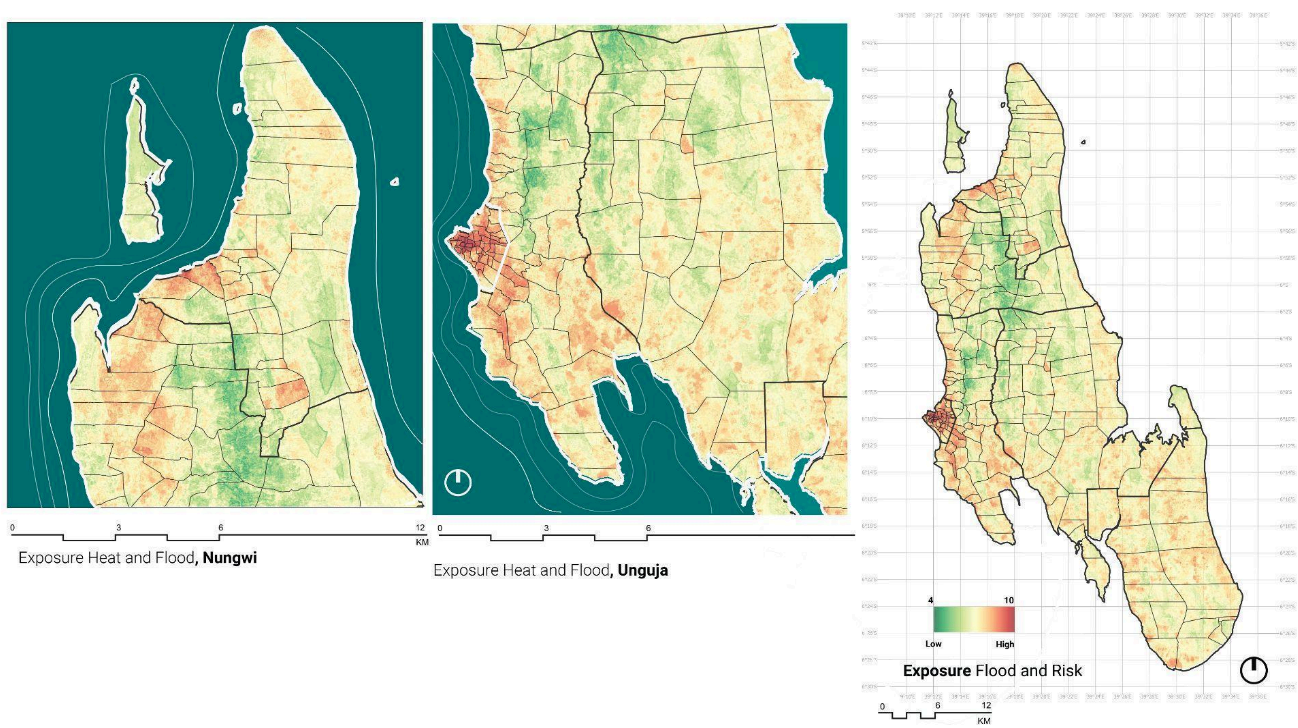


Figure 15 Exposure Map : Coastal and Extreme Heat

7.3 Vulnerability Index

The vulnerability map of Zanzibar (Fig. 17) was obtained by combining the socio-economic vulnerability and hazard bearing factors related as described in Equation 4 in the methodology. Within the study areas, spatial and temporal heterogeneity is evident across various parameters, including high population density living within greater inequality (higher gini-coefficient) and high unemployment rate. Highest vulnerability spatial clustering (score of 8 and above) is observed within the smallest district area of Zanzibar (7.8%) in Mjini housing the highest population density of 14600 people/KM2 (Figure 4). For the high vulnerability class (Fig. 18), the main vulnerability contributor is the socio-economic factor, also showing a balanced influence from the two other intermediate indices (exposure and hazard). The moderate vulnerability class (36.84%) of Zanzibar (Fig. 11) is characterized again by high socio-economic vulnerability and medium hazard vulnerability, while the low vulnerability class (Fig. 12) is similar, being characterized by high socio-economic vulnerability, but with a tendency towards exposure rather than hazard. The very low vulnerability class (32.89%) (Fig. 12) shows an equal tendency towards socio-economic vulnerability and exposure vulnerability. Hence, even with a geographic area particularly vulnerable to the risk of extreme heat and coastal flooding in Zanzibar, it poses a significant risk for the region due to its high population density living within the MMR wards.

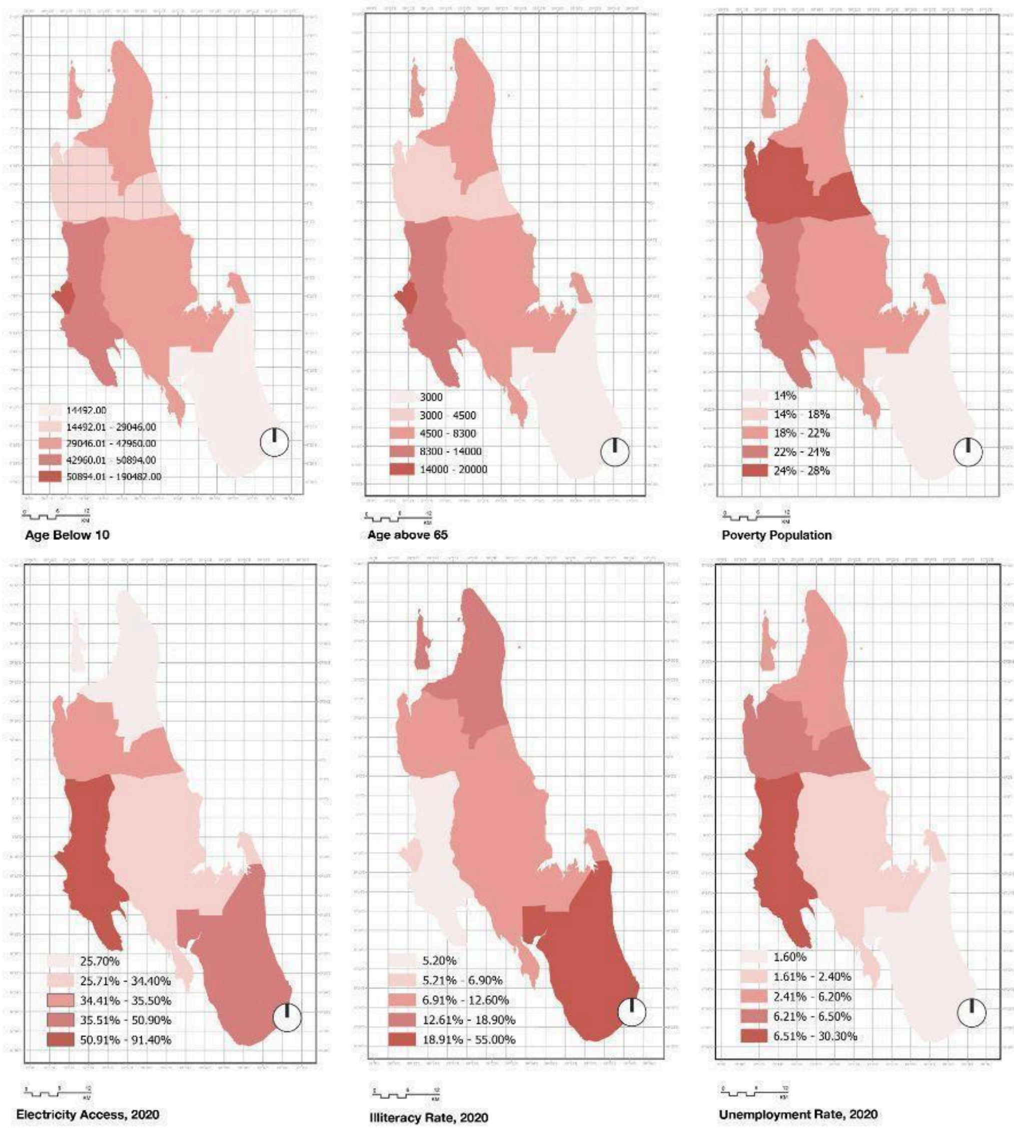


Figure 16 Vulnerability factors considered in the study.

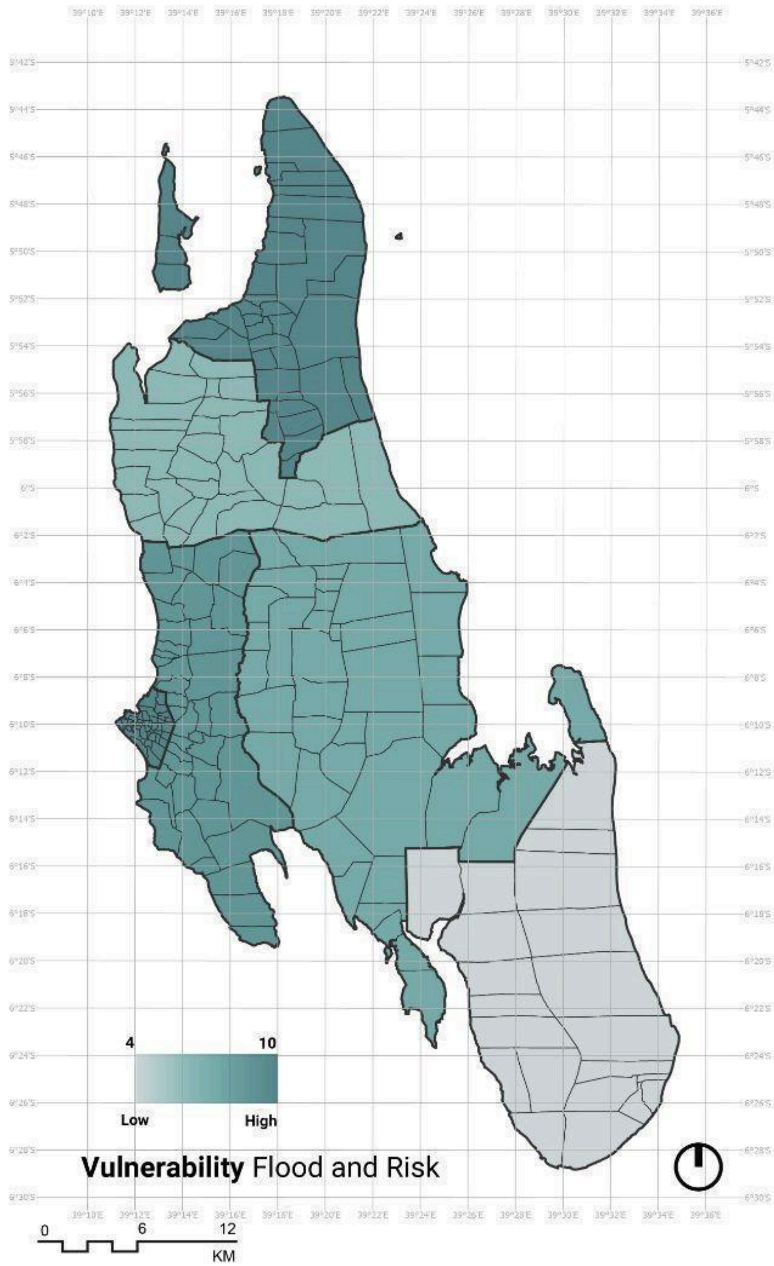


Figure 17 Vulnerability Map: Coastal and Extreme Heat

8.0 Spatial distribution of Heat Risk and Flood Risk in Zanzibar and its co-relationship

8.1 Heat:

On examining the inter-relationships between Heat Risk factors: There are three major trends to highlight here

1. ***Linear Relationship between Hazard and Exposure***

   There exists a strong and significant relationship between heat-related hazard and exposure factors. Specifically, as temperatures increase, more regions become exposed to heat risk, indicating a linear association between hazard and exposure (figure 18). For instance, in case of wards- Mwembe Tanga, Muembeshauri, Kwaalimsha, Mlandege, Kilimahewa and Bondeni have the highest score of 10 in case of hazard variable and they also fall under the high exposure category ranging between 8-10. This can be explained by the strong correlation between the variables of hazard and exposure indicating a significant impact of temperature on heat vulnerability.

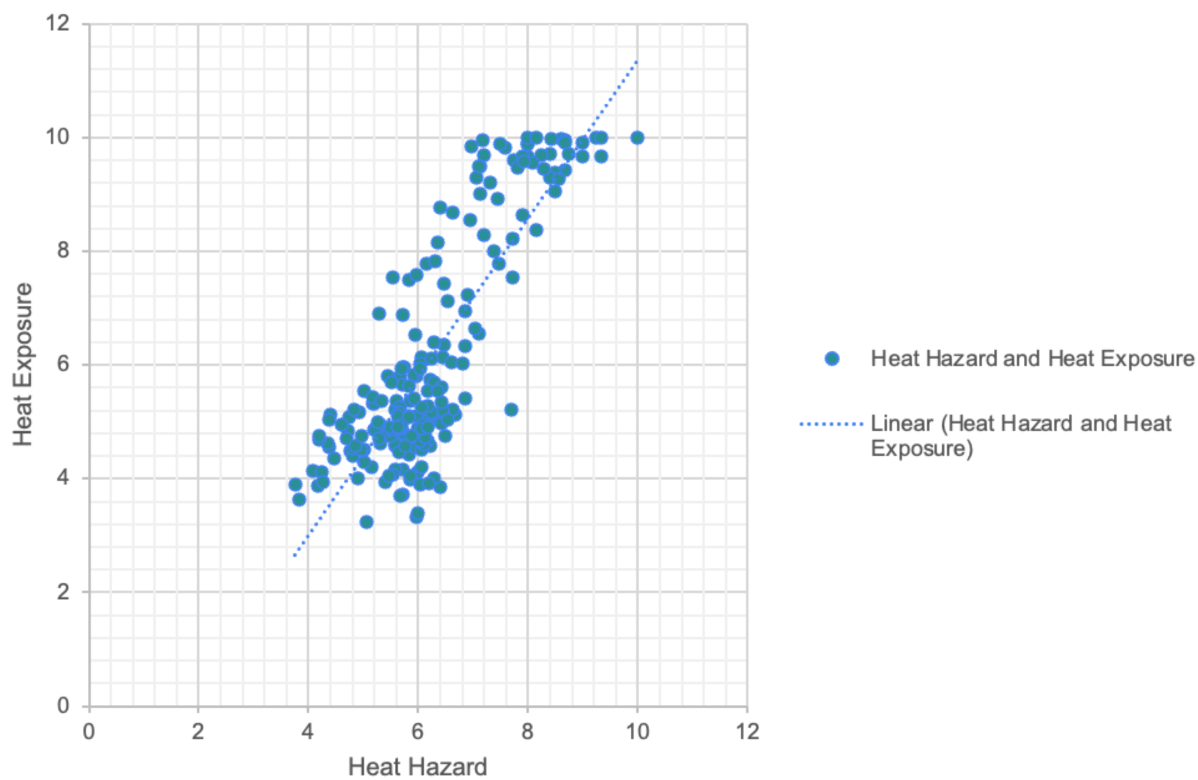


Figure 18 Relationship between Hazard and Exposure variables.

8.1.2 Contributing factors of Heat Risk

While temperature exerts a substantial influence on heat vulnerability, the Hazard factor contributes a mere 10% to the overall risk profile in Zanzibar. This suggests that rise in temperature alone is not a risk factor. Instead, its inter-relationship between exposure and vulnerability factors that amplifies heat risk, particularly due to the unequal distribution among socio-economic groups. This is explained by significant correlation between:

a) LST (hazard) and NDVI (exposure): In the figure (correlation matrix), the relationship between NDVI and LST is negative value of -0.74, which means greater the NDVI, higher is the surface temperature.
b) LST (hazard) and Population Density (exposure): Positive correlation between high population density and LST indicates spatial concentration of vulnerability. Higher temperature exposure is in regions with higher population density.
a) LST (hazard) and Unemployment population(vulnerability): Both unemployment and electricity access suggest that economically disadvantaged populations tend to reside in areas with higher surface temperatures, further exacerbating their vulnerability to heat-related risks. As a result, they are disproportionately exposed to higher temperatures. Other factors of exposure and vulnerability including Road Density, Land Use change also note higher variation in the overall risk of rising heat.

Heat Risk is Spatial and auto-colleralted: Examining the heat risk score at the ward-level, most wards which have higher risk value Mikunguni, Kwaalinatu, Kisiwandui, Kigunda, Gamba, Mkokoteni, Nungwi and Mwanakwerekwe are either located in the urban regions of Unguja or Nungwi or located closer to the coast. This re-affirms the above findings that spatial patterns of heat vulnerability that urban regions in coastal areas have relatively unfavorable characteristics for heat risk because of higher built-up density and rapid changes in land use patterns, increasing population density and lower clustering of open areas such as forest and agricultural areas. Such a scenario suggests that residing within urban settings is characterized by higher LST, which coincides with higher access to electricity, but within communities grappling with elevated levels of poverty and unemployment.

The connection between heat risk and economic vulnerability highlights how population density and socio-economic factors are intertwined with environmental factors, emphasizing the urgent need to address disparities in heat resilience. In terms of land-area 48% of the region is exposed to high medium and extreme heat risk which houses more than 75% (Mijni Municipal Region) of the population of Zanzibar. Only 15% of the area is at low risk, but evolving changing land use patterns suggest this may change. Thus, addressing heat risk in Zanzibar requires targeted interventions that consider environmental, socio-economic factors and spatial considerations to mitigate the adverse effects on vulnerable populations which could include:

a) *Environmental Resilienc*e: Implementing measures to mitigate urban heat islands through green infrastructure, urban greening, and sustainable land use planning can help reduce surface temperatures and enhance resilience to heatwaves.
b) *Socio-Economic Resilience:* Targeted interventions aimed at uplifting poor communities, such as job creation, access to affordable housing, and social safety nets, can mitigate the disproportionate impact of heat on vulnerable populations.

c) *Spatial Planning*: Incorporating heat resilience considerations into urban planning processes, including zoning regulations, building codes, and infrastructure development, can enhance the adaptive capacity of cities to withstand heat-related challenges.

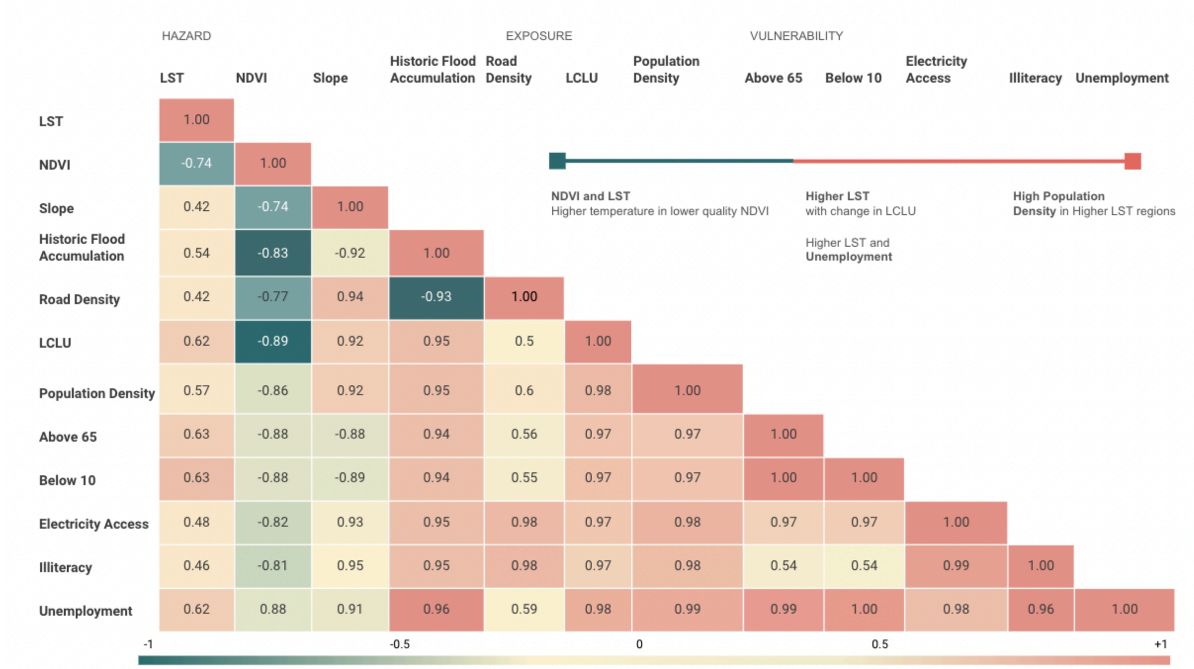


Figure 19 Correlation Coefficient Matrix: Heat

8.2 Flood:

In case of coastal hazards, flooding trends are more complex, as there does not appear to be a simple precipitation trend across the islands. However, there are indications of changes in hazard variability as there have been higher-intensity rainfall events recorded in recent years. For example, on 5 May 2015, Zanzibar recorded 172.00 millimeters of rainfall in three hours that caused serious flooding in different parts of Zanzibar, both urban and peri-urban (TMA, 2015). Another event was recorded on 24 November 2023 due to the so-called short rainy season that lasted from October to December causing floods, flash floods, rivers overflowing and triggering landslides (Al Jazeera, 2023). These changes are set to exacerbate existing precipitation trends and water management issues for floods in Zanzibar, a region that is particularly vulnerable to these impacts because it has large areas of low lying-land. (Figure 21)

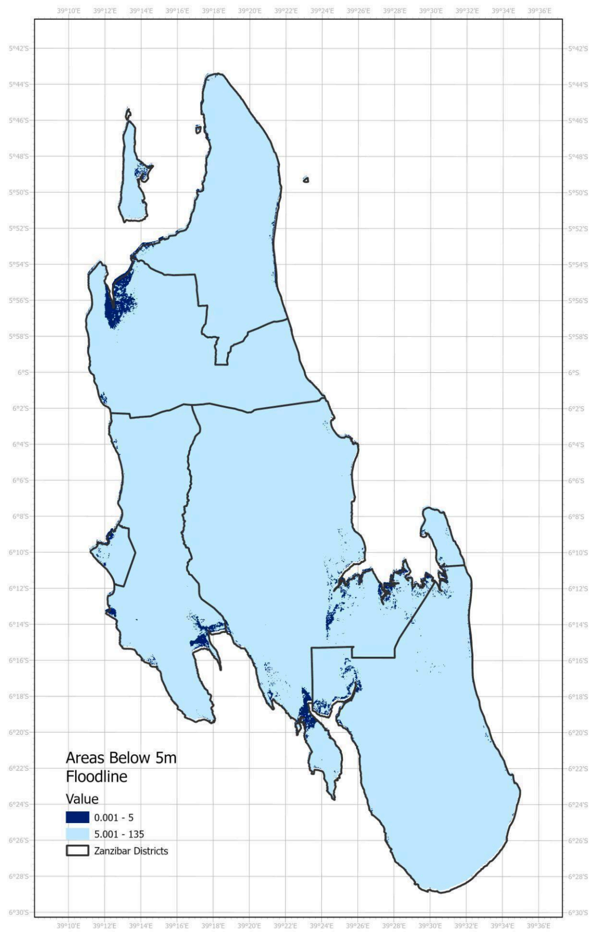


Figure 20 Around 20% of Unguja is in the coastal lower elevation zone and highly vulnerable to sea level rise.

Environmental factors, such as low-lying regions and areas prone to historic flooding, along with changing land-use patterns, are closely intertwined with socio-economic factors like poverty, population density, and access to services. In Zanzibar, there's a notable issue with historic land-use and cover change, exacerbated by a high density of housing, particularly in informal settlements. Records indicate significant expansion of Zanzibar Town between 1977 and 1994, with 2100 hectares (21 square kilometers) of prime agricultural land being absorbed (COLE 1995). There have been genuine complaints and warnings by the Ministry of Agriculture that the agricultural land is consistently decreasing due to over expansion of human settlements (Ali, et.al, 2006). This trend of unplanned construction is reflected in negative correlations between precipitation (hazard values) and regions undergoing substantial land-use changes (-0.60), juxtaposed with positive correlations in low-lying regions (0.61) prone to flood accumulation (0.60). Moreover, statistically significant positive correlations exist between flood accumulation in low-lying areas (0.90) and population density (0.91), poverty, and vulnerable age groups (0.87). That is to say that areas that are more exposed and vulnerable to flooding are more prone to flood risk which is evident in through the results of the PCA. It indicates that both exposure and vulnerability constitute over 75% of the flood risk while hazard contributes to 25% of the remaining risk. Precipitation contributes to 25% of the overall risk in case of Flood.

Like heat hazards, areas at risk of flooding are often situated within existing built-up regions near the coast. Specifically, low-lying, coastal, and urban areas face a threefold higher risk of flooding (Figure 9). These include Mwarusembe, Mikunguni, Kwaalinatu, Kisiwandui, Kigunda, Gamba, and Mkokoteni. Moreover, flood risk isn't limited to urban areas but extends to significant agricultural regions of Zanzibar (Figure 9), indicating a spatial correlation in flood risk. These spatial patterns highlight that both coastal and agricultural regions share unfavorable characteristics for flooding, such as low elevation, lower NDVI values with major changes in LCLU patterns.

Figure 21 Correlation Coefficient Matrix: Flood

9. Zanzibar's adaptation deficit: Geographies at Risk of Coastal flooding and Heat Hazards

Zanzibar remains particularly vulnerable to the impacts of climate change since its economy is very dependent on the climate-sensitive sector. As emphasized in the study, the convergence of socio-economic factors with heightened hazard variability has exacerbated this vulnerability. The impact of this has not only led to environmental degradation but also exacerbated social inequalities and incurred substantial economic costs in terms of GDP, which are significant at the macro-economic level reflecting Zanzibar's inadequate adaptation to the prevailing impacts of climate change. The island therefore has a large existing adaptation deficit. The thesis finds that the combined risk of Combined risk of extreme heat and coastal flooding is 41% leaving a total population of 74% of Zanzibar at the current risk of these two hazards which includes majorly urban/ built-up and agrarian land cover type of 64% and 25% respectively.

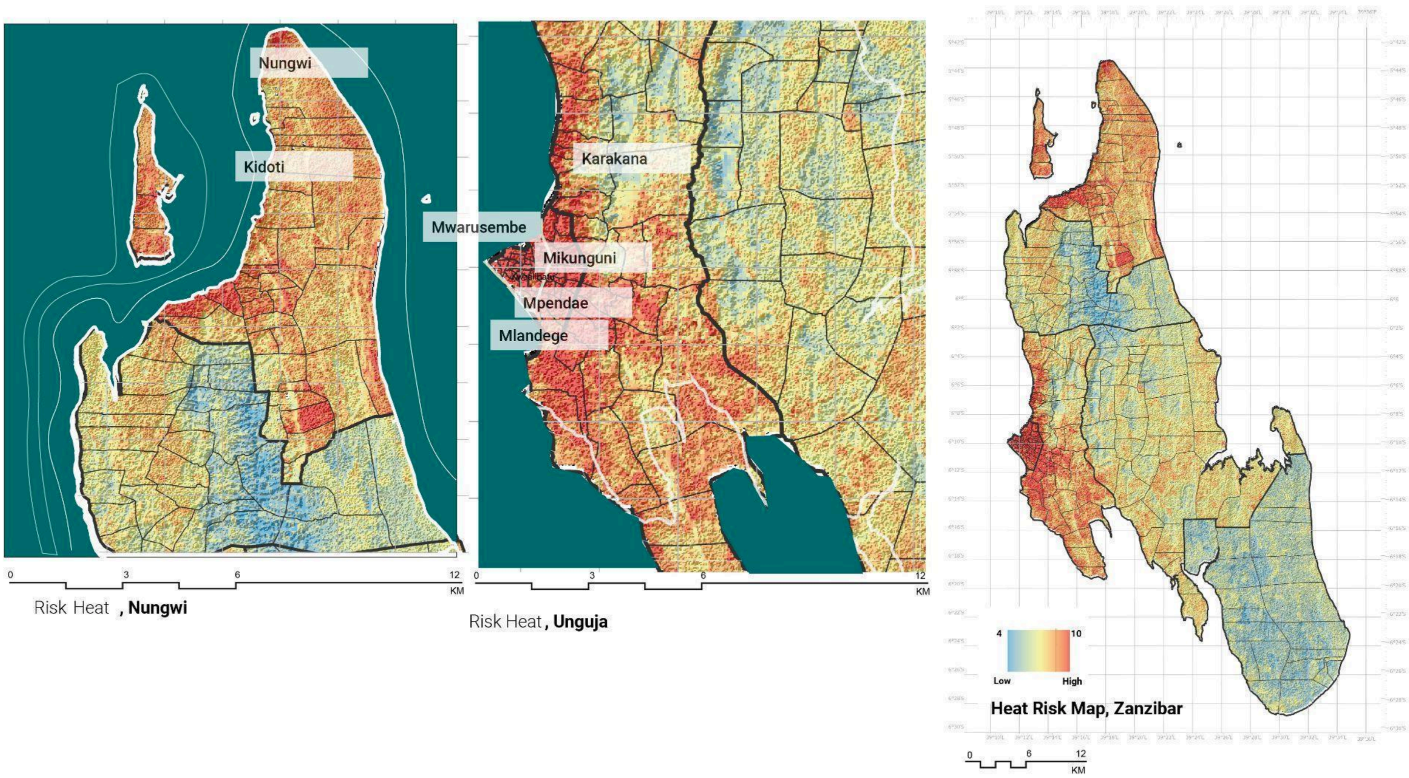


Figure 22 Heat Risk and Coastal Flooding Risk, Zanzibar

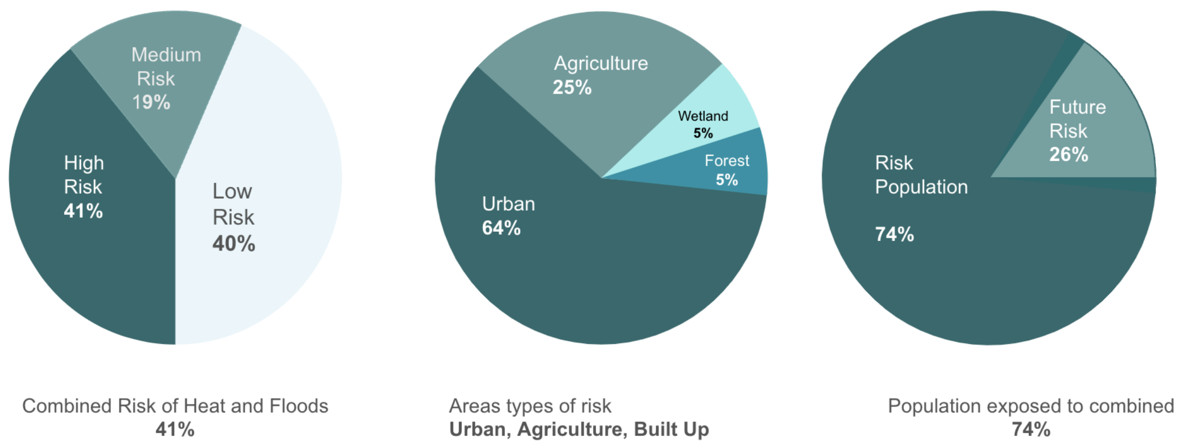


Figure 23 Zanzibar's adaptation deficit: Geographies at Risk of Coastal flooding and Heat Hazards

The major identified wards at risk are:

Table 7: High Risk- Heat

Ward Name	Mean Exposure	Mean Hazard	Mean Vulnerability	MeanRisk
Ndijani Muembe Punda	5.7	4.1	6.0	9.0
Mikunguni	8.7	9.7	8.0	8.3
Kibuteni	5.5	4.1	3.0	8.3
Kilimahewa Juu	7.2	9.6	8.0	8.2
Gulioni	8.4	9.7	8.0	8.0
Makadara	8.2	9.6	8.0	8.0
Meya	8.0	9.6	8.0	8.0
Tomondo	7.3	9.2	7.0	8.0
Kidongo Chekundu	8.5	9.0	8.0	8.0
Shangani	7.3	8.0	8.0	8.0
Dole	4.4	4.3	7.0	8.0

Table 8: Low Risk- Heat

Ward Name	Mean Exposure Score	Mean Hazard Score	Mean Vulnerability Score	Mean Risk Score
Sebleni	8.2	9.4	8	4.0
Mpendae	7.0	9.2	8	4.2
Melinne	7.9	9.5	7	4.3
Kidoti	5.6	4.9	8	4.3
Mpapa	6.5	5.0	6	4.3
Mwanakwerekwe	7.1	9.4	7	4.3
Tindini	6.1	4.9	6	4.3
Pangawe	6.4	8.7	7	4.4
Urusi	7.8	9.6	8	4.4
Fuoni Kibondeni	6.3	5.5	7	4.4

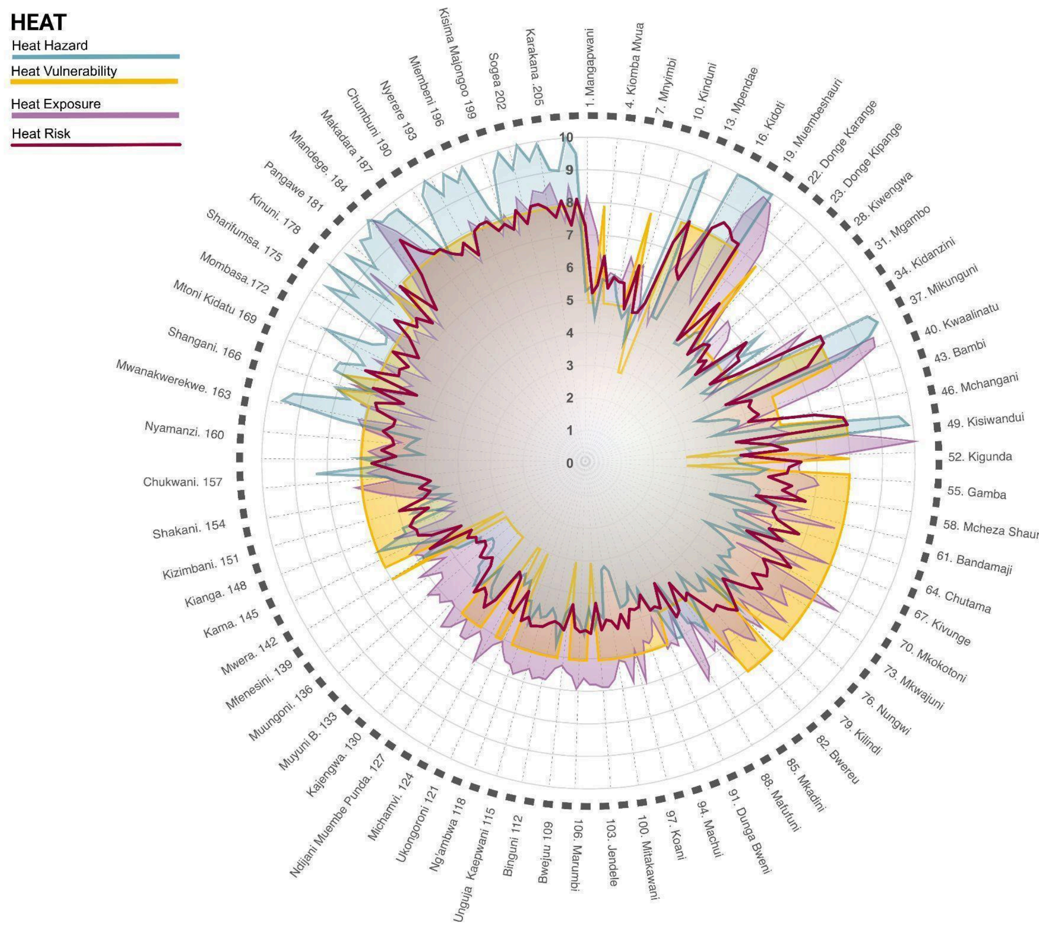


Figure 24 Rate of Heat Risk along and its interrelationship with hazard, exposure and vulnerability variables at ward level

Table 9: High Risk: Flood

Ward Name	Mean Exposure Score	Mean Hazard Score	Mean Vulnerability Score	Mean Risk Score
Rahaleo	9.2	8.9	8.0	9.0
Muembetanga	9.4	7.5	8.0	8.3
Mlandege	9.6	8.8	8.0	8.3
Muembeshauri	9.3	9.0	8.0	8.3
Kwaalimsha	8.1	10.0	8.0	8.3
Vikokotoni	8.7	7.8	8.0	8.2
Mwembeladu	9.5	8.7	8.0	8.2
Amani	8.3	9.1	8.0	8.1
Mikunguni	8.7	9.1	8.0	8.0
Matarumbeta	8.5	9.5	8.0	8.0

Table 10: Low Risk: Flood

Ward Name	Mean Exposure Score	Mean Hazard Score	Mean Vulnerability Score	Mean Risk Score
Tasani	5.5	5.1	3	4.50
Mgambo	4.3	6.2	5	4.56
Donge Vijibweni	4.5	5.8	5	4.73
Mbaleni	4.7	6.0	5	4.76
Kibuteni	5.9	5.1	3	4.79
Donge Karange	4.9	6.0	5	4.83
Mtende	6.2	4.2	3	4.84
Muyuni B	6.1	4.9	3	4.84
Nganani	5.9	5.8	3	4.85
Muungoni	6.1	5.0	3	4.85

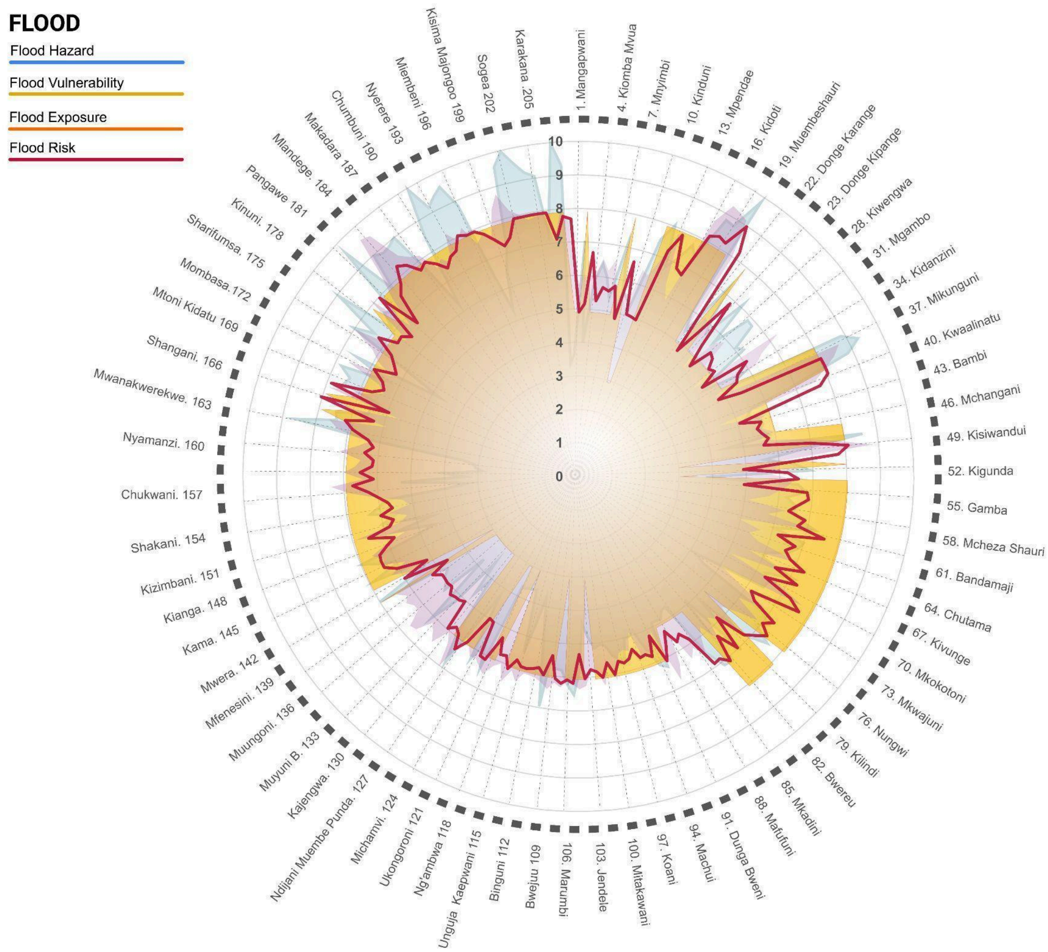


Figure 25 Rate of Flood Risk along and its interrelationship with hazard, exposure and vulnerability variables at ward level

The wards exhibit distinct levels of risk concerning heat and flooding. High-risk wards for heat are located in the Zanzibar city which include Ndijani, Muembe Punda and Mikunguni (Table 7 and 9), demonstrate elevated exposure, vulnerability, and overall risk, indicating significant susceptibility to urban heat island effects. Most houses in Zanzibar city are single-storied, characterized by concrete walls and asbestos roofs. They are widely accepted as a cheap and affordable material but have high heat-absorbing quality increasing the indoor and outdoor temperature of the region. Low-risk wards for heat, like Mpendae in Mjini ward on the outskirts of urban areas, exhibit higher hazard (9.2) and vulnerability (8), potentially due to Zanzibar's existing policy framework. The post-revolution Land Reform Policy aimed to provide land ownership to landless farmers through the distribution of 3-acre plots solely for agricultural use, prohibiting their sale or conversion into human settlements. However, urban population growth spurred demand for residential plots, leading to illegal conversions of 3-acre agricultural plots into human settlements, driving rapid land cover changes. Additionally, the adoption of sophisticated and rigid planning and surveying methods under neoliberal frameworks also posted significant challenges (ibid). Planning standards and building codes. In late 1970s and early 1980s one of the conditions for building a house in a planned area was that the value of the building must be over Tanzanian

Shilling 500,000. This deterred many from building in planned areas, resulting in rampant construction in more affordable but semi-planned areas like Mpendae and Muungano.

In terms of flooding, wards like Rahaleo, Muembetanga, Mikunguni are identified as high-risk areas for flooding, characterized by high exposure, hazard, vulnerability, and overall risk. These wards are all located in low-lying areas in the coastal zone. Mikunguni, being the main market area in the city, is at risk of both flooding and heat vulnerability due to its high road density, lack of green cover and higher flood accumulation area. While regions like Magapwani, known as "Arabian Shore," in Swahili, likely named during the black-market slavery period in the 19th century, boast numerous caves attracting tourists. Despite high tourist attractions, the region is at low risk due to factors such as tourism activities contributing to forest cover preservation and maintenance, counteracting broader land cover and land use changes observed in response to the land reform policy. Thus, tourism has acted as a factor aiding land preservation in these areas.

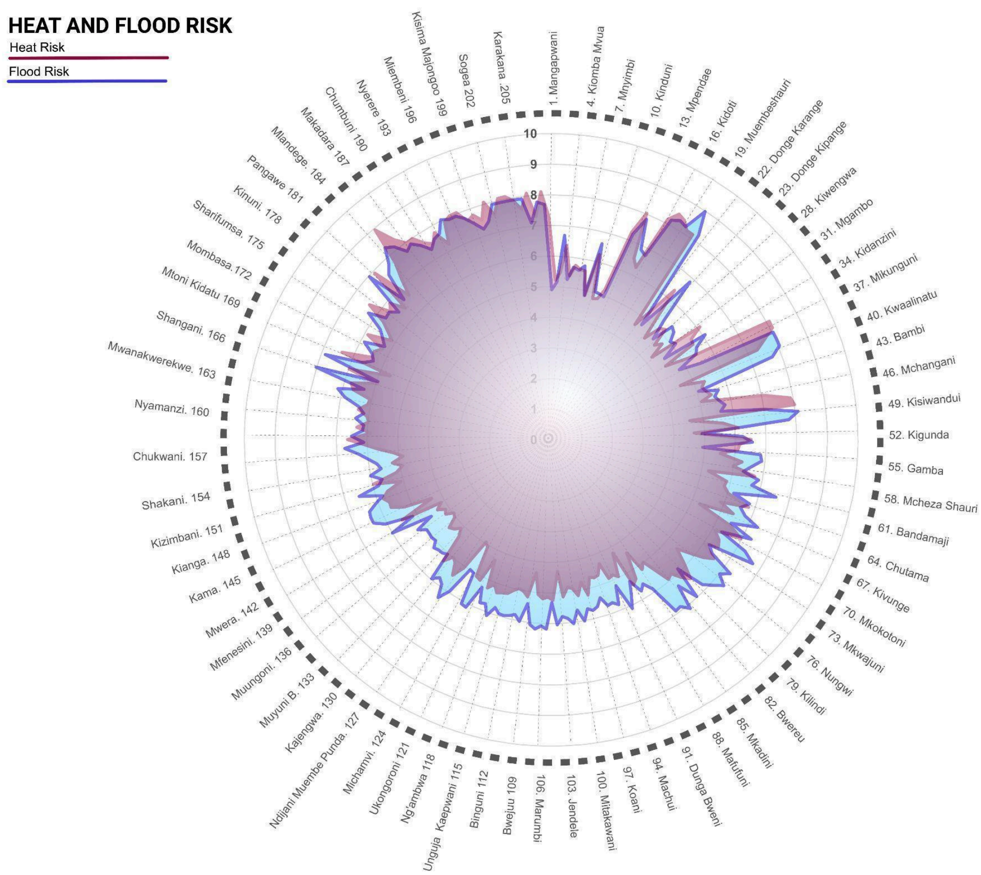


Figure 26 Inter-relationship between heat and flood risk score at the ward-level.

10. Conclusion

Zanzibar has remained particularly vulnerable to the dichotomy of climate change, with a large population relying on an ecology-based tourism economy. This vulnerability is causing growing concern among residents, as it impacts their everyday life and livelihood. Rapid urbanization, high population growth, climate change, and transformation of land cover (from vegetation and water bodies to built-up areas) are causing an increase in the magnitude of this hazard. To address this, this study estimated multi-hazard risk in the Zanzibar based on three latent vulnerability parameters: exposure, sensitivity, and adaptive capacity. It allows flexibility regarding the input variables, depending on the local context and availability of the data. This approach has been valuable for forecasting communities at risk in the event of flooding and heat hazards, while also highlighting geographies that are the most vulnerable.

The results indicate that MHR is strongly associated with exposure and vulnerability parameters, which means that an increase in temperature and precipitation—measured by hazard variables—is not a factor of risk. Instead, socio-economic conditions, coupled with inflexible planning and land-use changes under neoliberal frameworks, have exacerbated multi-hazard risks in the context of Zanzibar. For instance, urbanization impacts indicate higher susceptibility to heat-related hazards and flooding events, particularly in low-lying coastal regions of Mjini Magharibi and Kusini Region. Socio-economic factors such as poverty, unemployment, and inadequate access to basic services have compounded the vulnerability of marginalized groups, amplifying the magnitude of the risks they face. Most of the environmental fragility was mapped by the indicator of flood extent areas in 36% of wards, followed by physical land cover change in 31% of wards, then vulnerability factors including age population over 65—in 38% of LAUs, population less than 10—in 23% of wards, and poverty population 37%.

Therefore, social vulnerability is influenced not only by the inherent characteristics of a certain community but also by location, spatial distribution, hazard type, and hazard characteristics. The interaction between all these factors leads to complex relationships that must be considered and carefully analyzed. The community's resilience depends on these factors, which will change over time and will be different from community to community and from place to place. One indication of this phenomenon is the rural-urban divide. The historic urban center of Stone Town relies heavily on tourism, with beaches and waterfront attractions driving local businesses. Consequently, coastal erosion due to sea-level rise poses a significant threat to their economic stability. However, rural wards in the Magharibi district in the west are mainly affected by the conversion of agricultural land into settlements. While these regions are also affected by sea-level rise, a recent report by the Ministry emphasizes the primary concern in these regions is, in fact, the decrease in crop production and the income of impoverished agricultural families. Historically, these areas were vital for rain-fed rice cultivation. However, according to data from the Department of Land Resources (DoLR), the land area dedicated to agriculture diminished from 635 hectares in 1995 to 162 hectares in 2005, representing a loss of agricultural land amounting to approximately 75 percent. Moreover, the communities have adaptive behaviors, learning how to adapt and respond to disasters. On the one hand, urban areas, characterized by higher population densities and extensive infrastructure, confront increased exposure to hazards. But rural regions often grapple with limited resources and underdeveloped infrastructure, leaving them ill-equipped to cope with or preemptively address risks.

Vulnerability is a dynamic factor, and the approaches used to analyze this vulnerability must be adapted to specific situations. In conclusion, the findings underscore the critical need for proactive measures to address the escalating risks of heat and flooding in Zanzibar. The policies and reduction strategies must be context-adapted,

and it is essential to have a good knowledge of the local situation and social background when flood and heat risk management plans are developed. Addressing the adaptation deficit in the small island state requires a multifaceted and context-specific approach that integrates environmental resilience, socio-economic empowerment, and spatial planning strategies. Some of these interventions could include green infrastructure, sustainable land use practices, and urban greening initiatives, which can be useful in mitigating the urban heat island effect and reducing the risk of flooding. Targeted interventions aimed at uplifting poor communities, enhancing access to essential services, and promoting social safety nets are imperative. Additionally, incorporating heat and flood resilience considerations into urban planning processes, including zoning regulations, building codes, and infrastructure development, can enhance the adaptive capacity of cities to withstand climate-related challenges.

11. Recommendations and Learnings from Community

In response to the current findings from the MHRA, the thesis has developed a comprehensive response framework through a multifaceted approach involving semi-structured interviews with community leaders, engagements with ZEMA and DEA authorities, and focused group discussions in identified risk wards. These activities were undertaken to address four major takeaways:

1. **Community Perceptions of Risk:** *The communities identified; did they perceive the risk?* The study analyzed the alignment between actual and perceived vulnerability and people's perceptions of risk through on-ground interventions. While existing literature indicates that many urban dwellers find comfort in informal settlements, viewing them as the embodiment of Swahili life characterized by sharing and neighborly togetherness (Ali, M et. al, 2006). The focused group discussion revealed that communities residing in vulnerable wards expressed high degrees of risk associated with at least one hazard. This indicates a congruence between the communities' perceived vulnerabilities and their mapping as vulnerable. On a scale of 1-10, most communities expressed a degree of risk ranging between 8 to 10 (feel highly vulnerable).

Figure 27 Heat exposure is high due to no-vegetation in communities.

2. **Examining the Impact of Combined Hazards:** It is evident that the identified vulnerabilities align closely with the concerns expressed by residents, but the way these hazards impact these communities is different. For instance, certain wards like Mkunazini express concerns for rising heat only, while wards in Nyerere express concerns for both flooding and heat due to the growing issue of waste disposal within their community. The cumulative effects of various hazards have had impacts on their everyday life in the form of skin rashes, women's menstrual health, and emotional wellbeing. Secondly, the effects of heat are also felt differently among different population groups - younger children and people feel thirstier; community members say even if the temperature is 32°C now, it feels like 40°C. Trees have been cut, and there is no breeze to reduce the intensity of the rising heat. The lack of a drainage system along with an improper waste disposal system again poses a great concern, as during floods, the waste enters the house, causing various diseases like diarrhea and malaria among kids.

Figure 28 Lack of drainage system increases the susceptibility to flooding in Nyerere

3. **Ground Truthing Local Factors:** This aimed to identify the local factors responsible for exacerbating changes in vulnerability and specific socio-economic, environmental, and infrastructural factors responsible for heightened vulnerability. One significant factor that emerged strongly is tourism, which is considered a win-win for the region. While it impacts the urban and physical environment, it also generates considerable employment opportunities for locals, contributing to 30% of the economy and 80% of its foreign exchange (WB, 2021). However, there is a need for planned and culturally sensitive tourism to preserve the cultural sentiments of Zanzibar, a majority Muslim society. Tourism development should be diversified and resilient, especially in Stone Town, a historic UNESCO World Heritage Site. Here, limitations such as the inability to extend windows or retrofit existing buildings to respond to climate change necessitate resilient, sustainable, and low-carbon tourism practices. Secondly, the quality of housing materials significantly affects vulnerability. In Zanzibar city, single-storied houses characterized by concrete walls and asbestos roofs are widely accepted as cheap and affordable but have a high heat-absorbing quality, increasing indoor and outdoor temperatures. It's essential to promote locally available materials that do not trap heat, such as

4. **Identifying Institutional Gaps and Community Strategies:** The final hypothesis aimed to identify institutional gaps and explore community-driven strategies for risk reduction. By engaging with both government agencies and local communities, the interviews sought to identify domains where institutional support is lacking and opportunities for community-led interventions. One peculiar area that emerged here was the interaction between URT and Zanzibar. Zanzibar, being the semi-autonomous part of URT, sees major decision-making for climate change mitigation handled by URT as it serves as the focal point for the UNFCCC, leaving Zanzibar without direct representation

within the international climate change governance architecture. As a result, the Department of Environment (DEA) works in collaboration with ZEMA to shape policies and regulate the environment - emphasizing better coordination and regional independence as crucial. In terms of community-led interventions, there was a highlighted need for better integration and support from the government, extending beyond early warning systems. This includes initiatives such as drainage construction, establishment of waste disposal infrastructure, and efficient planning, with a focus on involving communities in decision-making processes before rather than after implementation. Additionally, integrating better community engagement in the early phases of planning policies related to climate change was emphasized as essential for effective and sustainable risk reduction strategies.

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13. Appendix

CoCHAP CWRA: MHRA

Zanzibar

Date: May 13, 2024

PART I- Semi-structured interviews

Community Questionnaire

1.What is the major source of employment for you and the people in the community?			
2.When was the latest flooding or extreme heat event you experienced?	2024	2023	2022
3.What parts of the area you found to be flooded?			
4.In your experience have the events accelerated in recent times?	Yes, a lot	Yes, little	No
5.If yes, why do you think so?	Physical Environment Change	Green cover loss	Other Social Vulnerabilities
6.Has the temperature increased significantly in recent years?	Yes, a lot	Yes, little	No
7.If yes, why do you think it is?	Trees being cut	More Houses being built	More people have started living in this neighborhood
8.Do you think tourism has led to more climate change in your community?			
9.In case of extreme flooding, what do you do?			
10.In case of extreme heat days, what do you do?			
11.Does the government support these events?			
12.What measures has the government taken in recent times to reduce the risk in your areas?			
13.What do you think can be done to reduce the severity of these events in your neighborhood?			

CoCHAP CWRA: MHRA

Zanzibar

Date: May 13, 2024

PART I- Semi-structured interviews

Community Leaders Questionnaire

1.Since how-long have you been working with TCRS?			
2.What are the primary concerns regarding coastal heat and flooding in our community?			
3.How have recent flooding or extreme heat events impacted the community?			
4.What parts of the area you found to be flooded? What areas in the community are most vulnerable to flooding or extreme heat?			
5.Are particular/specific groups affected more by heat or flooding within the community? If yes, like what?			
6.If yes, why do you think so?	Physical Environment Change	Green cover loss	Other Social Vulnerabilities
7.Have you noticed any trends or changes in the frequency or severity of these events?			
8.How do community members typically respond to flooding or extreme heat events?			
9. What resources or support does our community currently have in place to address these challenges?			
10. How does our community work with local authorities or government agencies to address coastal heat and flooding issues?			
11. Are there any ongoing initiatives or projects aimed at mitigating the risks associated with these events?			
12. How do you engage with community members to raise awareness about coastal heat and flooding issues?			
13. What are the long-term plans or strategies for building resilience to these challenges in our community?			
14. How do you envision the future of our community in the face of climate change and its impacts on coastal areas?			
15. Are there opportunities for collaboration with neighboring communities or organizations to address shared concerns related to coastal heat and flooding?			

CoCHAP CWRA: MHRA
Zanzibar

Date: May 13, 2024

PART I- Semi-structured interviews

TRCS Questionnaire

1.What motivated the TRCS to initiate the CoCHAP project focusing on heat and coastal flooding resilience in Zanzibar?
2. Could you describe the main objectives and goals of the CoCHAP project?
3. How does TRCS collaborate with community leaders in Zanzibar islands to implement the CoCHAP project?
4. What specific challenges or vulnerabilities related to coastal heat does the CoCHAP project aim to address?
5. How does TRCS assess and prioritize communities most at risk of coastal heat in Zanzibar islands?
6. What strategies or interventions does the CoCHAP project employ to build resilience to coastal heat in communities?
7. How does TRCS engage with local stakeholders, including community leaders, to ensure the success and sustainability of the CoCHAP project?
8. Are there any innovative or community-driven approaches implemented as part of the CoCHAP project?
9. What are some achievements or successes of the CoCHAP project thus far?
10. How does TRCS monitor and evaluate the effectiveness of interventions aimed at reducing heat risks in coastal communities?
11. What are the key lessons learned from implementing the CoCHAP project, and how are they being applied to future initiatives?

CoCHAP CWRA: MHRA

Zanzibar

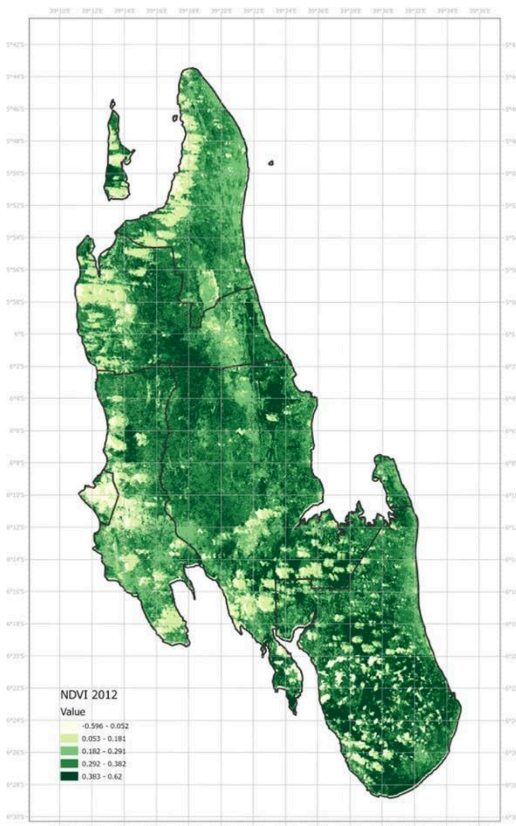
Date: May 13, 2024

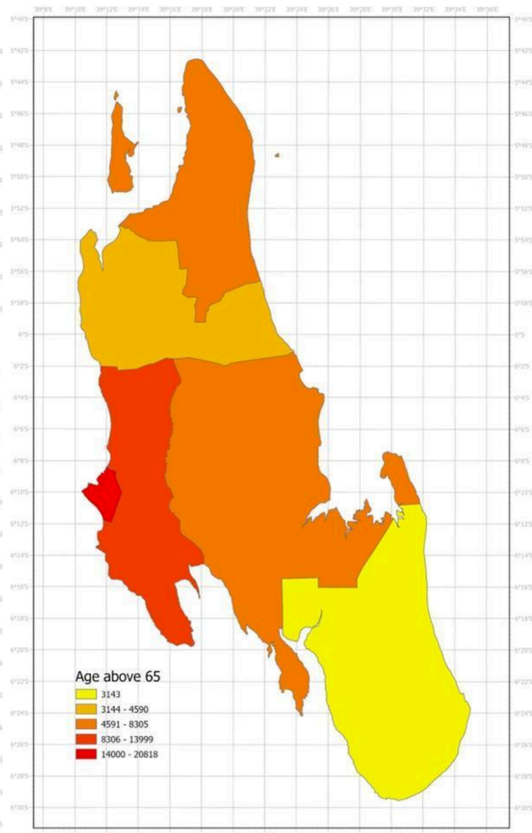
PART I- Semi-structured interviews

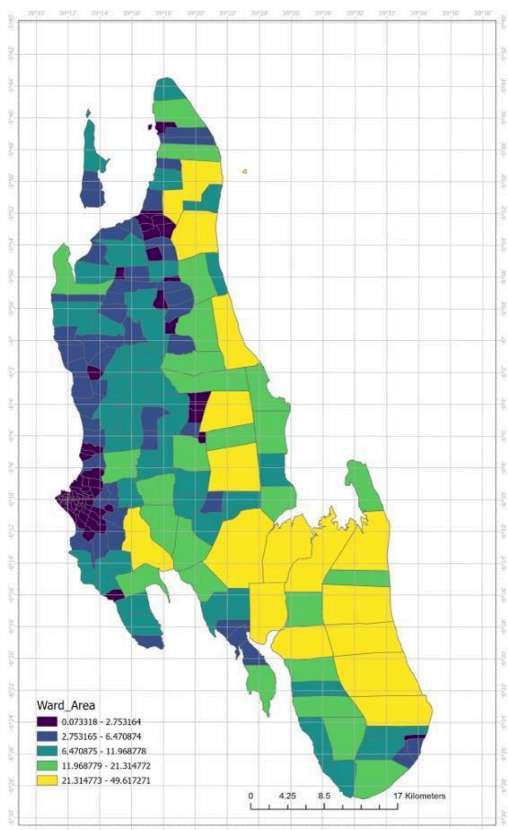
ZEMA Questionnaire: **Director General of Zanzibar Environment Management Authority**

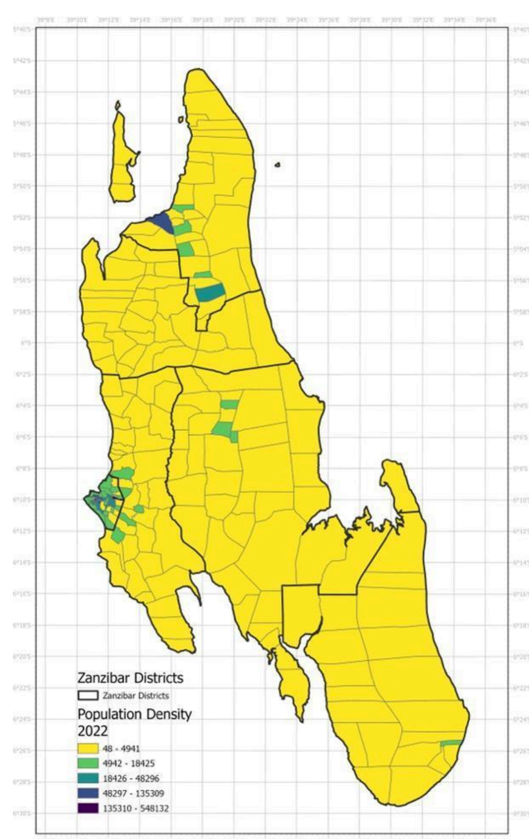
1.How (ZEMA) secure funding for climate change action in Zanzibar, and what sources of financing have been utilized?
2.What specific challenges or roadblocks does ZEMA encounter in its collaboration with Tanzania on environmental issues, and how are these addressed?
3.Can you highlight some notable achievements of ZEMA under the Environmental Policy Act, and how have these contributed to environmental sustainability in Zanzibar?
4.What are the main challenges faced by ZEMA in implementing environmental policies and initiatives, and what strategies are being employed to overcome them?
5.How does ZEMA collaborate with the Tanzania Red Cross Society (TRCS) on environmental projects or disaster response efforts, and what are the key areas of partnership?
6.In what ways do you believe the Tanzania Red Cross Society could enhance its support for ZEMA's environmental work in Zanzibar?
7.From ZEMA's perspective, what actions or initiatives can local communities undertake to improve environmental conditions in their respective wards?
8.How does ZEMA engage with other stakeholders, such as NGOs, businesses, and academic institutions, to address environmental challenges and promote sustainable development?
9.How does ZEMA prioritize environmental issues and allocate resources to address them effectively, considering the diverse range of challenges facing the region?

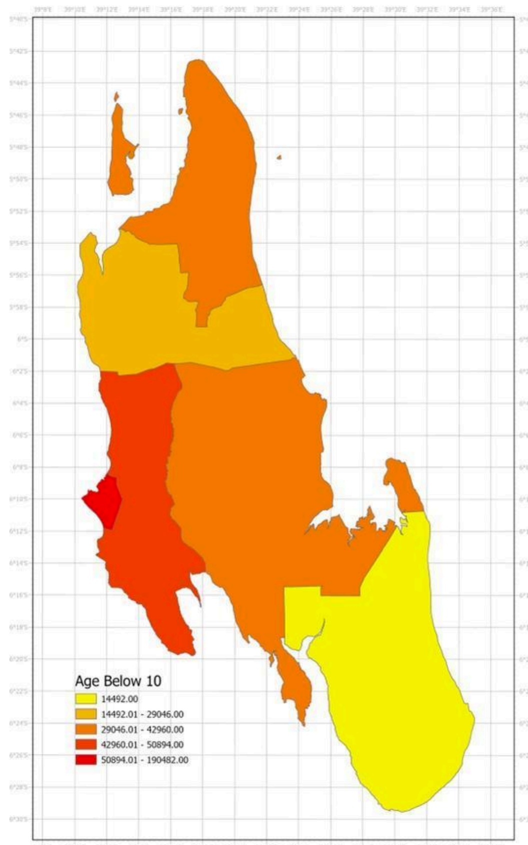
Demographic and Socio-economic factors







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14492.01 - 29046.00
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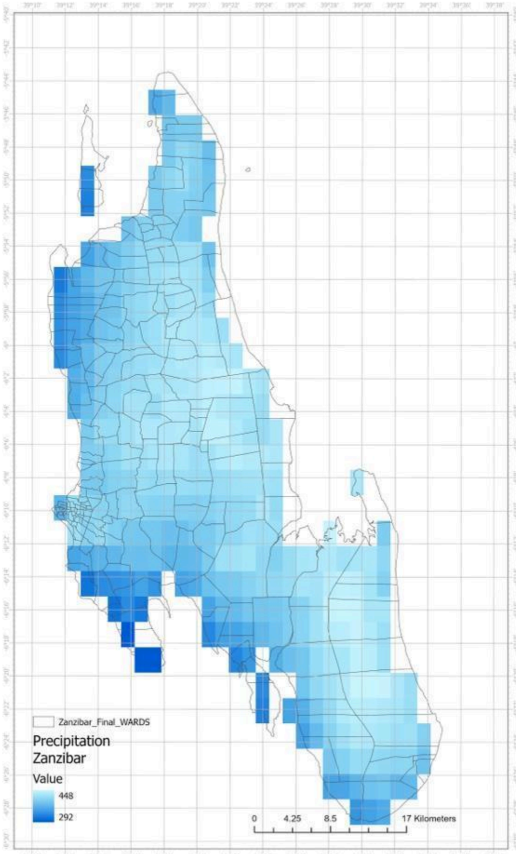
42960.01 - 50894.00
50894.01 - 190482.00


Zanzibar_Final_WARDS
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Zanzibar
Value
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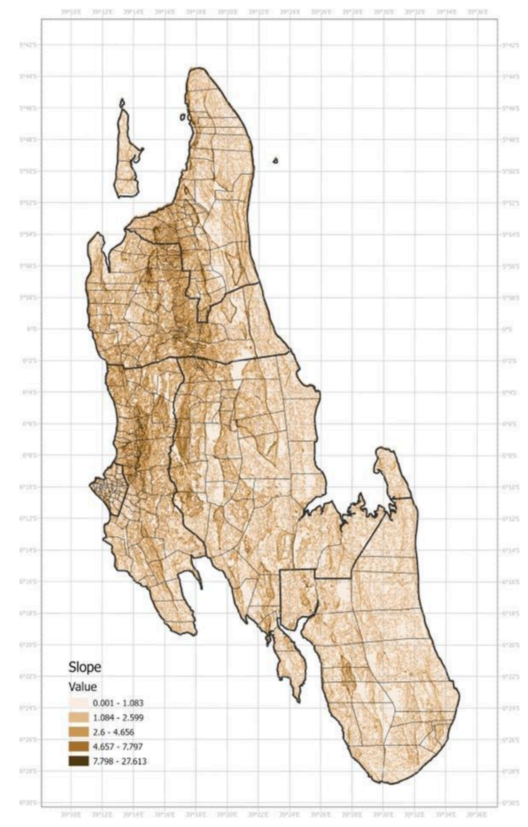
292
0 4.25 8.5 17 Kilometers


Slope
Value
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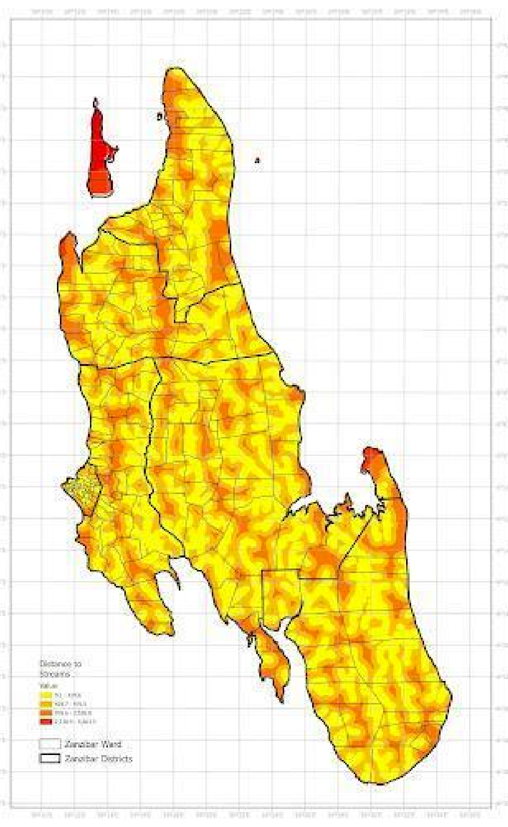
1.084 - 2.599
2.6 - 4.656
4.657 - 7.797
7.798 - 27.613


Distance to
Streams
Value
Zanzibar Ward
Zanzibar Districts