Coastal City Heat and Resilience Project (CoCHAP)

CITY WISE RISK ASSESMENT: AGIS PERSPECTIVE

TANGA CITY

January, 2024

Dr. Dorothea Deus

GIS and RS Expert

ACKNOWLEDGEMENT

I would like to ackwnoledge Tanzania Red Cross Society (TRCS) for giving us the opportunity to participate in the project. Implementation of the project would have not possible without the support of the project manager Ms. Magret Lugata whom I am indebted. I would like to acknowledg all those who supported the process whether directly or indirectly, most of whom I cannot appreciate by name.

EXECUTIVE SUMMARY

In partnership with the Government of Tanzania, the International Federation of Red Cross and Red Crescent (IFRC), universities, and with the support of the USAID Bureau for Humanitarian Assistance (BHA), Tanzania Red Cross Society (TRCS) is implementing a Coastal City Heat Action Project (CoCHAP). CoCHAP aims at addressing the escalating challenges presented by climate change and extreme weather events. To implement the project TRCS conducted City Wide Risk assessment September-October month with close support from IFRC, Local government, Universities and different stakeholders for both two cities of Tanga and Unguja. The assessment explored on different city systems related with environmental science, engineering, economics, social sciences, and community engagement. It was covering various aspects of its social, economic, environmental, and infrastructure components in play crucial role in guiding urban development and governance through providing of 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 compliments the findings obtained during the CWRA, GIS-based CWRA has been implemented in Tanga city with the aims to make the National Society, local government, stakeholders in Tanga city be more knowledgeable and empowered to be able to adapt to and reduce climate-induced coastal heat risks. The GIS mapping in Tanga city is crucial for reducing disaster risks, climate change mitigation and adaptation measures. This is simply because mapping can help identify the areas that are most vulnerable to disaster risks, climate change and prioritize adaptation measures. It also helps develop early warning systems and evacuation plans for climate-related hazards and policies for climate change adaptation and mitigation. This report presents GIS based analysis and mapping outcomes for Tanga City's environment, climate change and variability.

LIST OF ABBREVIATION

AET	Actual Evapotranspiration
BHA	Bureau for Humanitarian Assistance
CoCHAP	Coastal City Heat Action Project
GIS	Geographic Information System
HRI	Heat Risk Index
IFRC	International Federation of Red Cross and Red Crescent
LTM	Long Term Mean
NDVI	Normalized Difference Vegetation Index
PET	Potential Evapotranspiration
TRCS	Tanzania Red Cross Society
UHI	Urban Heat Island

TABLE OF CONTENT

List of Tables

List of Figure

CHAPTER ONE

INTRODUCTION

1.1 Background

Extreme heat is a hazard that is increasing in frequency, severity, and complexity due to climate change. In the last decade, heat waves caused more deaths globally than any other climate-related disaster (International Federation of Red Cross and Red Crescent Societies 2020). More importantly, while heat-related deaths are accounted for, the more chronic and subtly pervasive impacts of heat often go unreported and unmanaged. These impacts touch nearly every aspect of urban life, negatively impacting human, social, physical, financial, and natural capital. Together, these impacts can compromise human capital development, social mobility and welfare, and overall economic growth.

Heat has uneven spatial and social distributions, with wide variations in temperatures and adaptive capacities across buildings, communities, and cities around the world. Urban areas often experience higher temperatures by absorbing more solar radiation than surrounding rural areas, a phenomenon called the urban heat island (UHI) effect. Contributing factors may include reduced coverage of naturally cooling vegetation and water bodies, higher usage of heat-absorbing and heat-retaining building materials, reduced air circulation from densely built infrastructure, and higher output of anthropogenic heat sources, such as waste heat from vehicles and cooling devices (Stewart 2011; Mohajerani et. al., 2017). These spatial vulnerabilities can overlap with socioeconomic vulnerabilities, often heightening heat risks beyond levels captured in average temperature data.

Existing heat risks in cities are amplified by warming temperatures from climate change. Global surface temperatures have risen 1.1°C above pre-industrial levels and are continuing to rise (Dodman et al. 2022). As global average temperatures rise, so do the frequency, severity, and intensity of heat waves (Dodman et al. 2022). These global effects of climate change are amplified at a local level through the UHI effect. Between 1950-2017, 60 percent of the world's urban population experienced warming twice as large as the global average, and by 2100, 25 percent of the world's largest cities could warm by 7°C (Estrada, Botzen, and Tol 2017). Critically, the number of people impacted by this warming is set to rise with two out of three people living in an urbanized area by 2050 (United Nations Department of Economic and Social Affairs 2019).

The Tanzania Red Cross (TRCS) with support from the American Red Cross (AmCross) (For Tanzania replace it with 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 in Southeast Asia, Latin America and East Africa regions in nine secondary cities between September 2022- August 2027.

To ensure the achievement of the project conducted City Wide Risk assessment September-October month with close support from IFRC, Local government, Universities and different stakeholders for both two 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 was covering various aspects of its social, economic, environmental, and infrastructure components in play crucial role in guiding urban development and governance through providing of 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. Through this the report is still under development.

To compliments the achievement of this CWRA report, TRCS collaborated with the academia to carryout a GIS-based mapping of the Tanga City with the aims to make the National Society, local government, stakeholders and the targeted urban communities be more knowledgeable and empowered to be able to adapt to and reduce climate-induced coastal risks. Therefore, this report presents GIS based analysis and mapping outcomes for Tanga City's environment, climate change and variability. Different climate change data and information have been mapped to support informed decision making. These includes land cover changes, elevation, soil characteristics, geological features, population density, land surface temperature, heat risk index (HRI)

1.2 Goals and Objectives of the GIS based Assignment

1.2.1 General objective

The objective of this assignment is to develop municipality-level GIS-based, base map showing the details of existing land use pattern, including other associated features and attributes described in the specific objectives. The maps may be considered to assist in strategic planning, resource utilization management, planning and management of day-to-day operations and for the preparation of municipality-level disaster and climate risk management planning.

1.2.2 Specific Objectives

i. Collect and review recent high-resolution maps, satellite images, etc. covering the target areas.

i. Develop GIS based map of Tanga city (all wards), including structural assets and critical infrastructure, facilities and services (such as ward boundaries, buildings/built-up area, roads, waterbodies, important landmarks, physical features, open spaces, road network, flyovers, footpath, road dividers, public toilets, garbage collection points, landfills, drainage network, dustbins, hospitals, fire service, police stations, educational institutions, and so on)

ii. Identify critical facilities such as healthcare and hospital

iii. Identify probable evacuation/ shelter locations in the event of various emergencies / disaster situations.

iv. Update/ delineate the municipality and ward boundary areas.

v. Carry out field verification and collect missing data and attribute data by field survey, and handheld GPS and questionnaire surveys.

vi. Assign values of agreed set of attributes (such as footpath width, building heights/ floor numbers, garbage collection point type and so on) to the assets database.

vii. Finalize Base Map.

viii. Ensure all data and maps are compatible with OpenStreetMapping, Humanitarian Data Exchange (HDX), and other humanitarian data sharing platforms..

1.3 Description of the project area

Tanga City, with a population of 393,429 as per the 2022 census, is nestled along the western coast of the Indian Ocean on Tanga Bay. The city's lies between latitude 5°19' - 5°19' S and longitude 38°53'- 39°12'E longitude, with an elevation of 143 meters above mean sea level. In terms of climate, Tanga City experiences an annual mean maximum temperature of 30.7°C and an annual mean minimum temperature of 22°C. The city also receives an annual rainfall of 1290 mm per year. This combination of population, elevation, geographic location, and climate makes Tanga City a unique and dynamic coastal city along the shores of the Indian Ocean. Figure 1.1 show the location area of the city and project area in terms of wards.

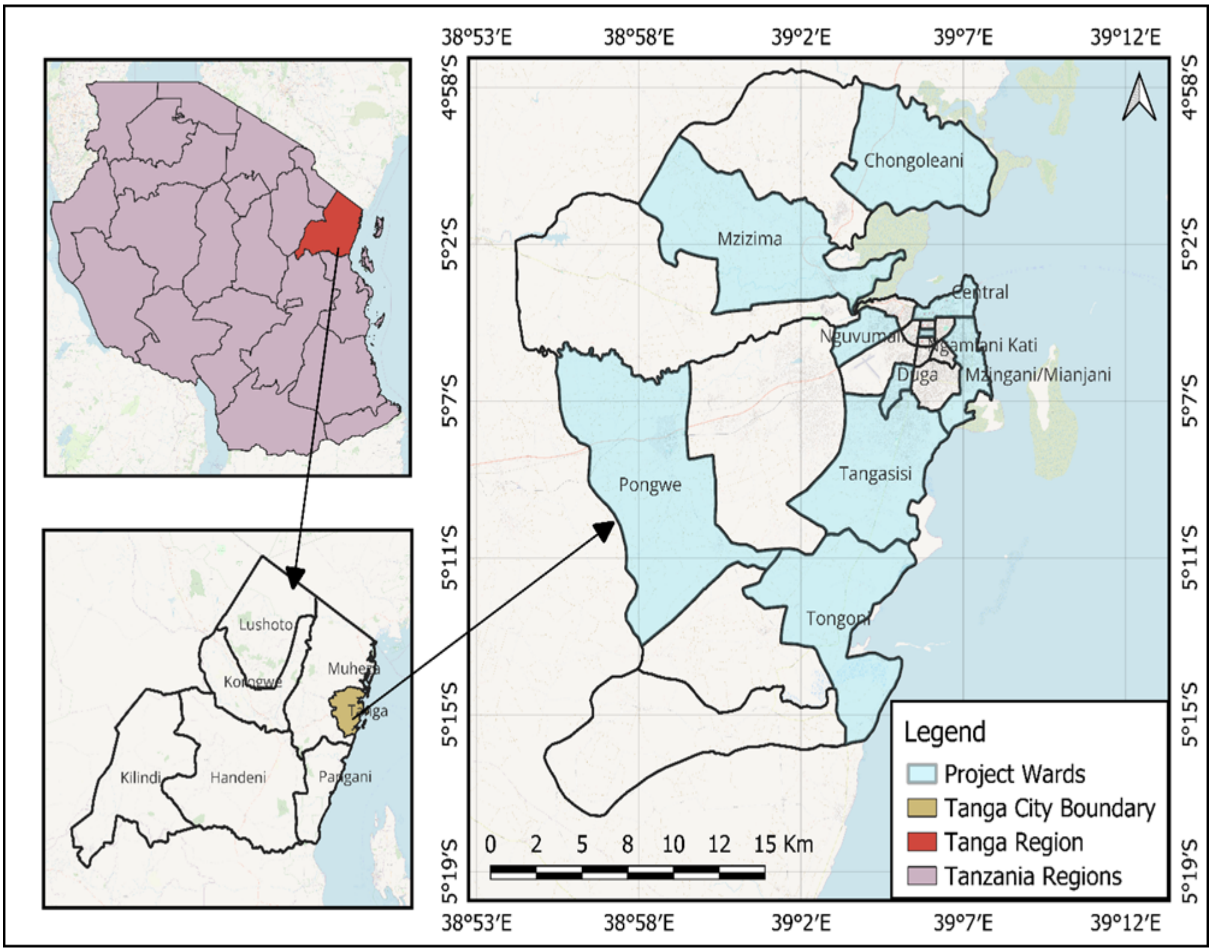

Figure 1. 1: Location of the Study Area

1.3.1 Description of the Project Area Specific Wards

a) Chongoleani Ward

Chongoleani, stands as an administrative ward within the Tanga City Council, situated in the Tanga Region of Tanzania. This ward is geographically bordered by Mtimbwani and Kwale wards of Mkinga to the north, the Pemba Channel's Tanga Bay to the east, and the Tanga Bay itself to the south. On its western side, it shares boundaries with Mabokweni ward. Spanning an area of 37 square kilometers (14 square miles) and boasting an average elevation of 10 meters (33 feet), Chongoleani is characterized by its coastal location and proximity to water bodies. As of the 2012 census, the ward sustains a population of 4,737 residents. Figure 1.2 present the extent of chongoleani ward.

Figure 1. 2: Location of Chongoleani Ward

b) Central Ward

Centralis a vital administrative ward nestled within the Tanga City Council, located in the Tanga Region of Tanzania. Bordered by significant landmarks, the northern edge of Central is defined by Tanga Bay, while the eastern boundary is marked by the Pemba Channel. To the south, it shares borders with Mzingani, Usagara, Ngamiani Kaskazini, and Majengo ward, creating a nexus of interconnection within the city. On the western side, Central is adjacent to the Chumbageni ward. Encompassing an area of 3.8 square kilometers (1.5 square miles) and boasting an average elevation of 10 meters (33 feet), this ward is characterized by its compact yet strategically positioned geography.

At the heart of Central is the Tanga City Council, the ward seat, which plays a pivotal role in local governance. Notably, Central is home to the Port of Tanga, adding economic significance to its administrative stature. The 2012 census data reports a total population of 5,739 residents, providing crucial demographic information for urban planning and developmental initiatives in the broader context of the Tanga City Council and the Tanga Region in Tanzania. Figure 1.3 depicts the coverage of central ward.

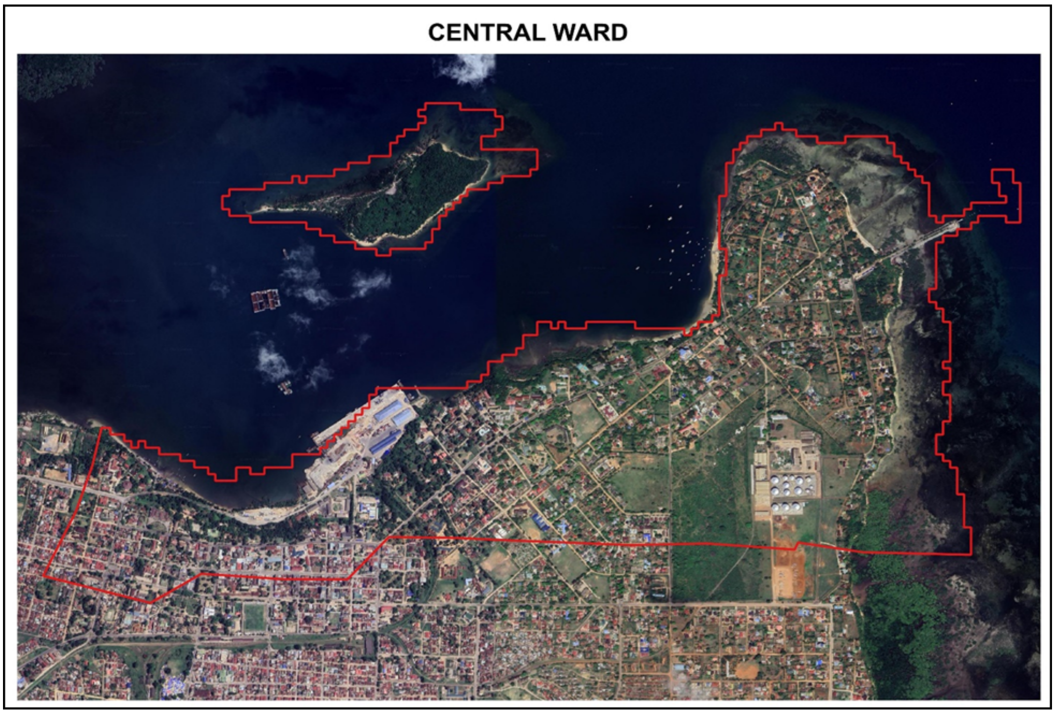

Figure 1. 3; Location of Central Ward

c) Duga Ward

Duga, stands as a significant administrative ward within the Tanga City Council, situated in the Tanga Region of Tanzania. Surrounded by distinctive neighboring wards, Mwanzange envelops Duga from both the north and west, while Mabawa lies to its east, and Tangasisi ward lies to the south. The ward encompasses an area of 2.4 square kilometers (0.93 square miles) and maintains an average elevation of 25 meters (82 feet), contributing to its varied and dynamic landscape.

A notable cultural landmark within Duga is the residence of the late Shaaban Robert, Tanzania's national poet. This dwelling stands as the ward's largest attraction, offering a cultural touchstone for residents and visitors alike. The 2012 census records a robust population of 18,704 residents within the ward, underscoring its significance within the broader administrative framework of the Tanga City Council and the Tanga Region. Duga's blend of geographical features, cultural heritage, and substantial population make it a distinctive and noteworthy component of the region's administrative landscape. Figure 1.4 depicts the extent and coverage of Duga ward

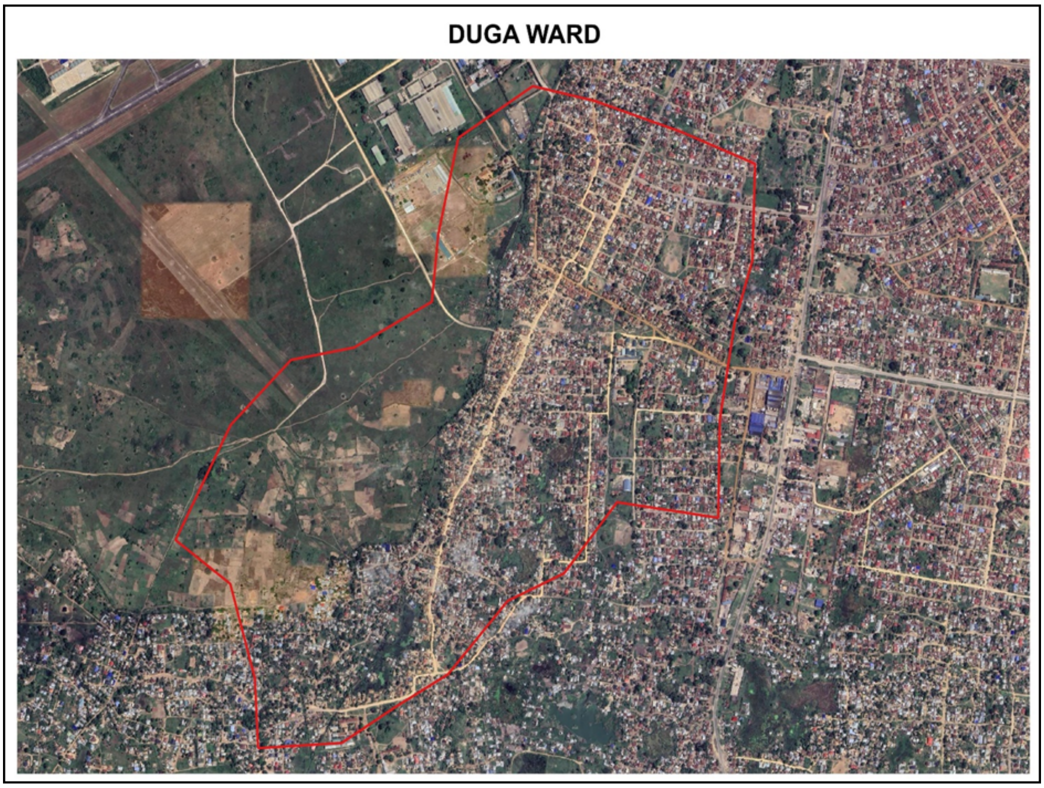

Figure 1. 4; Location of Duga Ward

d) Mzizima Ward

Mzizima, is a pivotal administrative ward within the Tanga City Council, situated in the Tanga Region of Tanzania. Bordered by Mabokweni ward to the north, Chumbageni and Tanga Bay to the east, Kiomoni to the south, and Gombero ward of Mkinga to the west, Mzizima occupies a significant position within the local administrative landscape. Encompassing a sprawling area of 56.2 square kilometers (21.7 square miles) and boasting an average elevation of 97 meters (318 feet), the ward features the picturesque Sigi River, which meanders through its terrain and flows into Tanga Bay. Additionally, Mzizima is home to the renowned Mzizima Hot Springs, also known as Galanos Hot Springs, contributing to its cultural and natural appeal. The 2012 census reports a population of 11,570 residents, highlighting Mzizima's importance within the broader context of the Tanga City Council and the Tanga Region. Figure 1.5 shows mzizima ward coverage.

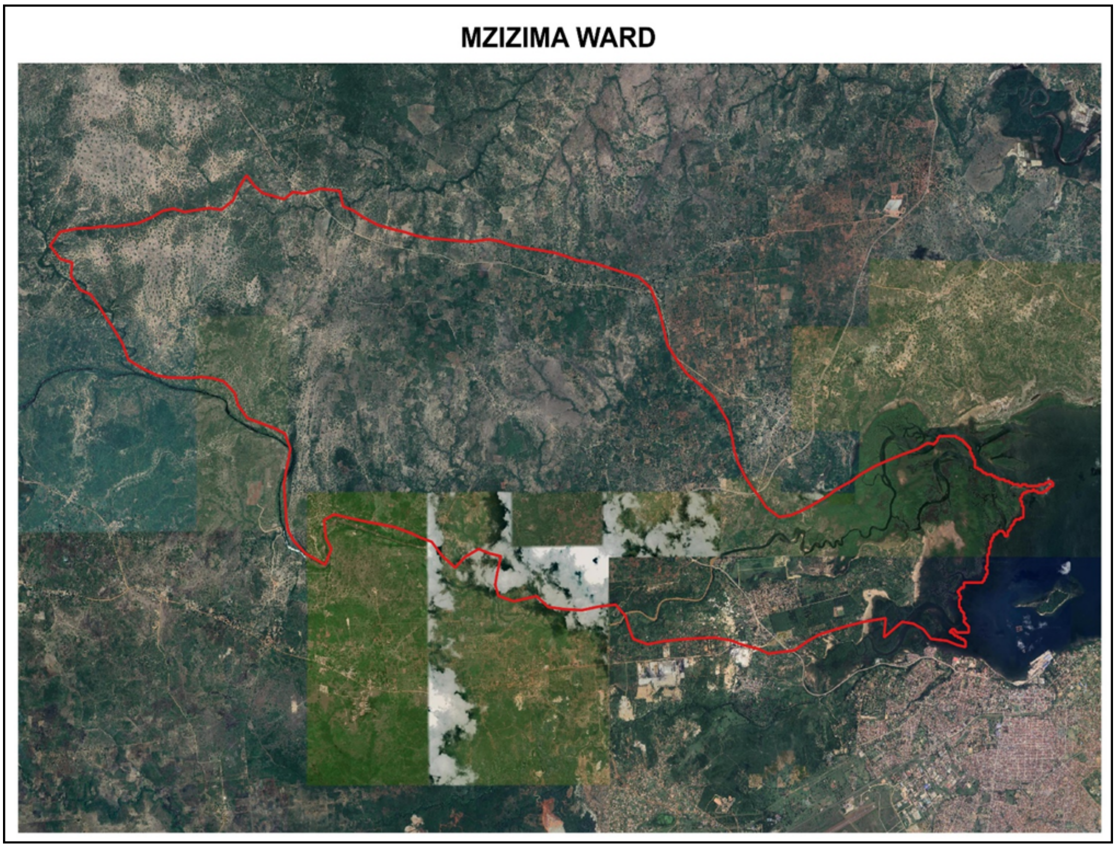

Figure 1.5: Location of Mzizima Ward

e) Pongwe Ward

Pongwe, known as "Kata ya Pongwe" in Swahili, is a significant administrative ward within the Tanga City Council, located in the Tanga Region of Tanzania. Surrounded by distinctive neighbouring wards, Kiomoni envelops Pongwe from the north, while Maweni delineates its eastern boundary, Marungu lies to the south, and the Muheza ward of Ngomeni borders it to the west. This expansive ward covers an area of 77.5 square kilometers (29.9 square miles) and boasts an average elevation of 74 meters (243 feet). Pongwe's diverse topography and strategic location within the Tanga City Council contribute to its administrative importance. The 2012 census records a population of 13,513 residents, underlining the ward's significance in the broader context of regional demographics and development initiatives. Figure 1.6 indicates the location of Pongwe Ward.

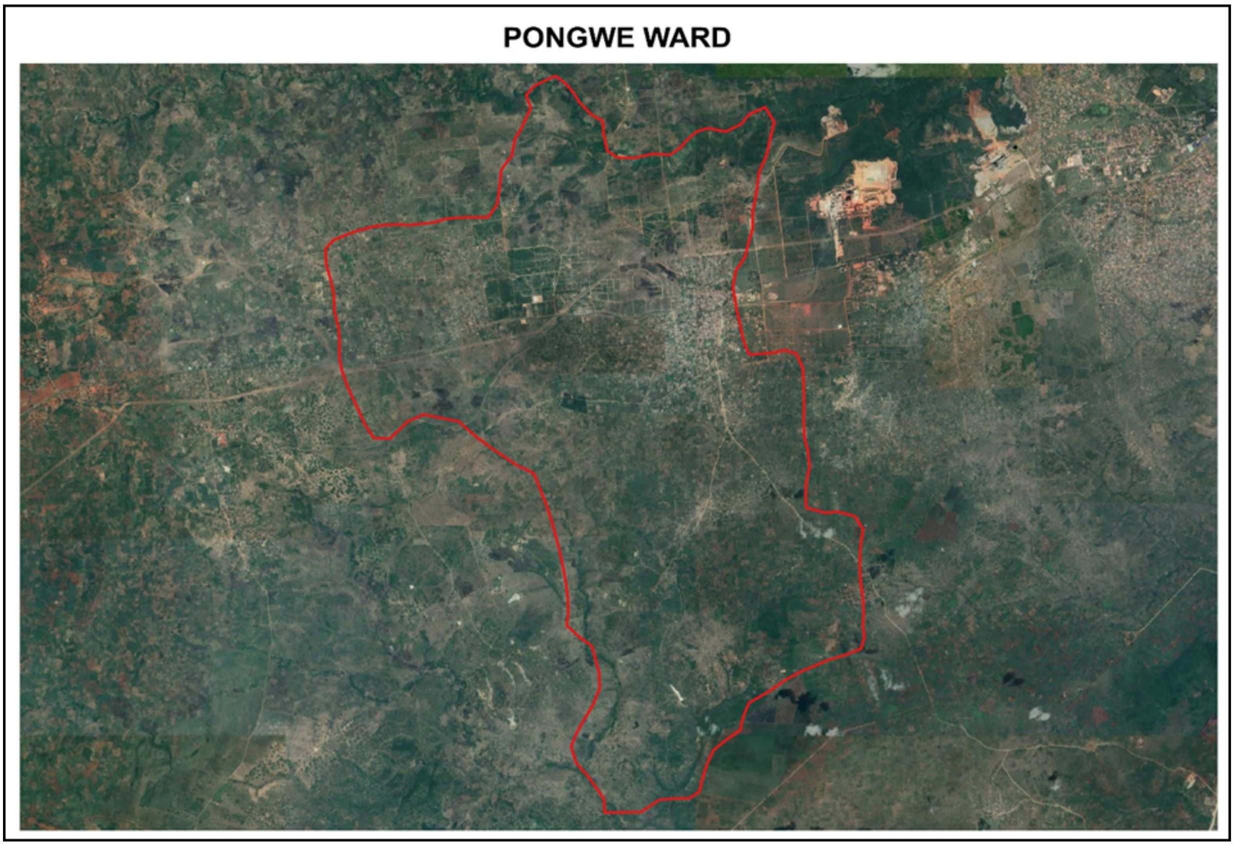

Figure 1.6: Location of Pongwe Ward

f) Tongoni Ward

Tongoni is an ward in Tanga City Council of Tanga Region in Tanzania. Tangasisi and Maweni wards form the ward's northern and western boundaries. The Pemba Channel forms the eastern boundary. The Kigombe Ward of Muheza is to the south. The wards of Kirare and Marungu are to the west. The ward covers an area of 44 km2 (17 sq mi), and has an average elevation of 30 m (98 ft). According to the 2012 census, the ward has a total population of 4,594. Tongoni ward is the home to the Tongoni ruins, a Medieval Swahili town. Figure 1.7 presents the location of Tongoni Ward.

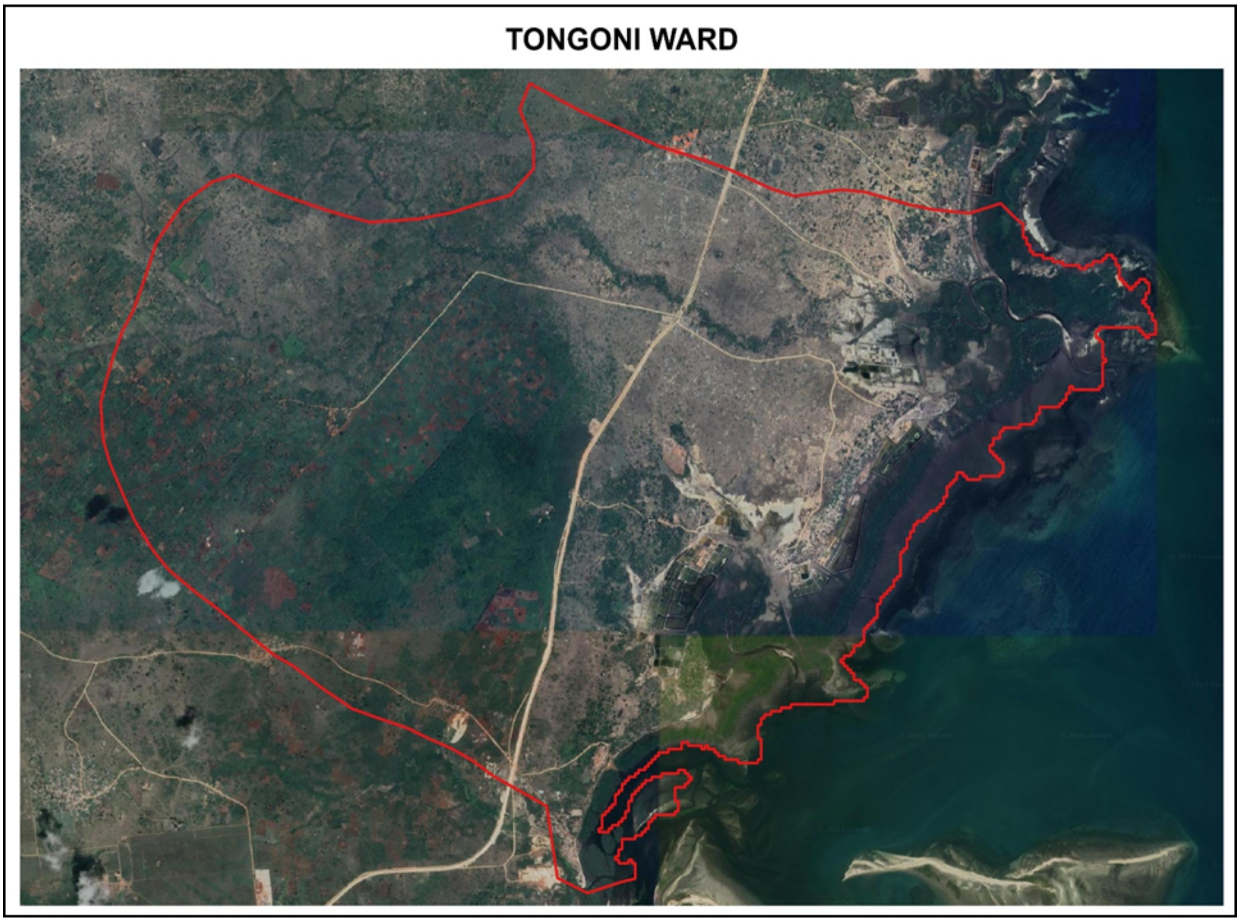

Figure 1.7: Location of Tongoni Ward

g) Tangasisi Ward

Tangasisi, holds a prominent position as an administrative ward within the Tanga City Council, situated in the Tanga Region of Tanzania. Its northern border is defined by Mwanzange, Duga, Mabawa, and Mzingani. To the east, the ward is bordered by the Pemba Channel, while Tongoni lies to the south, and Maweni marks its western boundary. Encompassing an expansive area of 38.9 square kilometers (15.0 square miles) and featuring an average elevation of 27 meters (89 feet), Tangasisi's diverse geography and strategic location contribute to its administrative significance. According to the 2012 census, the ward sustains a total population of 19,149 residents, highlighting its demographic importance within the Tanga City Council and the broader Tanga Region. Figure 1.8 depicts the location of Tangasisi Ward.

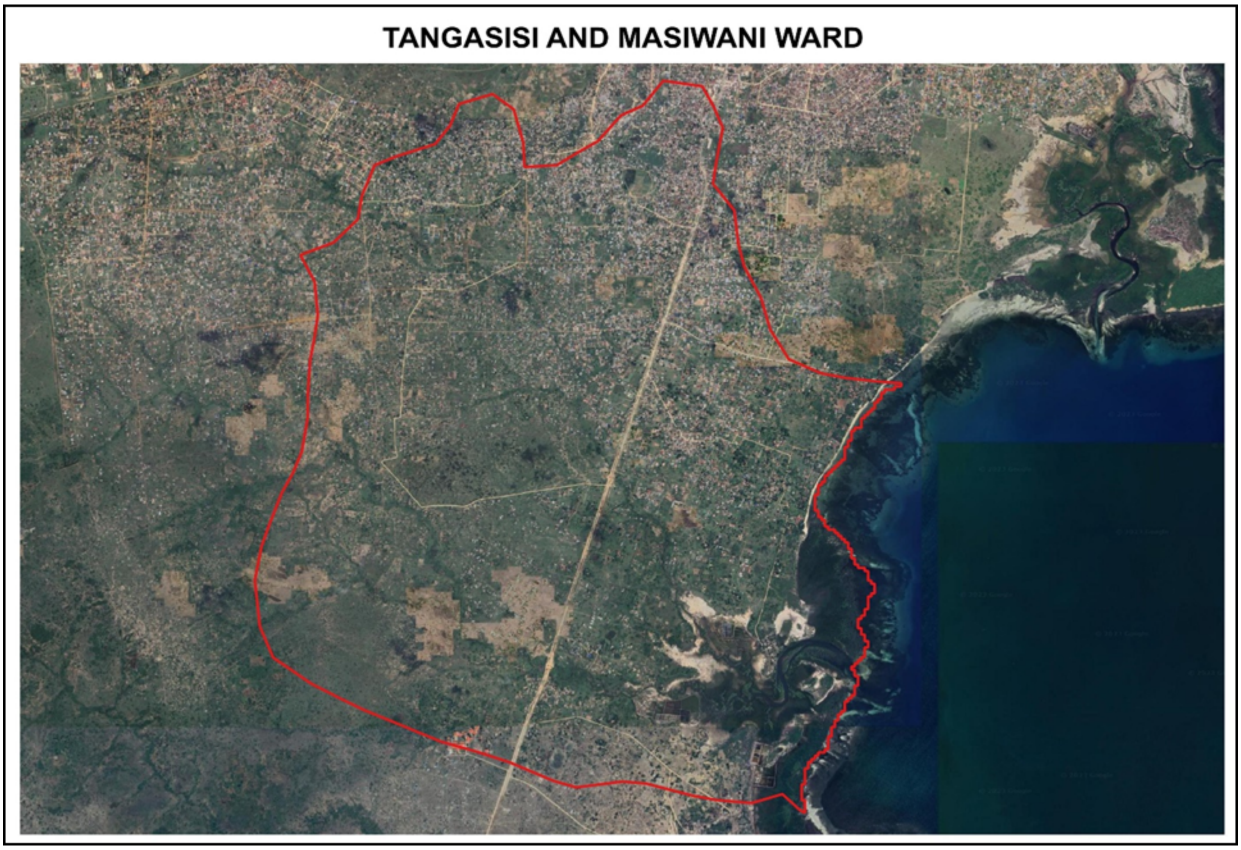

Figure 1.8: Location of Tangasisi Ward

h) Mzingani Ward

Mzingani, is a vital administrative ward within the Tanga City Council, situated in the Tanga Region of Tanzania. It is encompassed by the Central ward to the north, with the Pemba Channel lying to the east. The southern boundary is formed by Tangasisi, while Mabawa, Makorora, and Usagara wards flank it to the west. Spanning across 8.1 square kilometers (3.1 square miles) and maintaining an average elevation of 7 meters (23 feet), Mzingani's strategic location and varied surroundings contribute to its administrative importance. The 2012 census reports a total population of 29,041 residents, underscoring the ward's demographic significance within the broader framework of the Tanga City Council and the Tanga Region. Figure 1.9 describe the Location of Mzingani Ward.

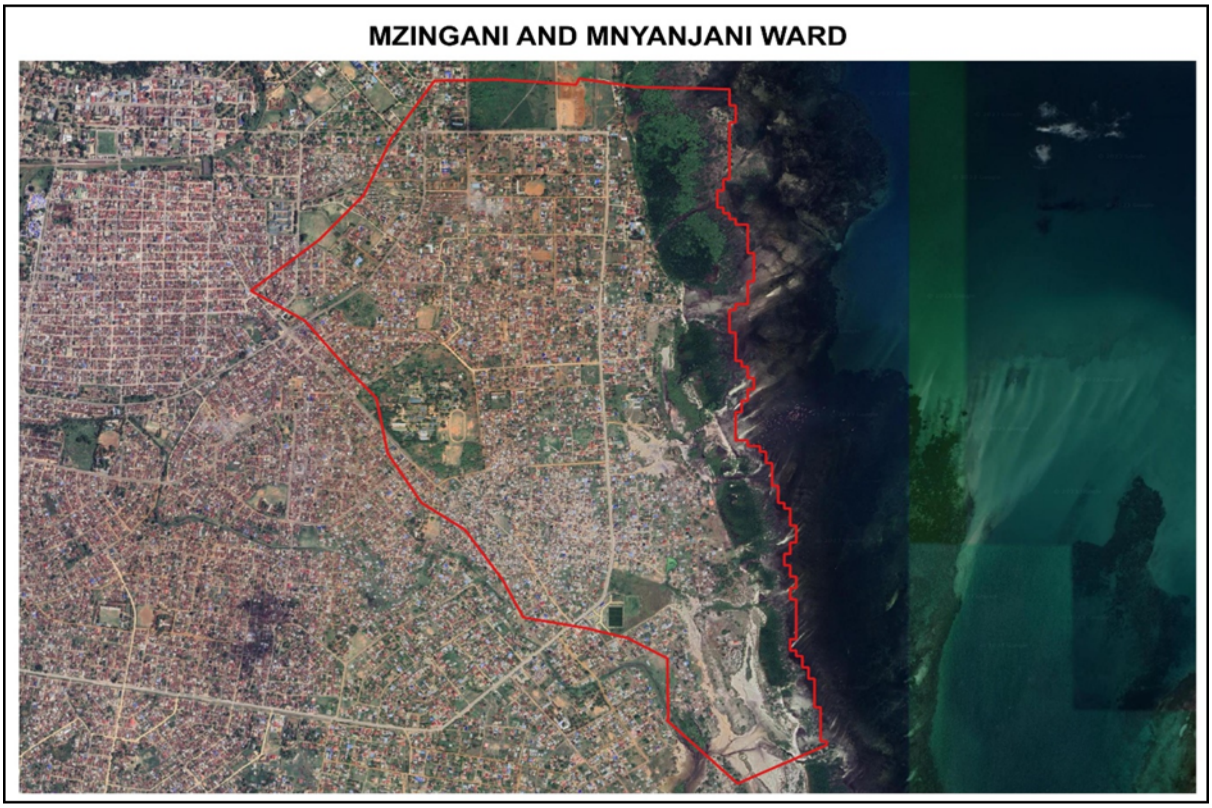

Figure 1.9: Location of Mzingani Ward

i) Nguvumali Ward

Nguvumali, holds significance as an administrative ward within the Tanga City Council, situated in the Tanga Region of Tanzania. The ward is demarcated by Chumbageni and Kiomoni, forming its northern and southern borders respectively, while Majengo marks its eastern boundary. To the south lies Mwanzange, and to the west is Maweni Ward. Covering a land area of 5.7 square kilometers (2.2 square miles) and featuring an average elevation of 26 meters (85 feet), Nguvumali's geographical characteristics contribute to its distinctiveness within the administrative landscape. As per the 2012 census, the ward sustains a population of 15,133 residents, emphasizing its demographic relevance within the broader context of the Tanga City Council and the Tanga Region. Figure 1.10 depicts the location of Nguvumali Ward

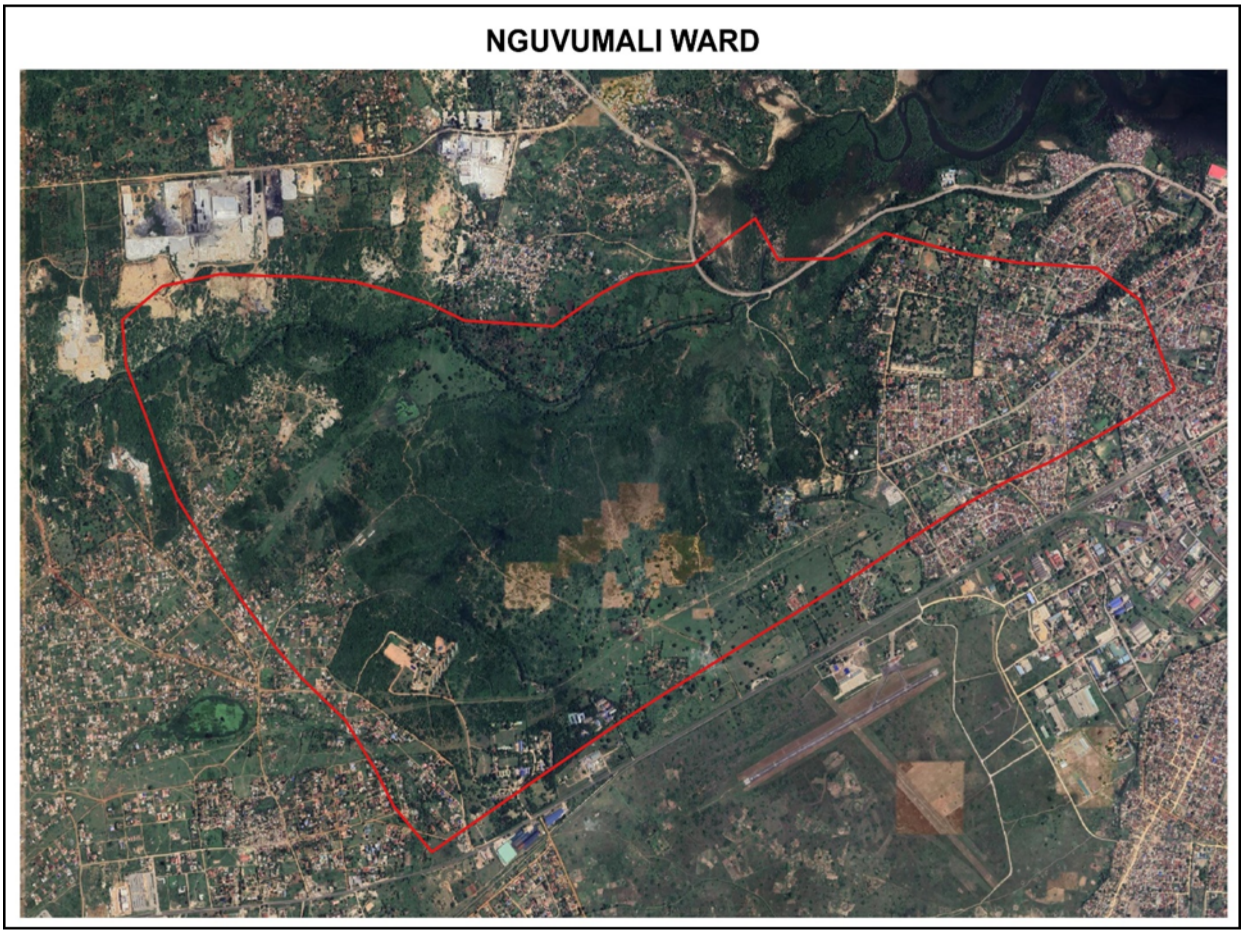

Figure 1.10: Location of Nguvumali Ward

j) Ngamiani Kati Ward

Ngamiani Kati stands as an administrative ward within the Tanga City Council, located in the Tanga Region of Tanzania. Its geographical boundaries are defined by Usagara and Ngamiani Kaskazini to the east and north, respectively. To the south lies Ngamiani Kusini, while Majengo Ward forms its western boundary. Spanning a compact area of 0.3 square kilometers (0.12 square miles) and featuring an average elevation of 15 meters (49 feet), Ngamiani Kati's modest size is complemented by its strategic location within the city. The 2012 census indicates a total population of 4,755 residents, underlining the ward's demographic relevance within the Tanga City Council and the broader Tanga Region. Figure 1.11 depicts the location of Ngamiani Kati Ward

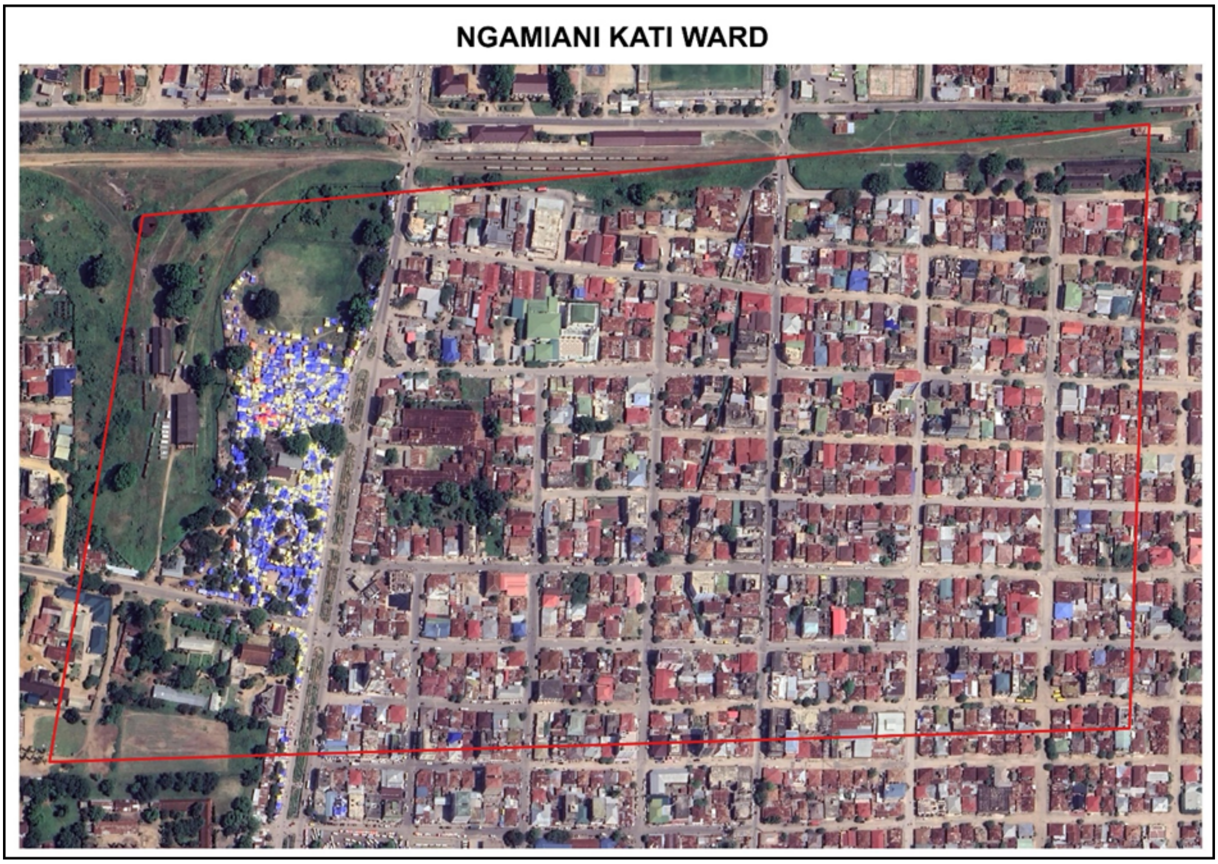

Figure 1.11: Location of Ngamiani Kati Ward

1.4 Significance of Tanga City Risk Assessment

The following are the significance of the Tanga GIS based City Wise Risk Assessment.

(i) Targeted Resilience Building: The risk assessment allows for a focused understanding of the specific vulnerabilities and challenges faced by Tanga City concerning extreme heat and coastal threats. It provides the foundation for tailoring resilience-building strategies and interventions that are context-specific and responsive to the unique risks of Tanga.

(ii) Informed Decision-Making: The risk assessment provides data and insights necessary for informed decision-making at the local level, involving collaboration with local governments, National Meteorological and Hydrological Services, and communities. Decision-makers can use the assessment findings to prioritize actions, allocate resources efficiently, and implement measures that address the identified risks effectively.

(iii) Integration with Local Policies: The risk assessment contributes to the integration of local policies by working collaboratively with the Government of Tanzania. It ensures that the findings align with and support existing policies and regulations, fostering a harmonized and effective approach to climate resilience.

(iv) Long-Term Climate Resilience: The risk assessment is a crucial step in the broader goal of building long-term climate resilience. It sets the stage for ongoing monitoring and adaptation strategies, ensuring that urban communities in Tanga remain resilient to climate-related challenges beyond the project's timeframe.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter discusses key parameters and climate change related variables that influences the variability of heat along the coastal environments. These includes vegetation indexes, land surface temperatures, land covers changes, rainfall and temperature trend analysis, urban heat index and so on.

2.1 Vegetation Cover Assessment

The Normalized Difference Vegetation Index (NDVI) stands as a foundational vegetation metric widely employed in geospatial contexts, particularly for land cover classification. Acknowledged as one of the oldest vegetation indices (VIs), NDVI is instrumental in assessing temporal and spatial variations in vegetation density, as well as the overall health and viability of plant cover [Rousel et al., 1974]. Leveraging surface reflectance in the red and near-infrared (NIR) regions of the electromagnetic spectrum, NDVI effectively discriminates between diverse land cover types. The index's values, ranging from -1 to 1, offer distinct indications for water and non-water features, with values between -1 to 0 signifying water presence. Bare soil is characterized by values between 0.0 and 0.2, while values between 0.2 and 0.3 represent shrub and grassland areas. Fully vegetated regions are denoted by values greater than 0.5, while the range for green vegetation spans from 0.2 to 0.9. Dense forests and agricultural crops exhibit values between 0.6 and 0.9 during their peak growth.

2.2 Land Surface Temperature

This section emphasizes the significance of Land Surface Temperature (LST) as a crucial indicator of the energy balance at the Earth's surface, playing a pivotal role in understanding land surface processes. LST is integral to the physics of these processes, offering insights into surface-atmosphere interactions and energy fluxes between the atmosphere and the ground. LST is essentially the measure of the radiation emitted by the land surface. This parameter becomes particularly valuable when seeking a comprehensive understanding of the Earth system on a global scale. The Earth Observing System (EOS) has been designed to provide accurate surface kinetic temperatures, with specified accuracies of 0.3K for oceans and 1K for land. This precision is crucial for capturing and interpreting temperature variations across different surface types. Normally, Lower values of LST are observed in colder months and higher values in hotter months in coastal environments.

2.3 Land Cover of Dynamics

The spatial dynamics of land cover refer to alterations in the distribution and composition of various cover types over time, encompassing both losses and gains. Analyzing land cover changes (LCC) serve as pivotal tools for assessing shifts in ecosystems and understanding the resulting environmental implications. This process is critical for evaluating the impact of human activities, climate variations, or natural processes on landscapes at different temporal and spatial scales. Understanding the spatial dynamics of land cover involves the quantitative analysis of alterations in the distribution of cover types over time, providing valuable insights into the evolving state of ecosystems and their environmental implications. Land cover changes has a significant impact on the formation of Urban Heat Island (UHI).

2.4 Climate Change and Variability

Climate change, as defined by (Paavola,2004), encompasses any alteration in climate conditions over time, whether arising from natural variability or human-induced factors. It involves a systematic transformation in key climate dimensions, including average temperature, wind patterns, and rainfall distributions, observed over an extended period. This comprehensive description underlines the significance of understanding climate change as a phenomenon that goes beyond short-term fluctuations, impacting fundamental climate characteristics.

In contrast, climate variability refers to the deviation of climatic parameters in a region from their long-term averages. This deviation can manifest in various aspects, such as alterations in mean states, statistical measures (e.g., standard deviations), and the occurrence of extremes. In summary, climate change denotes a sustained and systematic alteration in key climate dimensions over an extended duration, encompassing both natural and anthropogenic influences. On the other hand, climate variability refers to short-term fluctuations and deviations of climatic parameters from their long-term averages, influencing weather conditions within specific timeframes. These concepts together contribute to our understanding of the dynamic nature of Earth's climate system

2.5 Trend in Rainfall and Temperature

Trend analysis plays a crucial role in understanding the spatial and temporal patterns of rainfall and temperature extremes, serving as essential inputs for effective coping and adaptation strategies to climate change impacts (Chang'a, 2017).

In a study conducted by (Gebrechorkos,2019) on long-term trend analysis in seasonal rainfall in Ethiopia, Kenya, and Tanzania, non-significant changes were observed in large parts of the region. The study highlighted a non-significant decreasing trend in rainfall during the MAM season in eastern Ethiopia, Kenya, and significant increasing trends in seasonal maximum temperatures across the region. Similarly, the study revealed a significant rise in minimum temperatures, particularly in Kenya and Tanzania, emphasizing the changing climate patterns.

Another investigation by (Chang'a,2017) focused on the analysis of rainfall and temperature extreme indices in Tanzania from 1961-2015. The study demonstrated statistically significant increasing trends in both maximum and minimum temperatures at monthly and annual scales. In contrast, rainfall exhibited a non-statistically significant decreasing trend, as depicted by the percentage change in mean rainfall anomaly and the standardized precipitation index.

2.6 Evapotranspiration Analysis

Evapotranspiration is a crucial variable for estimating the energy budget in the Earth's atmospheric system and the water balance in a given region (Huang et al., 2015). Potential evapotranspiration (PET) specifically refers to evaporation and transpiration over a surface under certain meteorological conditions, considering sufficient water and an unlimited soil water supply. Studies have examined the spatiotemporal characteristics (Zongxing et al., 2014), impact of climate change (Han et al., 2015), and variations in potential evapotranspiration in relation to influencing factors (Zhao et al., 2018)

2.7 Urban Heat Islands

Urbanization entails the substitution of natural landscapes with constructed elements like structures, roads, and parking areas. This alteration of land cover also transforms the characteristics of the land surface. These modifications can affect the extent of radiation absorption and reflection by the surface, as well as the dissipation of heat from the surface (for instance, the elimination of vegetation for urban development diminishes evaporative cooling). These alterations in surface properties have the potential to influence local weather and climate (Kalnay and Cai 2003). The extensively researched local climate alteration resulting from urbanization is the urban heat island (UHI) effect (Arnfield 2003; Qian et al. 2022). The UHI is the occurrence where a city exhibits higher temperatures than either its surroundings or a comparable surface that is not urbanized. Our understanding of the UHI effect dates back almost 200 years (Howard 1833).

Traditionally, the UHI was characterized as the disparity in air temperature, recorded by weather stations, between a city and a rural reference area outside the city (Oke 1982). One challenge with this approach is that different parts of the city may experience varying air temperatures, complicating the capture of the UHI for the entire city. The utilization of satellite observations in the thermal bands enables an alternative temperature measure: the radiometric skin temperature, commonly referred to as the land surface temperature (LST). LST can be employed to compute a surface UHI (SUHI) intensity, detailing its variations within cities at the pixel scale (Ngie et al. 2014). It is crucial to emphasize that UHI values observed through satellites and those calculated using air temperature measurements can exhibit notable differences (Chakraborty et al. 2017, Hu et al. 2019, Venter et al. 2021).

2.8 GIS Applications in Urban Risk Assessment

Geographic Information System (GIS) applications play a pivotal role in urban risk assessment by providing a powerful platform to collect, analyze, and visualize spatial data related to potential risks and vulnerabilities in urban areas. The following are some key GIS applications in urban risk assessment:

i. **Spatial Data Collection:** GIS allows the integration of various spatial datasets, including land use, infrastructure, population density, and environmental factors. This comprehensive spatial data collection helps in understanding the complex urban landscape and identifying potential risk factors.
ii. **Hazard Mapping:** GIS is instrumental in mapping and analyzing natural and man-made hazards that pose risks to urban areas. This includes mapping of flood-prone areas, drought

zones, and areas susceptible to other hazards. By overlaying these hazard maps with urban infrastructure data, planners can identify high-risk zones.

iii. **Vulnerability Assessment:** GIS enables the assessment of vulnerability factors within urban areas, such as the condition of buildings, socio-economic status, and accessibility to emergency services. Combining vulnerability data with hazard maps helps in identifying areas with heightened risk levels.

iv. **Climate Change Impact Analysis:** GIS facilitates the analysis of climate change impacts on urban areas by integrating climate data and projecting future scenarios. This includes assessing thee changes in temperature patterns, and the increased frequency of extreme weather events.

v. **Evacuation Planning:** GIS plays a crucial role in evacuation planning by modeling potential evacuation routes, identifying safe zones, and estimating evacuation times. This information is vital for emergency management and response efforts during natural disasters or other emergencies.

vi. **Urban Heat Island (UHI) Analysis:** GIS is used to analyze and visualize Urban Heat Islands, areas within cities where temperatures are significantly higher than their surrounding rural areas. This information is critical for understanding heat-related risks and implementing strategies to mitigate the impacts on public health.

CHAPTER THREE

METHODOLOGY

3. Overview

This chapter focuses on the description of the overall data collection and GIS based Mapping process, ranging from data acquisition to output generation.

3.1 Data Collection

The GIS based Risk Assessment assignment involves the acquisition of various geospatial data to comprehensively understand and analyze the factors influencing coastal city heat resilience. Table 3.1 present a list of collected data to facilitate the analysis and mapping.

Table 3. 1: Summary of Data Collection and Acquisition

S/N	DATASET	SOURCE	TEMPORAL RESOLUTION
1	Rainfall data	CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data)	1982 - 2022
2	Maximum Temperature and Minimum Temperature	TerraClimate/ NASA POWER (Prediction of Worldwide Energy Resource) Access	1982 - 2022
3	Actual Evapotranspiration (AET), Wind Speed, Potential Evapotranspiration (PET)	TerraClimate	1982 - 2022
4	Land Surface Temperature	MODIS	2002,2012,2022
5	Land Cover	ESRI	2015,2021,2022
6	Digital Elevation Model (DEM)	SRTM (Shuttle Radar Topography Mission)	2002
7	Relative Humidity	NASA POWER (Prediction of Worldwide Energy Resource) Access	1982 - 2022
8	Soil Data	ISRIC (International Soil Reference and Information Centre)	Available
9	Geology Data	Geological Survey of Tanzania (GST)	Available

3.2 Field data collection

In addition to satellite-derived geospatial data, on-the-ground field data collection has been integral to the Tanga City Risk Assessment project, enhancing its comprehensiveness. Collected datasets include information on offices, hospitals, schools, health centers, bus routes, bus stations, main roads, and railway data. This data was gathered through a combination of on-site surveys, collaborations with local authorities and institutions. Figure 3.1 depicts some of the photos captured during the data collection process.

Figure 3.1 Depicts the field data collection

The data collection process started with the acquisition of wards offices locations. Each ward office within the study area is visited, and the handheld GPS device is employed to record accurate geographic coordinates (latitude and longitude). Additional relevant details, such as office name and other descriptive information, are documented. Subsequently, the same methodology is applied to hospitals and health centers. The GPS device captures the exact location of each facility, and accompanying information, including services offered, is recorded.

After collection of ward offices, all bus stops locations were aquired. Each location served as a bus stop within the study area was systematically visited. Details such as stop name, routes served, and other pertinent information were documented. Throughout the data collection phase, validation checks are implemented to ensure accuracy and reliability.

During the post-data collection step, the gathered data was integrated with mapping software to enable visualization and analysis of the spatial distribution of these features. This integration facilitates the identification of patterns or trends within the study area. The results were analyzed and presented through maps, or graphs to offer a comprehensive representation of the distribution and characteristics of wards offices, hospitals, health centers, and bus stops.

3.3 Data Processing and Analysis

In this study, a comprehensive methodology was implemented to handle a diverse set of raster datasets crucial for the research objectives. The acquisition of data was primarily executed through Google Earth Engine (GEE), leveraging its capabilities for efficient access to and management of large-scale remote sensing datasets. The selected datasets, including MODIS Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), Rainfall, Actual Evapotranspiration (AET), Potential Evapotranspiration (PET), Wind Speed, Shuttle Radar Topography Mission (SRTM) data, and European Space Agency (ESA) classified Land Cover, were sourced from authoritative platforms within GEE, ensuring reliability and spatial relevance.

The processing phase within GEE involved several key steps, encompassing image compositing, atmospheric correction, and mosaicking. GEE's cloud-based infrastructure and parallel processing capabilities facilitated the efficient handling of large datasets while maintaining data integrity. Following the GEE processing, the datasets were further analyzed using Geographic Information System (GIS) software.

The GIS software played a pivotal role in conducting spatial analyses, overlaying various raster datasets to extract meaningful insights and in mapping of the processed outputs so as to visualize the spatial data. Temperature trends, vegetation health through NDVI, evapotranspiration patterns, and the influence of topography on climate variables were explored. Additionally, land cover classifications were scrutinized to discern land cover patterns and temporal changes.

Spatial patterns and relationships identified through analysis were translated into maps using GIS software and graphs using statistical software such as R, serving as powerful tools for interpretation and presentation of research findings.

CHAPTER FOUR

RESULTS

4.1 Climate Change Analysis

4.1.1 Heat Patterns in terms of Maximum and Minimum Temperature

In the analysis of maximum and minimum temperature variations among different wards, distinctive patterns emerged. Wards such as Tangasisi, Tongoni, Duga, Mzingani, Ngamiani Kati, Central, and Nguvumali Kati consistently exhibited high maximum temperatures ranging from 31.24 °C -31.52 °C, indicating warmer conditions during the day. Conversely, Pongwe and Mzizima consistently showed lower maximum temperatures ranging from 30.81°C – 31.09°C, suggesting relatively cooler daytime climates. This variance in maximum temperatures has potential implications for urban heat stress, evaporation rates, and increased energy demand for cooling in warmer wards.

Simultaneously, the analysis of minimum temperatures showcased a similar trend. The aforementioned wards, including Tangasisi, Tongoni, Duga, Mzingani, Ngamiani Kati, Central, and Nguvumali Kati, consistently reported high minimum temperatures ranging from 22.34 °C – 22.86 °C, signifying milder night-time conditions. On the other hand, Pongwe and Mzizima consistently recorded lower minimum temperatures ranging from 21.56 °C – 22.08 °C, indicative of cooler night-time climates. Connecting these temperature patterns with humidity, it was inferred that wards experiencing higher temperatures, both maximum and minimum, might generally exhibit lower humidity levels. The recorded temperature trends reveal a noteworthy increase in both maximum and minimum temperatures over the specified years. In 2008, the maximum temperature peaked at 33.5°C, showing a warming trend compared to the lower value of 30.4°C observed in 1982. Similarly, minimum temperatures exhibited an upward trend, with higher values of 24°C recorded in 2016 and 2019, in contrast to the lower values of 22°C noted in 1985 and 2020. These temperature variations underscore the overall warming trend in both maximum and minimum temperatures over the specified time period. The propensity for higher temperatures to contribute to increased evaporation and reduced condensation aligns with expectations of drier conditions in these wards. In contrast, wards with lower temperatures, like Pongwe and Mzizima, may experience relatively higher humidity levels, as cooler temperatures tend to support greater moisture retention. Figure 4.1 and 4.3 depicts the maximum and minimum temperature distribution maps. Figure 4.2 and 4.4 illustrated the Maximum and Minimum temperature linear trend in the project area spanning from 1982 – 2022.

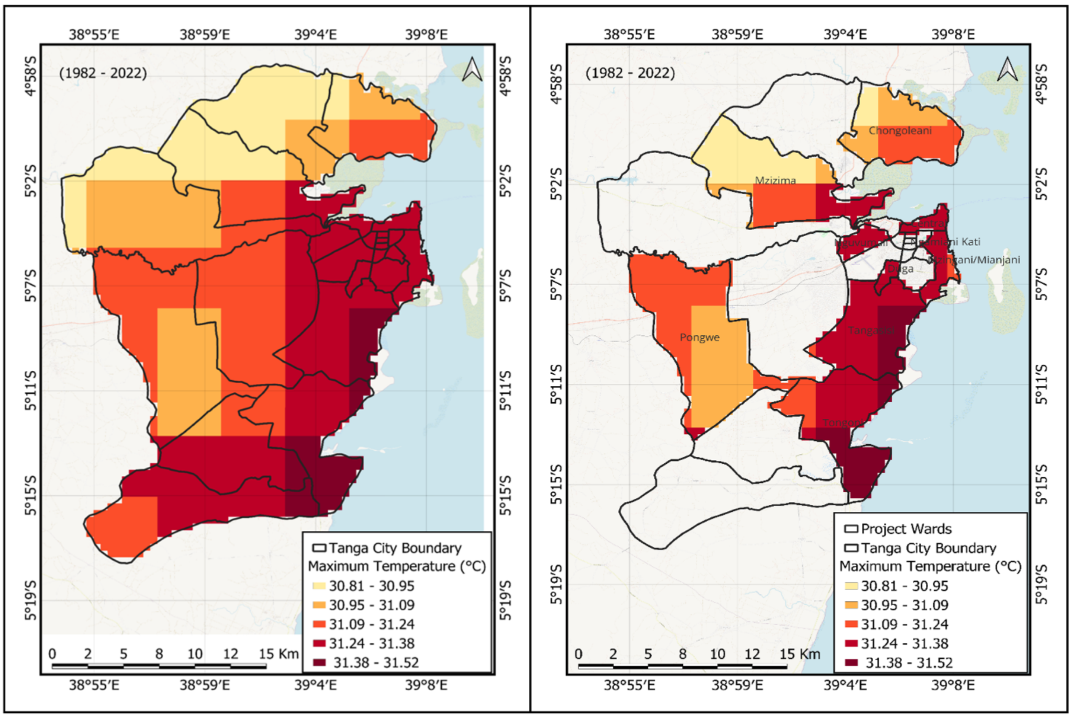

Figure 4.1: Long term mean Maximum Temperature distribution 1982 – 2022

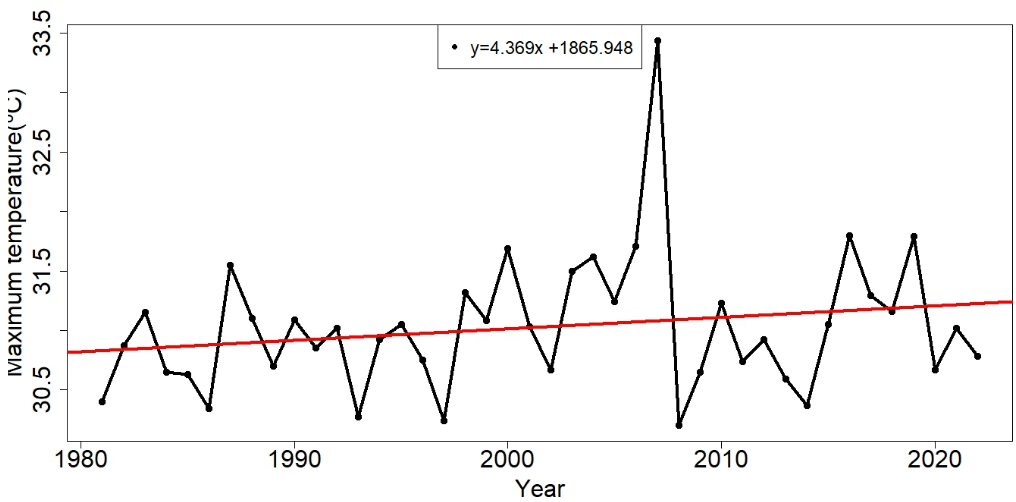

Figure 4.2: Maximum Temperature linear trends in the project area

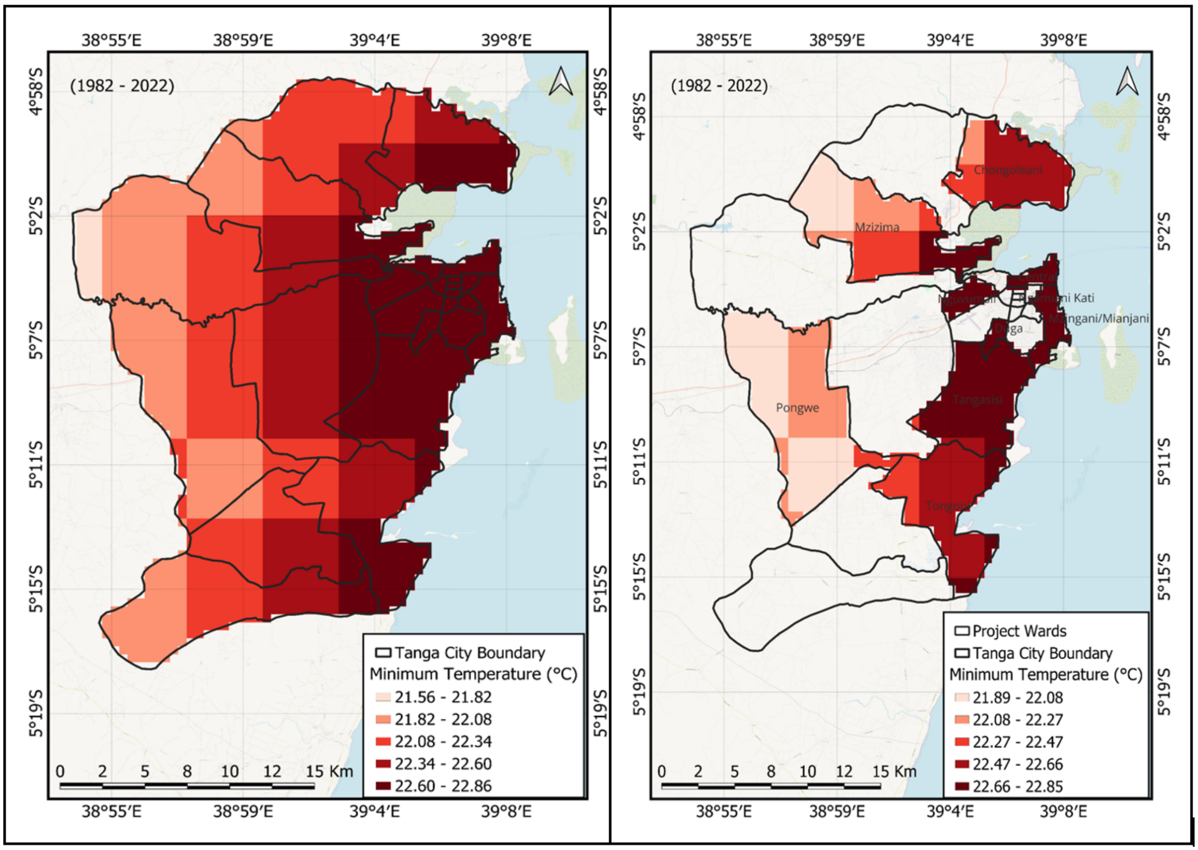

Figure 4.3: Long term mean Minimum Temperature distribution 1982 – 2022

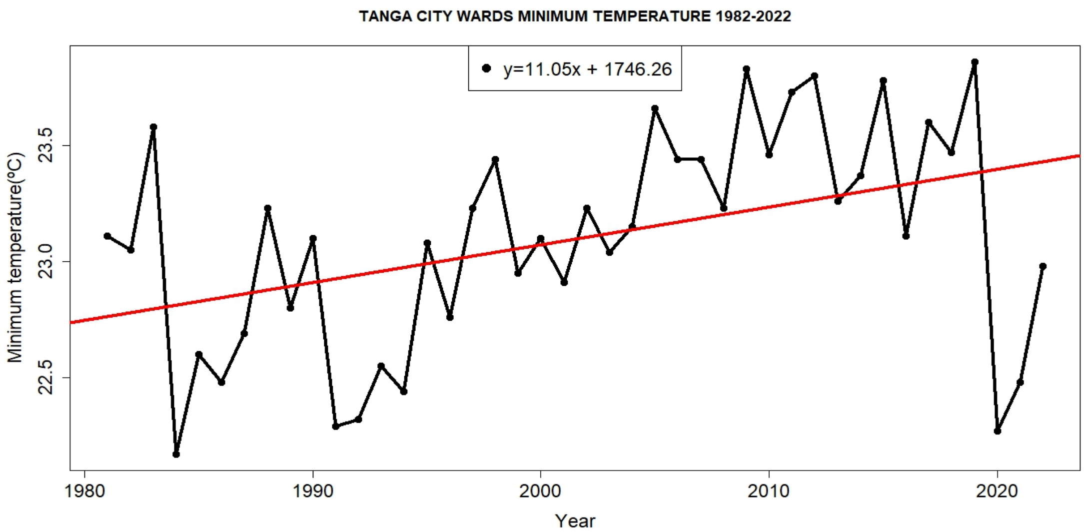

Figure 4.4: Minimum Temperature linear trend from 1982 - 2022 at Project Wards

4.1.2 Rainfall Distribution

Rainfall, a critical climate variable, significantly influences water availability, agriculture, and ecosystem health. In the study area, an annual rainfall ranging from 1225mm – 1329mm indicates relatively dry conditions, posing challenges for agriculture, water availability, and ecosystem health. The potential concerns include water scarcity, drought stress, and adverse impacts on local ecosystems. Conversely, a high annual rainfall ranging from 1382mm - 1486 mm suggests wetter conditions, which, while generally beneficial for agriculture and water resources, may lead to flooding, soil erosion, and water runoff challenges. The trend analysis of annual rainfall indicates significant variations, with the year 2019 experiencing a notably high amount of nearly 1400mm, while the region in 2004 recorded a much lower amount of approximately 200mm. This variation in annual rainfall highlights distinct patterns in precipitation over the specified years.

The analysis of rainfall patterns across different wards revealed notable variations. Pongwe, Ngamiani Kati, and Central experience higher rainfall amounts, while Nguvumali, Chongoleani, and Mzizima receive lower rainfall. This variation has implications for local humidity levels, with areas experiencing higher rainfall, like Pongwe, Ngamiani Kati, and Central, likely exhibiting elevated humidity due to increased atmospheric moisture content. On the contrary, wards with lower rainfall amounts, such as Nguvumali, Chongoleani, and Mzizima, may tend to have lower humidity levels, contributing to drier conditions. Figure 4.5-4.6 illustrates the Long Term Mean (LTM) annual Rainfall linear trend and and rainfall distribution map.

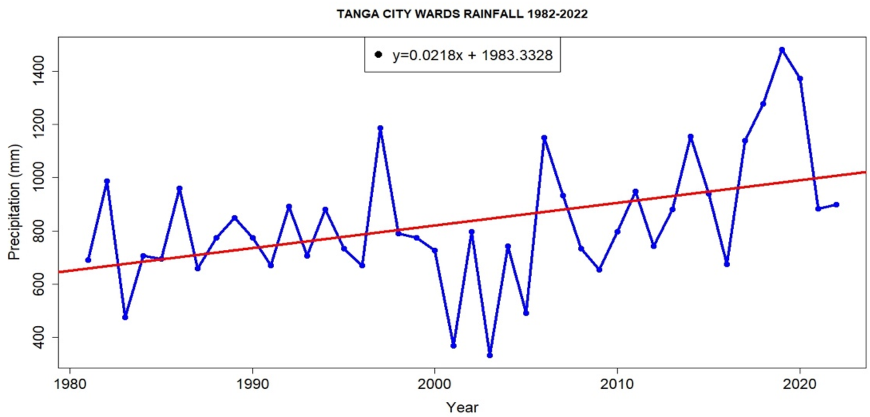

Figure 4.5: Rainfall linear trend from 1982 - 2022

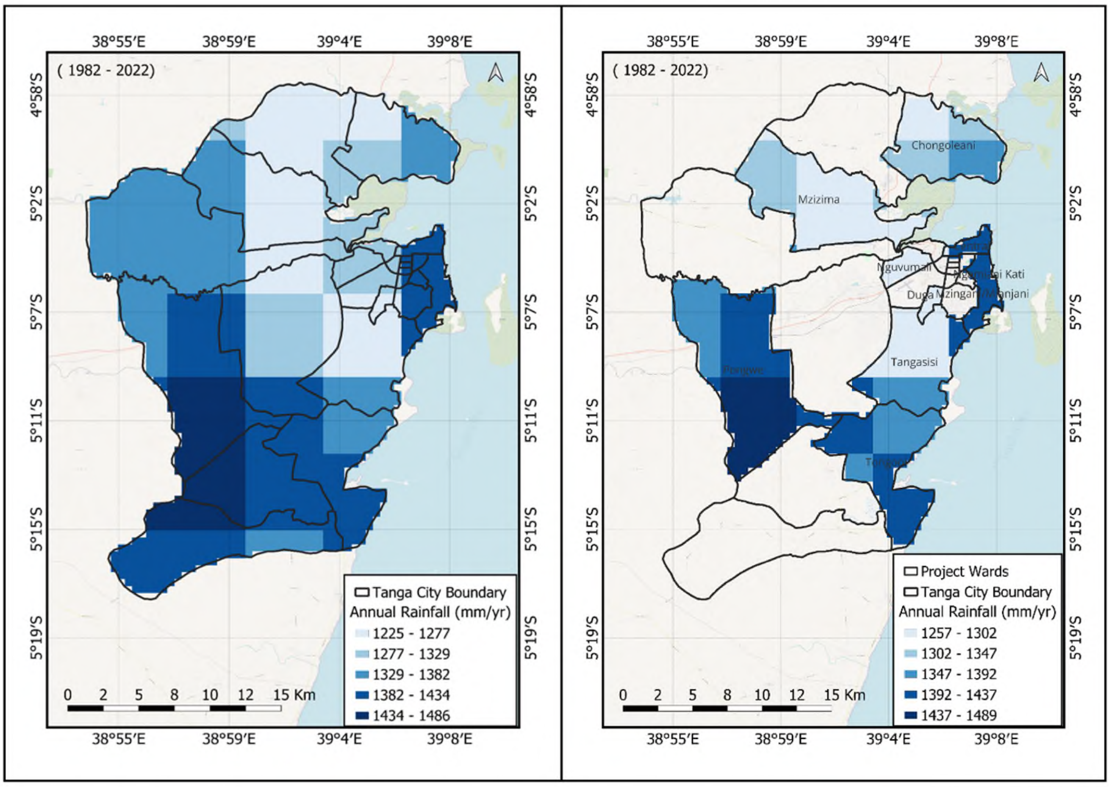

Figure 4.5: Long term mean annual rainfall distribution from 1982 - 2022

4.1.3 Actual Evapotranspiration (AET) Analysis

Actual Evapotranspiration (AET), a critical measure representing the actual water evaporated from the Earth's surface and transpired by plants, plays a crucial role in understanding the water balance of a region. When AET is smaller than Potential Evapotranspiration (PET), it indicates limitations due to factors like soil moisture deficiency or environmental constraints. High AET values suggest active transpiration and evaporation, indicative of a well-watered environment, often associated with periods of ample rainfall or effective irrigation. Conversely, low AET values signal restricted evapotranspiration, potentially due to water limitations during dry periods, droughts, or in regions with insufficient water supply.

Analyzing AET variations across different wards revealed that Pongwe, Mzizima, Duga, and Tangasisi exhibit lower AET values of about 700mm, possibly associated with reduced evaporation rates due to lower temperatures and higher rainfall leading to soil saturation. In contrast, Chongoleani shows higher

AET of about 789mm, likely influenced by elevated temperatures and potentially lower rainfall, promoting increased evapotranspiration. These observations provide valuable insights into local water dynamics and environmental stress, aiding in informed water resource management within the study area. Figure 4.6a presents the Actual Evapotranspiration distribution across the study area while Figure 4.6b presents the linear trend from 1982-2022.

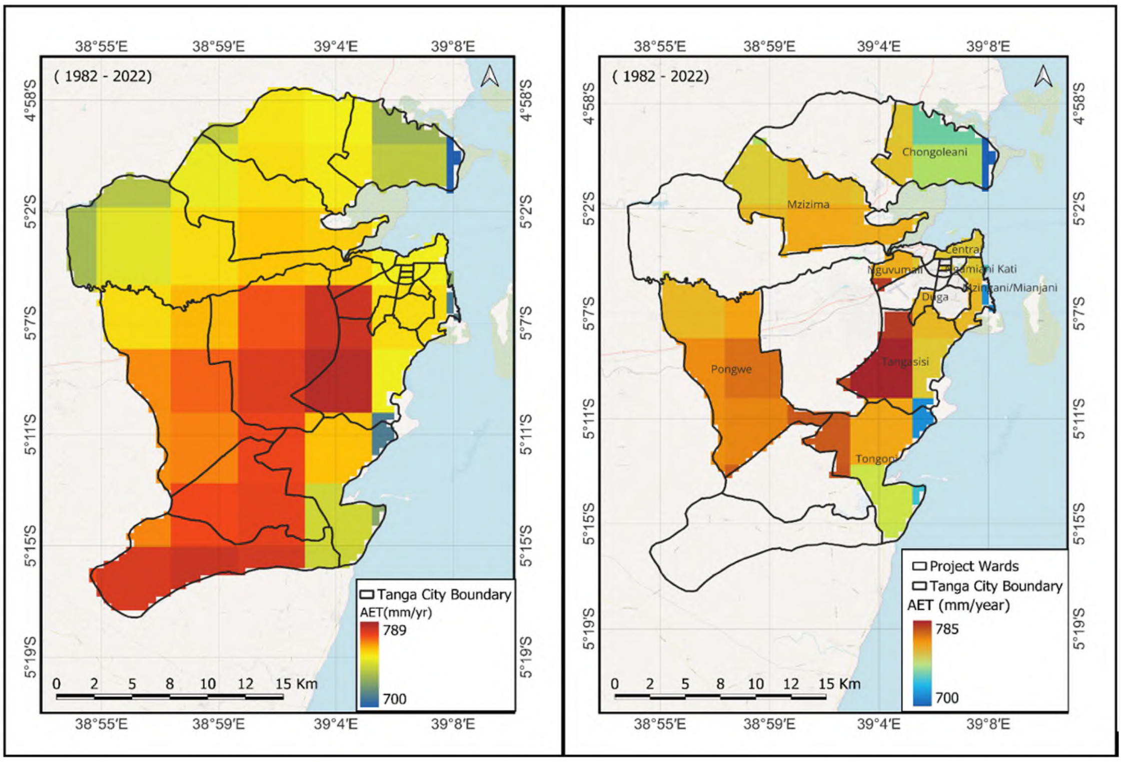

Figure 4.6a: LTM Actual Evapotranspiration (AET)

4.1.4 Potential Evapotranspiration (PET) Analysis

Potential Evapotranspiration (PET) serves as an estimate of the maximum potential evaporation and transpiration of water under standard climatic conditions, representing the demand for water by healthy vegetation in the absence of limitations. PET values, expressed in millimeters per day,
indicate the maximum potential water demand in an environment. Unlike Actual Evapotranspiration (AET), PET does not account for factors like soil moisture limitations. Higher PET values signify significant water demand under ideal conditions, often associated with regions experiencing high temperatures, intense solar radiation, and well-vegetated surfaces. Conversely, lower PET values suggest a reduced potential demand for water, which may be due to cooler temperatures, less solar

radiation, or decreased vegetation cover. Analyzing PET across different wards revealed that Pongwe and Mzizima record lower PET values of about 1143mm, potentially associated with cooler temperatures and higher rainfall, limiting water demand through evapotranspiration. In contrast, wards like Chongoleani, Central, Ngamiani Kati, Duga, and Mzingani exhibit higher PET values of about 1303mm, likely influenced by elevated temperatures and potentially lower rainfall, leading to increased water demand for evapotranspiration. Figure 4.7 present Potential Evapotranspiration distribution from 1982 – 2022 at the Study Area.

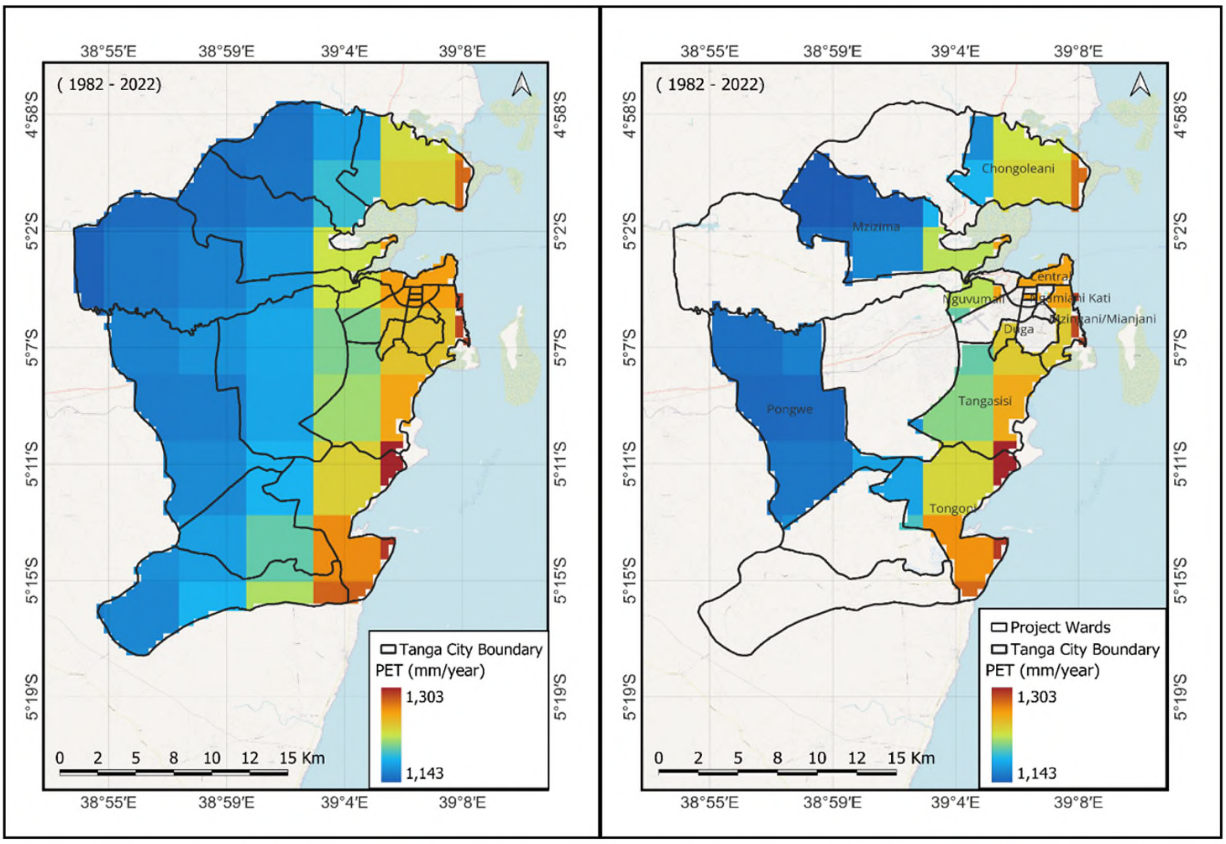

Figure 4.7: LTM Potential Evapotranspiration (PET) 1982-2022

4.1.5 Wind Speed Analysis

Wind speed, a crucial meteorological factor, measures the horizontal movement of air at the Earth's surface. Expressed in units of meters per second or kilometers per hour, wind speed significantly influences local climate patterns, weather conditions, and environmental processes. High wind speeds indicate potentially turbulent atmospheric conditions with implications for wind energy potential, air circulation, and dispersion of pollutants. In contrast, low wind speeds suggest calmer conditions, potentially leading to stagnant air and localized heat accumulation.

Across different wards, a clear variation in wind speed is evident. Pongwe and Mzizima exhibit lower wind speeds of about 264m/s, potentially influenced by local topography or vegetation, creating more sheltered conditions. On the other hand, Chongoleani, Central, Ngamiani Kati, Duga, and Mizingani display higher wind speeds of about 401m/s, indicating exposure to open or elevated landscapes. The intricate relationship between wind speed, temperature, and rainfall is noted, where higher wind speeds may be associated with lower temperatures and reduced humidity, impacting local evapotranspiration rates. Figure 4.8 depicts the Long term mean Wind Speed from 1982 – 2022 at the project area.

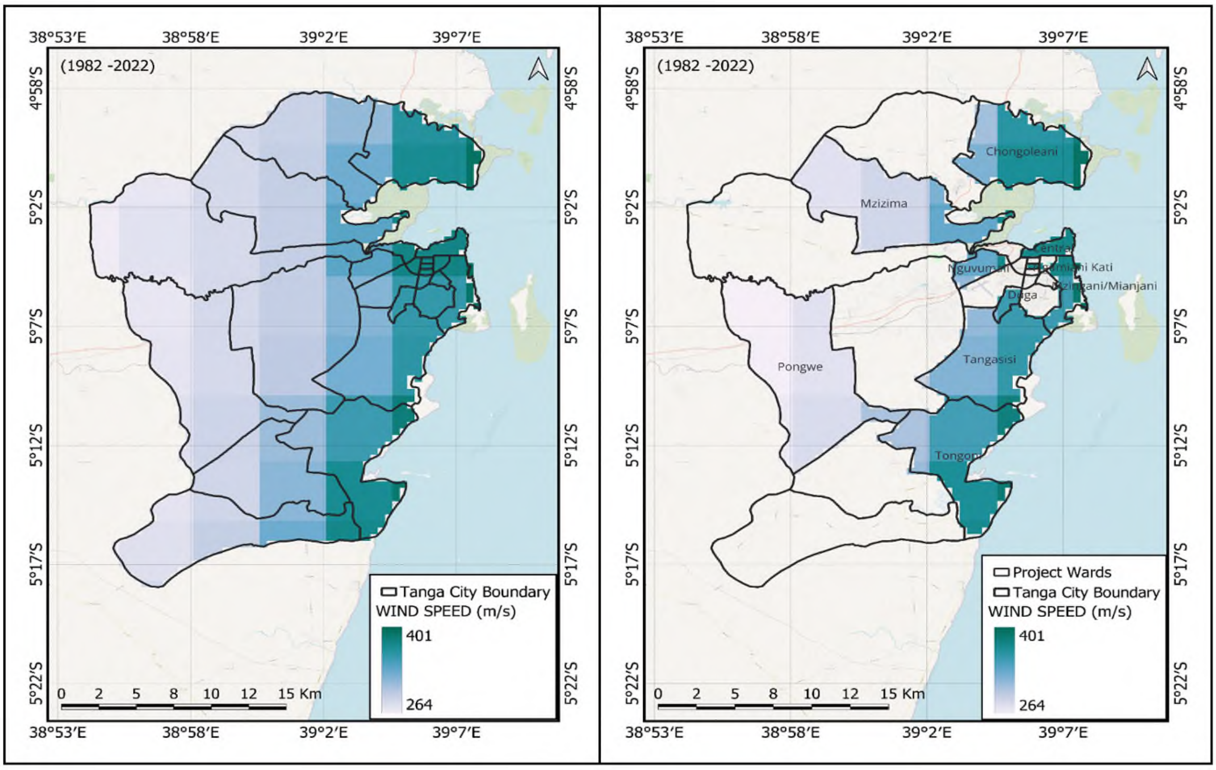

Figure 4.8: LTM Wind Speed 1982-2022 in the project area

4.1.6 Relative Humidity Trend Analysis

Analyzing the relative humidity data spanning from 1982 to 2022 in Tanga City provides valuable insights into the city's climate dynamics. During the early years, from 1982 to the early 1990s, the data indicates a relatively stable humidity pattern with minor fluctuations oscillating within the mid to high 70s percentage range. A noticeable transition occurs in the mid-1990s through the early 2000s, showcasing an increase in relative humidity, suggesting a potential shift in local climatic conditions. Subsequent years exhibit a fluctuating pattern with sporadic peaks and troughs, notably peaking in 2006. The latter part of the dataset, from 2010 onwards, demonstrates a more variable but generally higher trend in relative humidity, culminating in a significant peak in 2020. This upward trend hints at a potential climatic shift towards increased humidity levels in Tanga City, emphasizing the relevance of these findings for geospatial climate analysis and adaptation strategies in the region. Figure 4.9 illustrate the Relative Humidity linear trend spanning from 1982 – 2022.

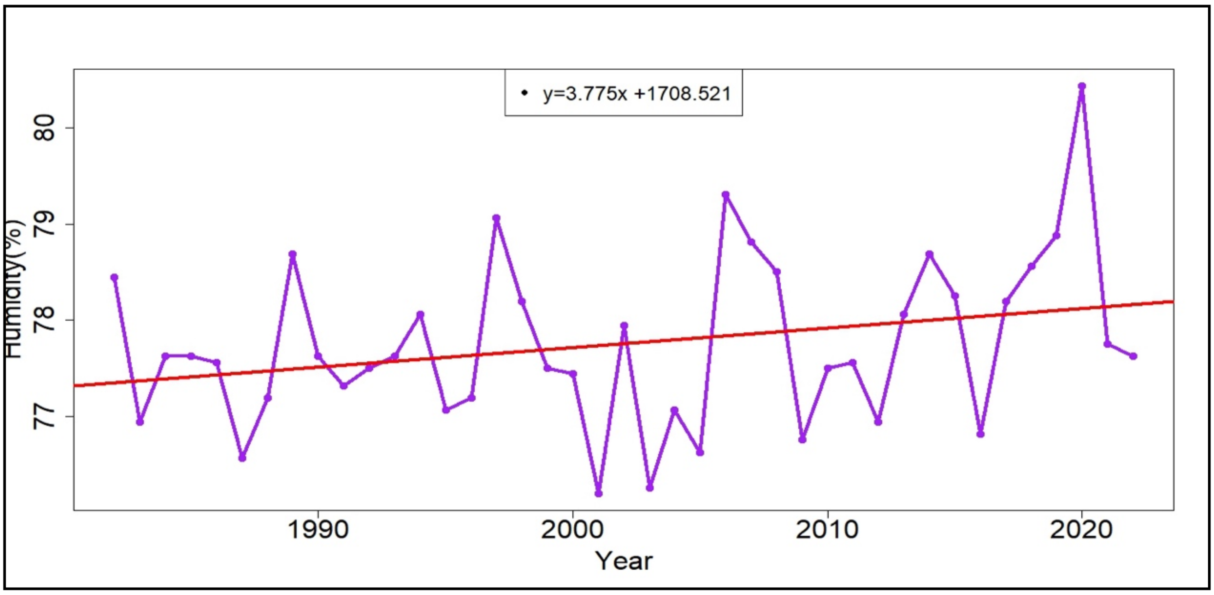

Figure 4.9: Relative humidity linear 1982-2022 in the project area

4.2 Environmental Factors

4.2.1 Land Surface Temperature (LST)

Land Surface Temperature (LST) refers to the temperature of the Earth's surface as measured from a satellite or other remote sensing platforms. It represents the thermal energy emitted by the land surface, including natural features such as soil, vegetation, water bodies, and anthropogenic elements like urban infrastructure.

a) MODIS LST- 2002

In the analysis of Land Surface Temperature (LST) for the year 2002, significant variations were observed across different wards. Ngamiani Kati and Duga displayed high LST values, reaching 34°C, suggesting localized areas experiencing intense heat. This elevation in LST can be indicative of factors contributing to urban heat islands, minimal vegetation cover, or surfaces with low albedo, leading to increased heat absorption in these wards. Conversely, Chongoleani, Tongoni, and Pongwe exhibited low LST values, measuring 27°C, indicating relatively cooler areas. Potential factors contributing to these lower LST values include increased vegetation cover, presence of water bodies, or surfaces with higher albedo. These observations highlight the diverse thermal characteristics across wards, emphasizing the influence of land cover, urbanization, and environmental features on local temperature patterns in the year 2002. Figure 4.10 shows the distribution of Land Surface Temperature in 2002 across the city.

b) MODIS LST – 2012

In the assessment of Land Surface Temperature (LST) trends, significant variations were observed in different wards. Duga and Nguvumali displayed high LST values, measuring 36°C, suggesting an increase in localized heat compared to the year 2002. Factors such as changes in land use, urbanization, or climatic conditions may contribute to the elevated LST values in these wards. Analyzing the factors influencing high LST is crucial for understanding the impact on urban heat islands, vegetation health, and potential heat stress in the environment. Conversely, Tongoni and Chongoleani exhibited low LST values, measuring 28°C, indicating cooler areas. Potential factors contributing to these lower LST values may include increased green spaces, presence of water bodies, or changes in land cover. Identifying areas with lower LST is essential for understanding temperature variations and can have implications for local climate, environmental planning, and community well-being. Figure 4.11 illustrate the variation of Land Surface Temperature in 2012 across the Tanga City and Project Wards.

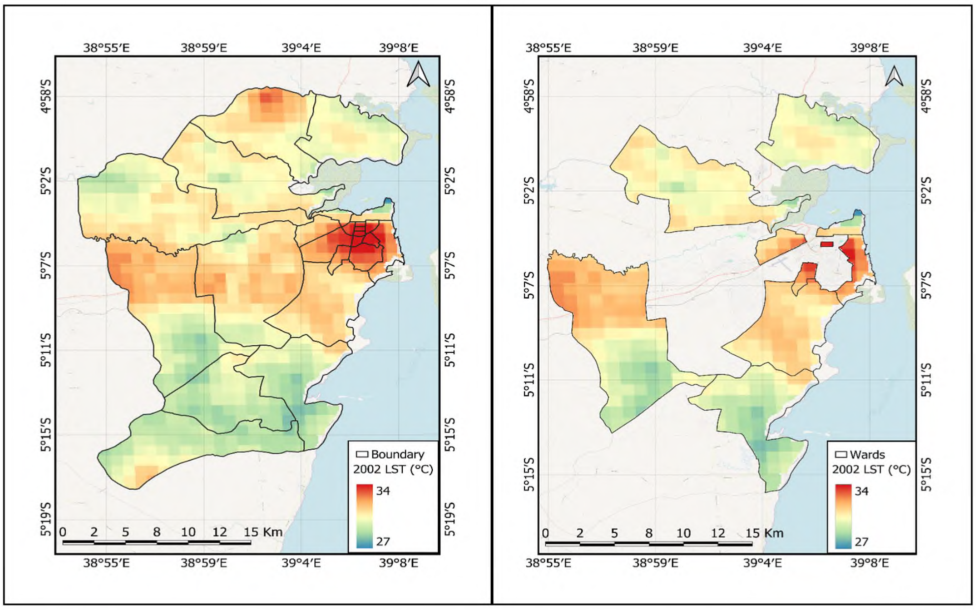

Figure 4.10: Land surface temperature variability in 2002 the project area

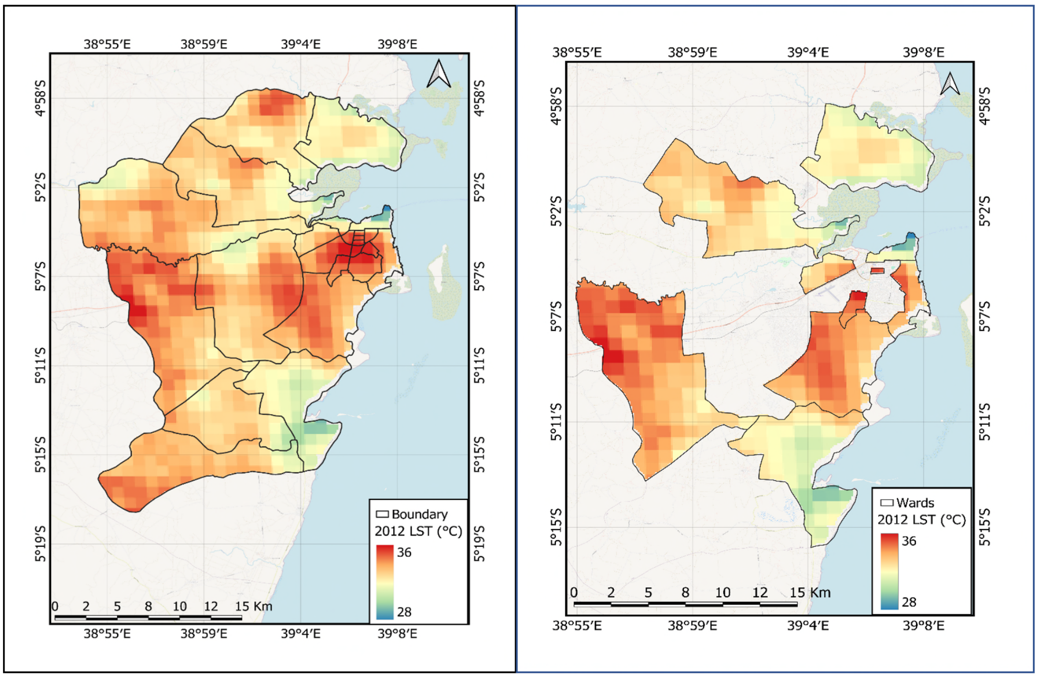

Figure 4.11: Land surface temperature variability in 2012 the project area

c) MODIS LST – 2022

In the assessment of Land Surface Temperature (LST), distinctive patterns were observed in different wards. Duga and Nguvumali exhibited high LST values, measuring 35°C, indicating continued or altered localized heat patterns. Potential contributors to these variations include changes in land cover, urban expansion, or climate fluctuations. Conversely, Tongoni and Chongoleani displayed low LST values, measuring 27°C, suggesting cooler areas. Factors influencing these lower LST values may include increased vegetation cover, presence of water bodies, or changes in land management practices. Figure 4.12 illustrates the variation of Land Surface Temperature in 2022 for both Tanga City and Project Wards.

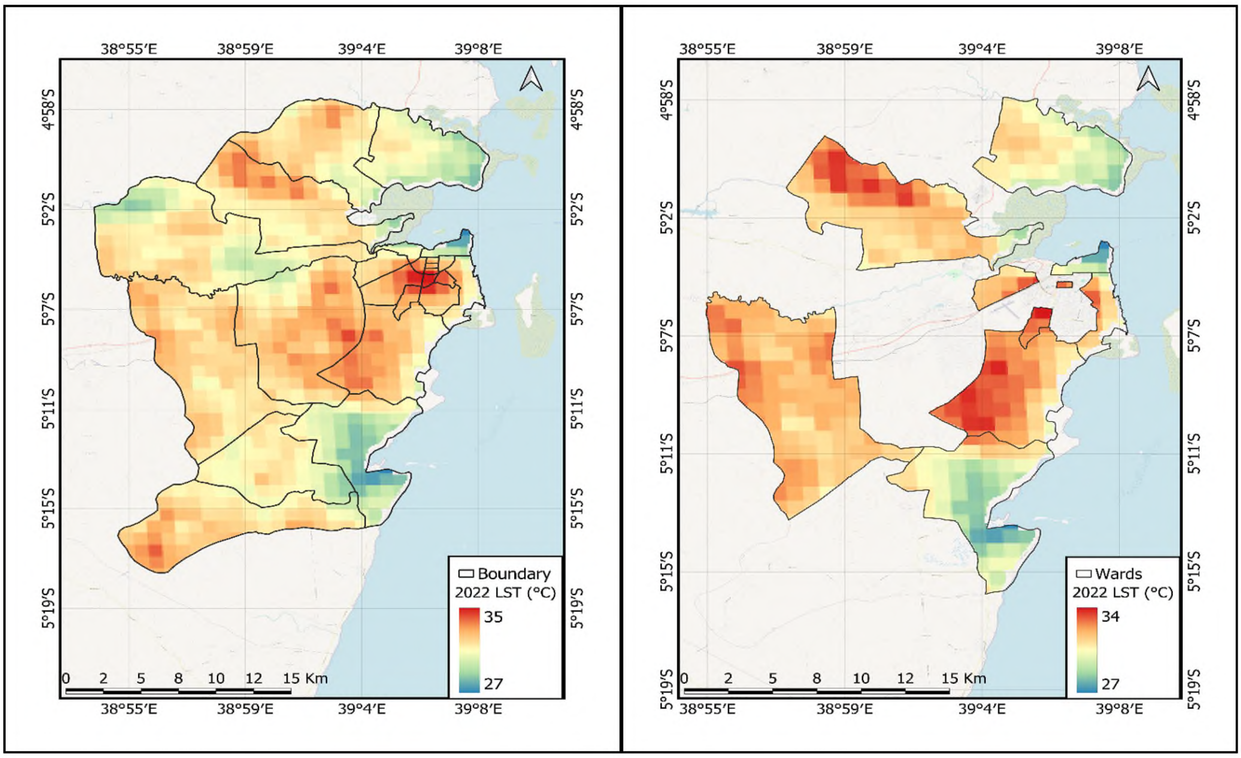

Figure 4.12: Land surface temperature variability in 2022 the project area

4.2.2 Land Cover Analysis

Land cover change plays a pivotal role in shaping local climates, heat resilience, and broader environmental dynamics. As natural landscapes transform due to urbanization, deforestation, and agricultural expansion, the resulting alterations in land cover have significant implications for temperature patterns, ecosystem health, and overall environmental resilience. The relationship between land cover change, heat resilience, and environmental dynamics underscores the importance of sustainable land management practices. Balancing urban development with ecological preservation, adopting green infrastructure, and recognizing the role of land cover in climate adaptation are crucial steps toward building resilient and sustainable communities.

a) Land Cover Analysis – 2015

In the assessment of land cover across different wards, distinct patterns were identified. Central, Ngamiani, and Duga exhibited a high rate of built-up class, suggesting significant urban development or infrastructure presence in these areas. Conversely, Pongwe, Tongoni, and Mzizima were observed to be more covered with trees and grass, indicating a prevalence of natural vegetation in these wards. These variations in land cover have important implications for urban planning, environmental conservation, and can influence local climate and ecosystem health within the study area. Figure 4.13 depicts the Land Cover Distribution across the Tanga City and Project Wards

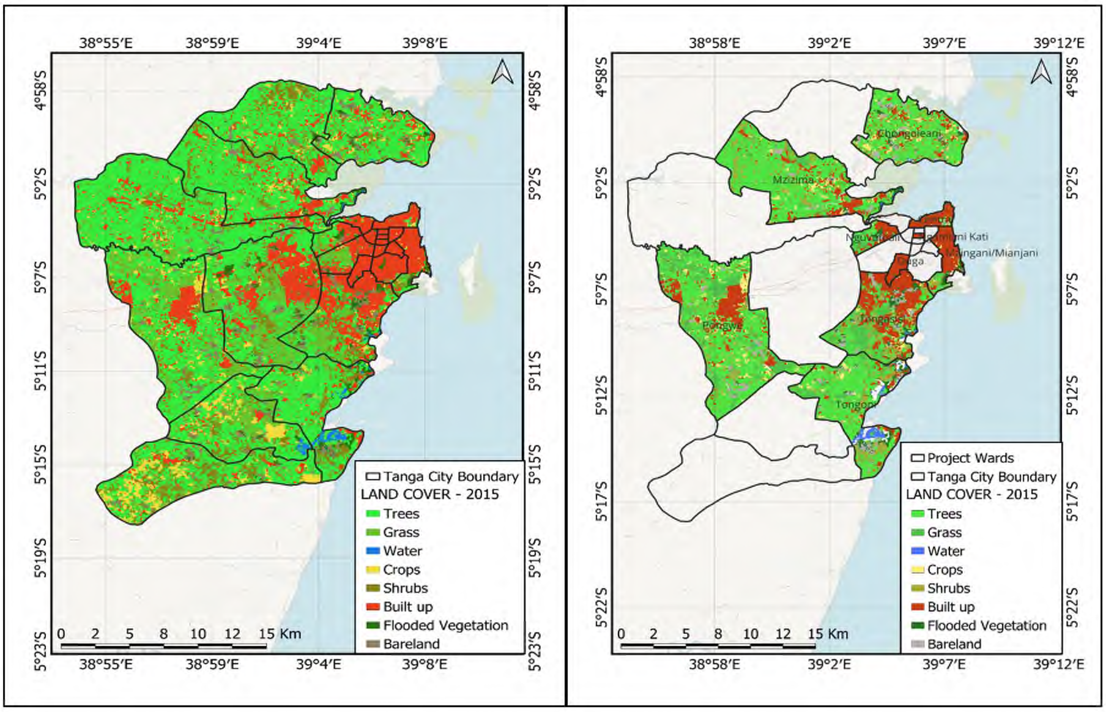

Figure 4.13: Land cover distribution in 2015 across project area

a) Land Cover Analysis – 2021

The analysis of land cover patterns across wards revealed distinct characteristics. Duga, Tangasisi, Central, Ngamiani Kati, and Mzingani exhibited a high rate of built-up areas, indicating significant urban development or infrastructure presence in these regions. In contrast, Pongwe, Mzizima, and Chongoleani were observed to be more covered with shrubs, suggesting a prevalence of natural vegetation in the form of shrubbery in these wards. These variations in land cover have implications for urban planning, environmental conservation, and can influence local climate and ecosystem dynamics within the study area. Figure 4.14 shows the Land Cover Distribution in 2021 across the Tanga City and Project Wards

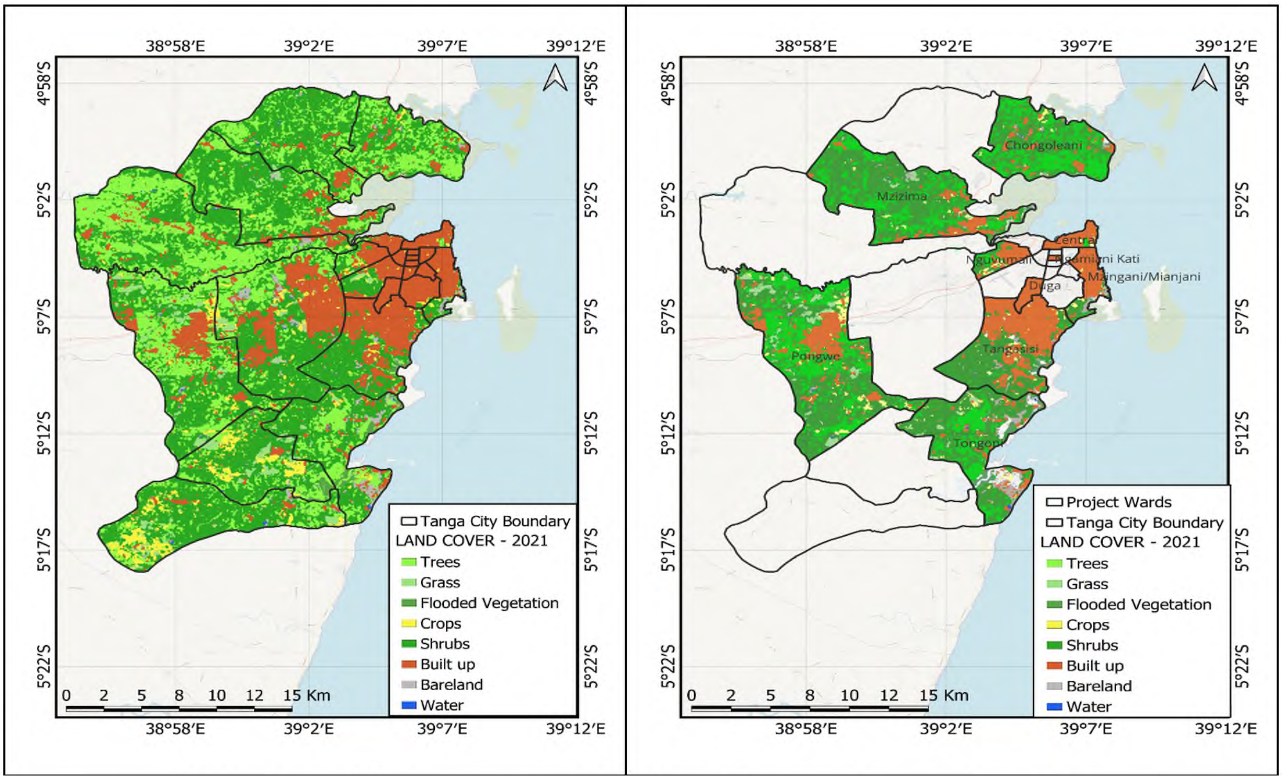

Figure 4.14: Land cover distribution in 2021 across project area

a) Land Cover Analysis – 2022

An examination of land cover classes in Pongwe, Tangasisi, Tongoni, Mzizima, and Chongoleani revealed a dominance of built-up areas, cropland, and bareland compared to other classes. These wards exhibit significant urban development with a prevalence of built-up infrastructure. Additionally, cropland indicates agricultural activities, and bareland suggests areas with minimal vegetation cover. This land cover composition reflects the influence of human activities, urbanization, and agricultural practices in shaping the landscape of these wards. Figure 4.15 presents the Land Cover Distribution in 2022 across the Tanga City and Project Wards.

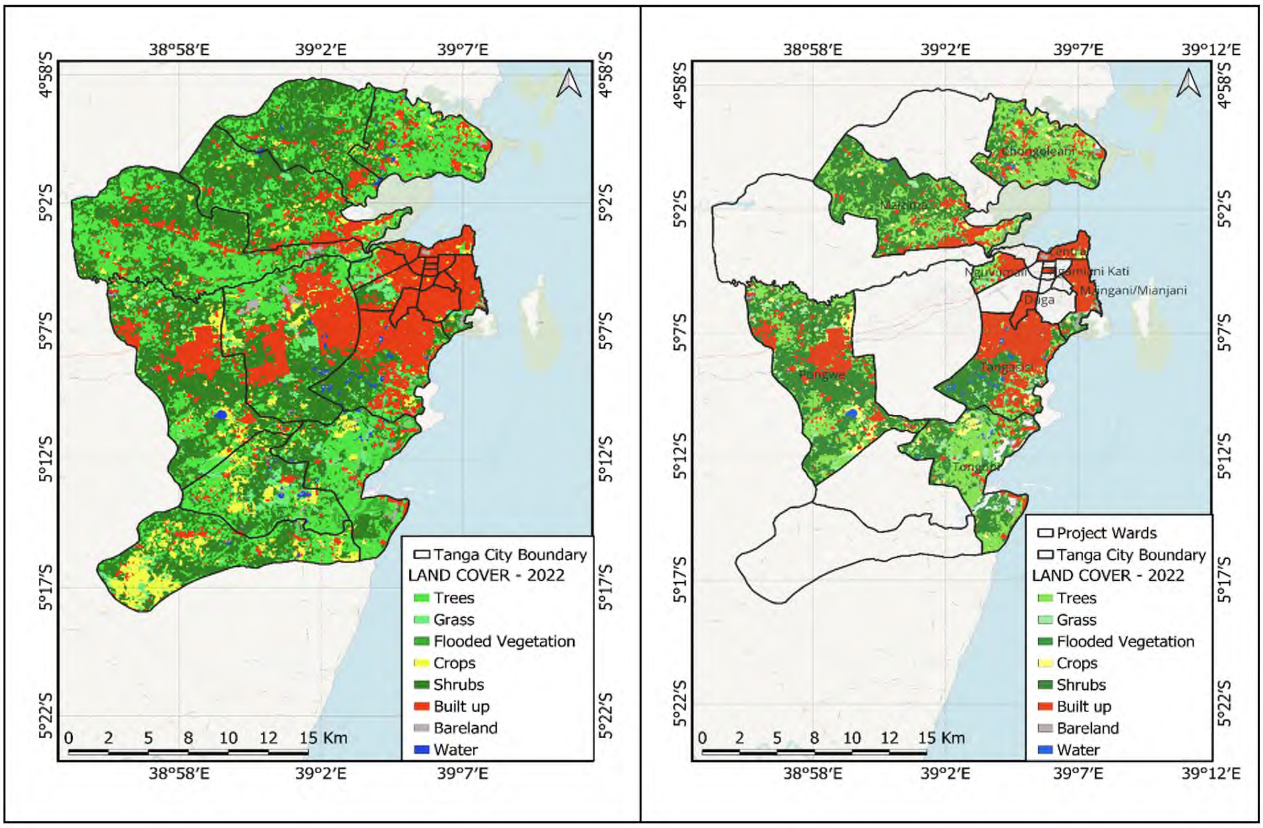

Figure 4.15: Land cover distribution in 2021 across project area

4.2.3 Normalized Difference Vegetation Index (NDVI)

NDVI Distribution in 2002

In 2002, NDVI values served as crucial indicators of the diverse vegetation conditions prevailing across the study area. Higher NDVI values, approaching 1, were likely associated with healthy and dense vegetation, signifying flourishing ecosystems. Conversely, lower NDVI values suggested areas with potentially sparse or stressed vegetation, indicating environmental challenges. Specific wards, including Mzizima, Chongoleani, Nguvumali, and Pongwe, were notable for exhibiting very dense vegetation cover, as evidenced by high NDVI values. These regions boasted robust and thriving plant life, contributing to the overall greenery and biodiversity of the landscape. Additionally, moderate vegetation cover was observed in these wards, further enhancing their environmental richness.

In contrast, Tongoni stood out for its distinctive landscape characterized by more water coverage, as reflected in lower NDVI values, accompanied by lower vegetation cover. This unique feature highlighted a pronounced influence of water bodies on the NDVI values, setting Tongoni apart in its environmental context compared to other wards. Figure 4.16 depicts Vegetation Cover Distribution in 2002 across the Tanga City and Project Wards.

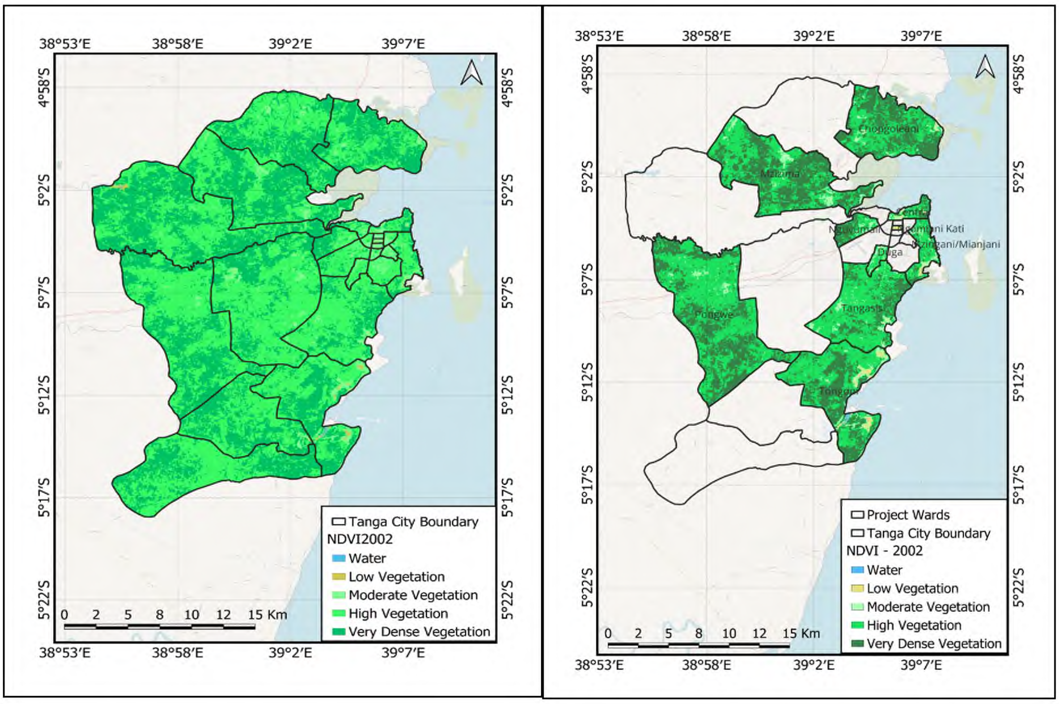

Figure 4.16: Vegetation distribution in 2002 across project area

NDVI Distribution 2012

Comparing NDVI values between 2012 and 2002 provides insights into the decade-long changes in vegetation cover. A decrease in NDVI values may signify deforestation, land degradation, or alterations in land use practices, emphasizing the importance of comprehending these changes for assessing environmental impacts and guiding sustainable land management practices.Specifically, in the comparison, Tangasisi, Chongoleani, Central, Ngamiani Kati, and Mzingani were identified as areas more covered with low vegetation in 2012. This observation may indicate a decline in the density of plant life in these wards over the decade, potentially attributed to various environmental factors or human activities affecting vegetation health.

In contrast, Pongwe and Mzizima exhibited a contrasting trend, showcasing more coverage of high to very high vegetation in 2012. This increase in vegetation cover suggests positive ecological dynamics in these wards, potentially linked to conservation efforts, afforestation initiatives, or natural regrowth. Figure 4.17 shows Vegetation Cover Distribution in 2012 across the Tanga City and Project Wards

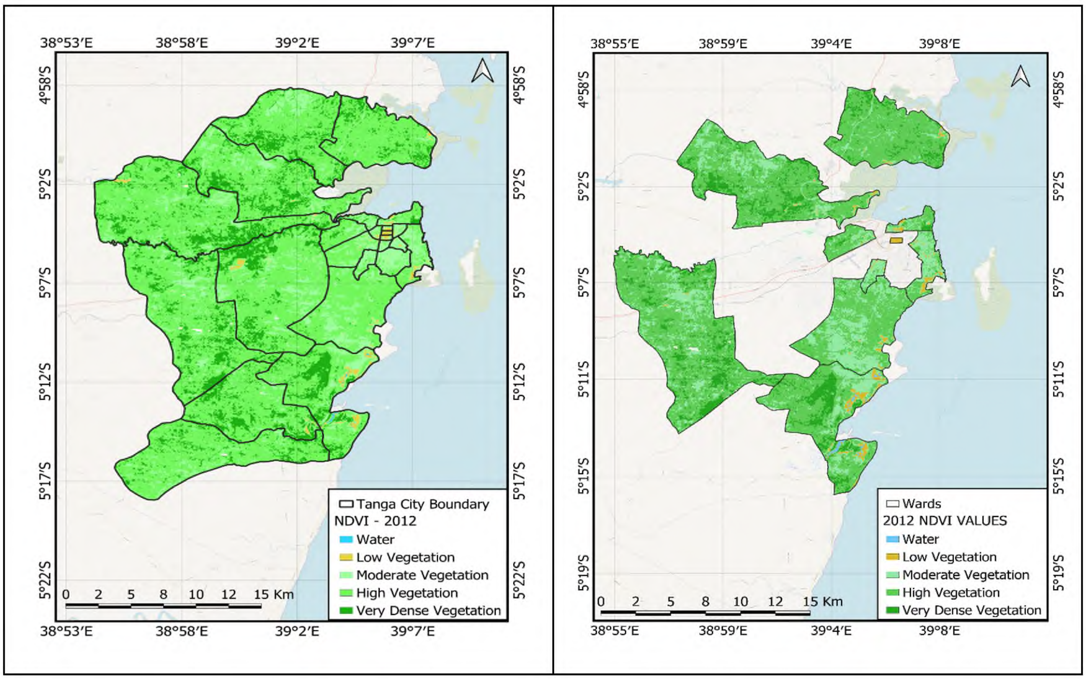

Figure 4.17: Vegetation distribution in 2012 across project area

NDVI Distribution 2012

Examining NDVI values in 2022 offers valuable insights into the persistence or evolution of vegetation trends within the study area. Consistent or increased NDVI values across certain areas may signify successful conservation efforts or natural regeneration, contributing to enhanced vegetation health. Conversely, declining NDVI values in specific regions may indicate ongoing land degradation or alterations in environmental conditions, emphasizing the need for further investigation and targeted interventions. Notably, a reduction in very high vegetation cover is observed in Pongwe, Tangasisi, Mzingani, and Duga in 2022. This decline may point to changes in land cover, environmental stressors, or human activities impacting the density of lush vegetation in these wards over time. Understanding the factors contributing to this reduction is crucial for implementing effective conservation strategies and mitigating potential environmental degradation. In contrast, Tongoni exhibits an opposite trend, being more covered with very high vegetation in 2022. This observed increase suggests positive vegetation dynamics in Tongoni, potentially associated with favorable environmental conditions, afforestation efforts, or natural regrowth. Figure 4.18 illustrate the Vegetation Cover Distribution in 2022 across the Tanga City and Project Wards

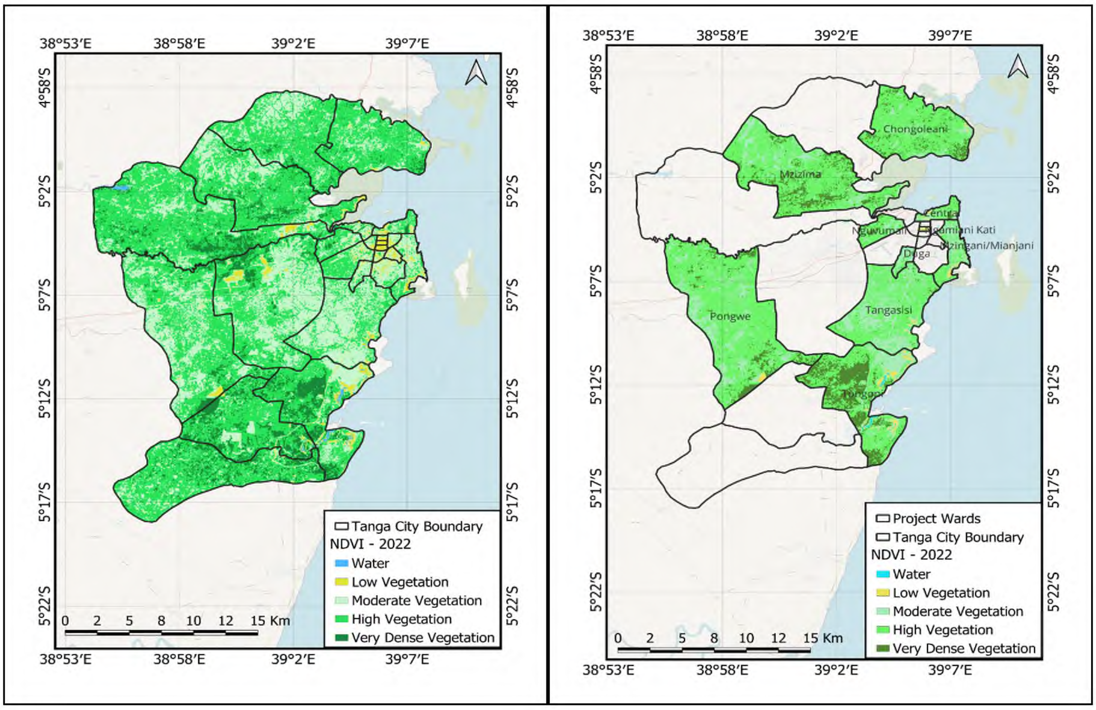

Figure 4.18: Vegetation distribution in 2022 across project area

4.2.4 Topographical Influence

Elevation, denoting the vertical distance above a reference point, such as sea level, is a critical geographic parameter that characterizes the height or altitude of locations on the Earth's surface. Measured in units like meters or feet, elevation provides valuable information about the topography of the terrain, spanning from low-lying areas to towering mountain peaks. This fundamental geographic characteristic holds broad significance for various aspects, including climate, ecosystems, water resources, and human activities, contributing to a comprehensive understanding of a region's environmental dynamics. In the specific context of the project area, it is observed that Pongwe and Mzizima are wards characterized by high elevation levels compared to others such as Central, Ngamiani Kati, Duga, Mzingani, Tangasisi, and Tongoni. This variation in elevation across wards has implications for local climate patterns, water drainage, and ecological systems. Understanding these elevation differences enhances our ability to address challenges related to natural resource management, climate resilience, and sustainable development within the study area. Figure 4.19 show the terrain variability across the Tanga City and Project Wards.

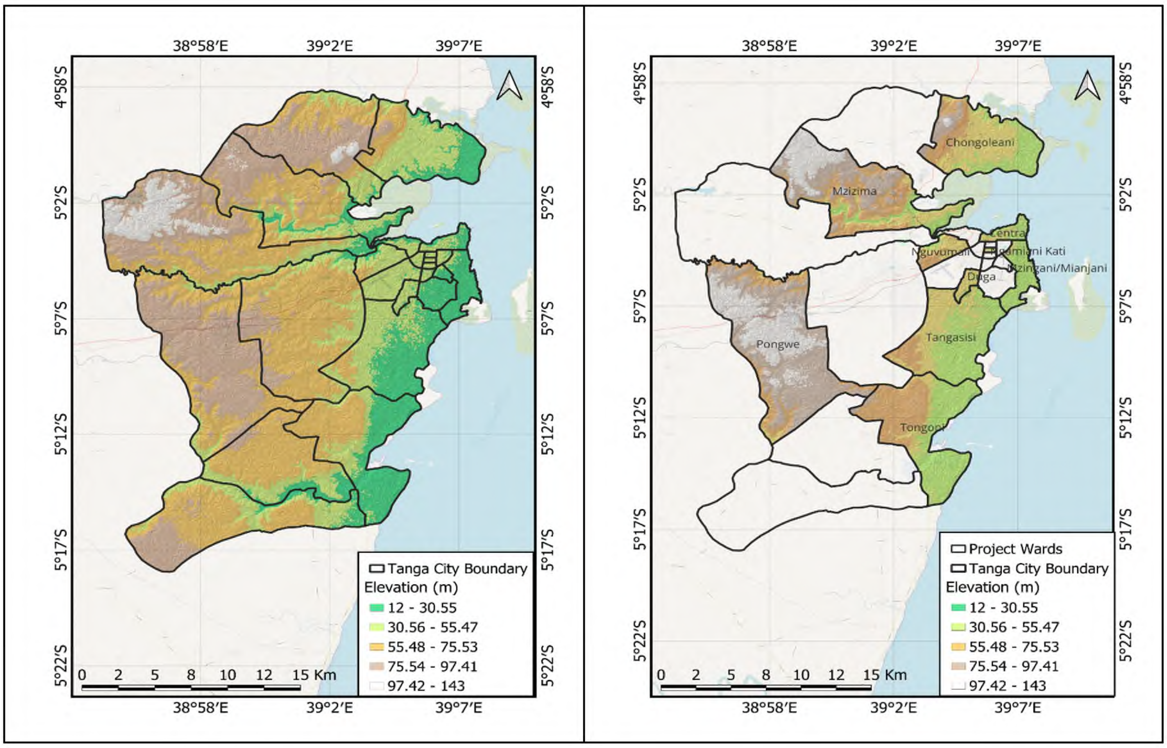

Figure 4.19: Topography across the project area

4.3 Geological and Soil Characteristics

4.3.1 Geological Characteristics of Tanga City

Geology serves as a pivotal factor in shaping landscapes and profoundly influences both heat resilience and responses to climate changes. The type of rocks and geological formations present in an area play a crucial role in determining soil composition, drainage patterns, and topography, all of which collectively impact local microclimates. Specific rock types contribute to the formation of soils that can either enhance or limit water retention, consequently influencing vegetation growth and temperature regulation. Moreover, geological features such as mountains can significantly affect rainfall patterns, creating distinct microclimates and contributing to overall heat resilience. Understanding the geological context is paramount for assessing natural hazards like landslides or earthquakes, as these events can have cascading effects on climate resilience.

In the studied area, Tongoni, Tangasisi, Duga, Nguvumali, Central, and Ngamiani Kati are characterized by the SO2 geological type, whereas Pongwe and Mzizima consist of the SC geological type. Chongoleani, on the other hand, is composed of the UM geological type. This diversity in geological compositions across wards contributes to the unique environmental characteristics and challenges in each area, further emphasizing the importance of incorporating geological considerations in comprehensive climate resilience and hazard mitigation strategies. Figure 4.20 shows the Geology across the Tanga City and Project Wards.

4.3.2 Soil Characteristics

Soil plays a pivotal role in enhancing heat resilience and facilitating climate change adaptation. The thermal properties of soil, encompassing its capacity to retain and release heat, play a crucial role in shaping local microclimates. Well-structured and organic-rich soils exhibit the ability to moderate temperature extremes, offering a significant contribution to heat resilience in both urban and rural areas. Furthermore, soil serves as a vital carbon sink, influencing greenhouse gas levels and thereby impacting the broader dynamics of climate change. Changes in soil health, such as erosion or degradation, have the potential to exacerbate temperature extremes and contribute to various climate-related challenges. Hence, understanding and effectively managing soil conditions are imperative steps in building resilience against rising temperatures and addressing the broader impacts of climate change.

In the specific context of the study area, Chongoleani, Mzizima, and Pongwe are characterized by Cambisols as the predominant soil type, while the remaining wards consist of Arenosols. This variation in soil types across wards underscores the diverse environmental conditions within the region, necessitating tailored approaches for soil management and climate resilience strategies to address the unique characteristics of each area. Figure 4.21 present the distribution of different Soil types across the Tanga City and Project Wards.

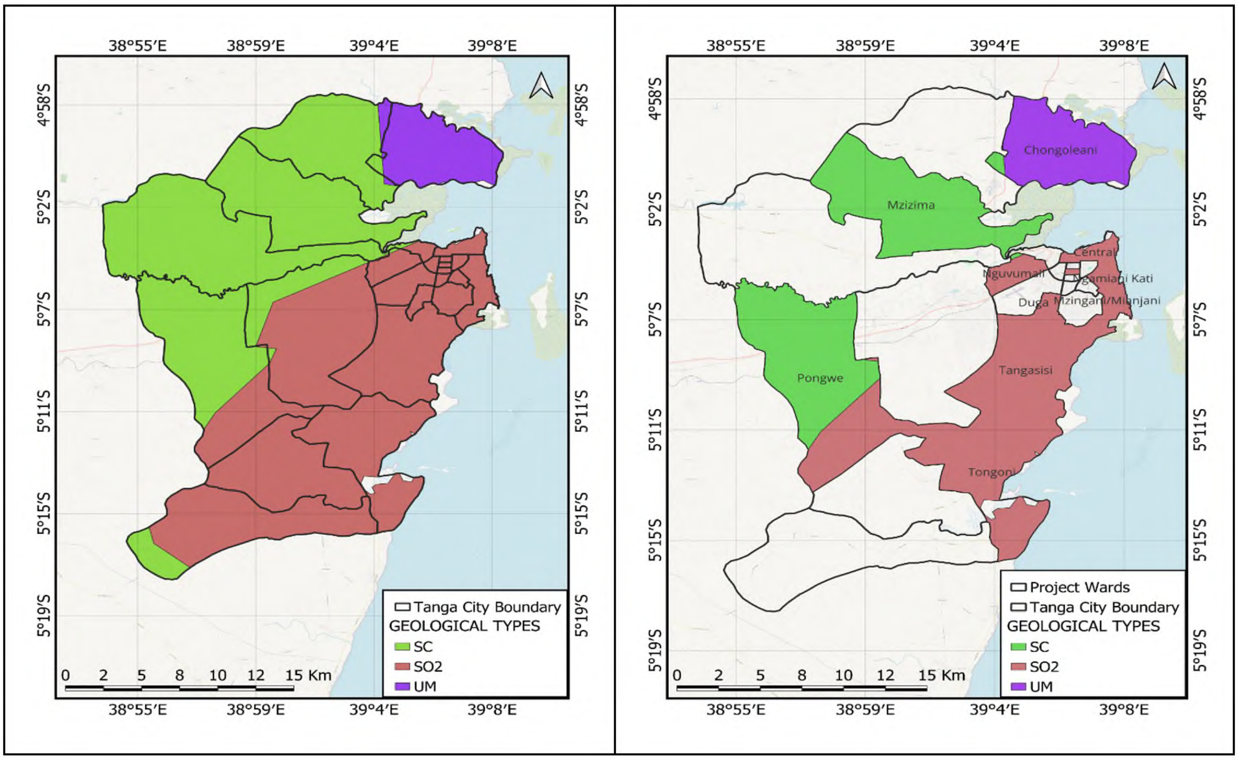

Figure 4.19: Geology across the project area

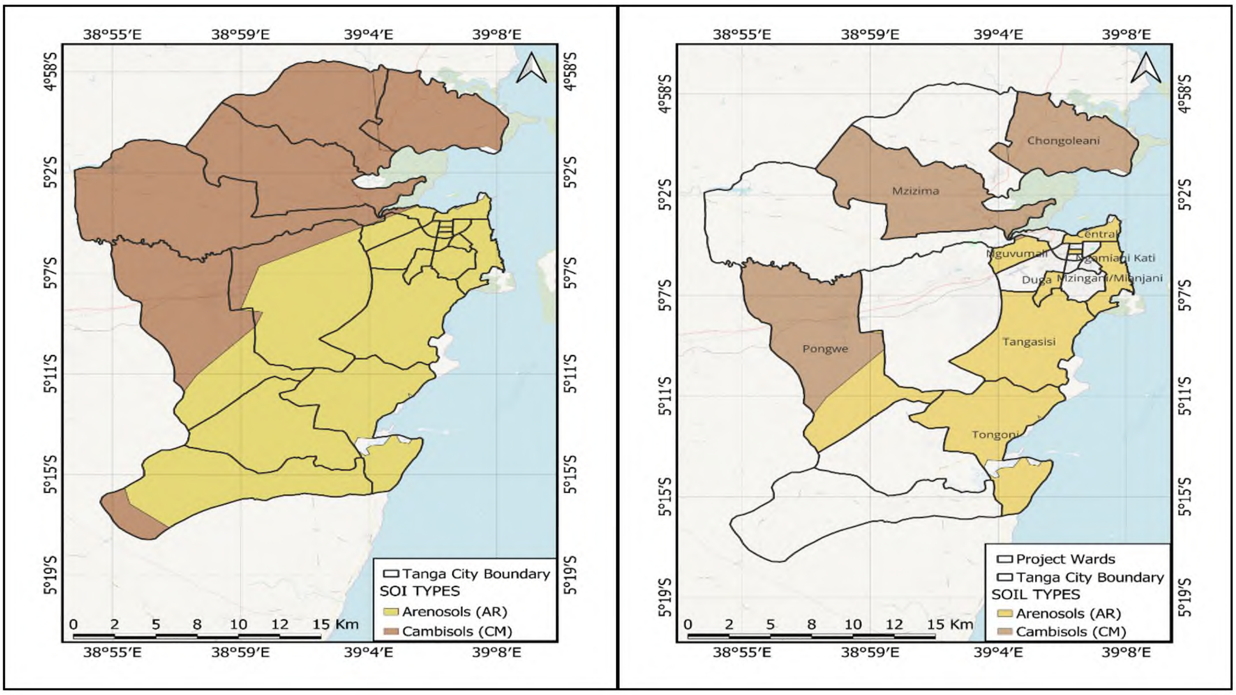

Figure 4.21: Soil type distribution across the project area

4.4 Infrastructure and Urban Analysis

4.4.1 Transportation Network Analysis

Analyzing the transportation network, specifically roads and railways, is pivotal to the project's theme, offering a clear geospatial understanding of critical infrastructure within the study area. Examining the distribution and connectivity of roads provides insights into accessibility and potential vulnerabilities to climate-related disruptions, crucial for ensuring smooth transportation and logistics operations. Simultaneously, assessing the spatial arrangement of the railway network offers valuable information on the resilience and connectivity of this vital transportation mode, influencing regional mobility and trade. This focused analysis helps identify potential weak points and areas for improvement in the transportation network, contributing to the development of targeted climate resilience strategies for these essential infrastructure components. Figure 4.21 illustrate the Transportation Network across the Tanga City and Project Wards.

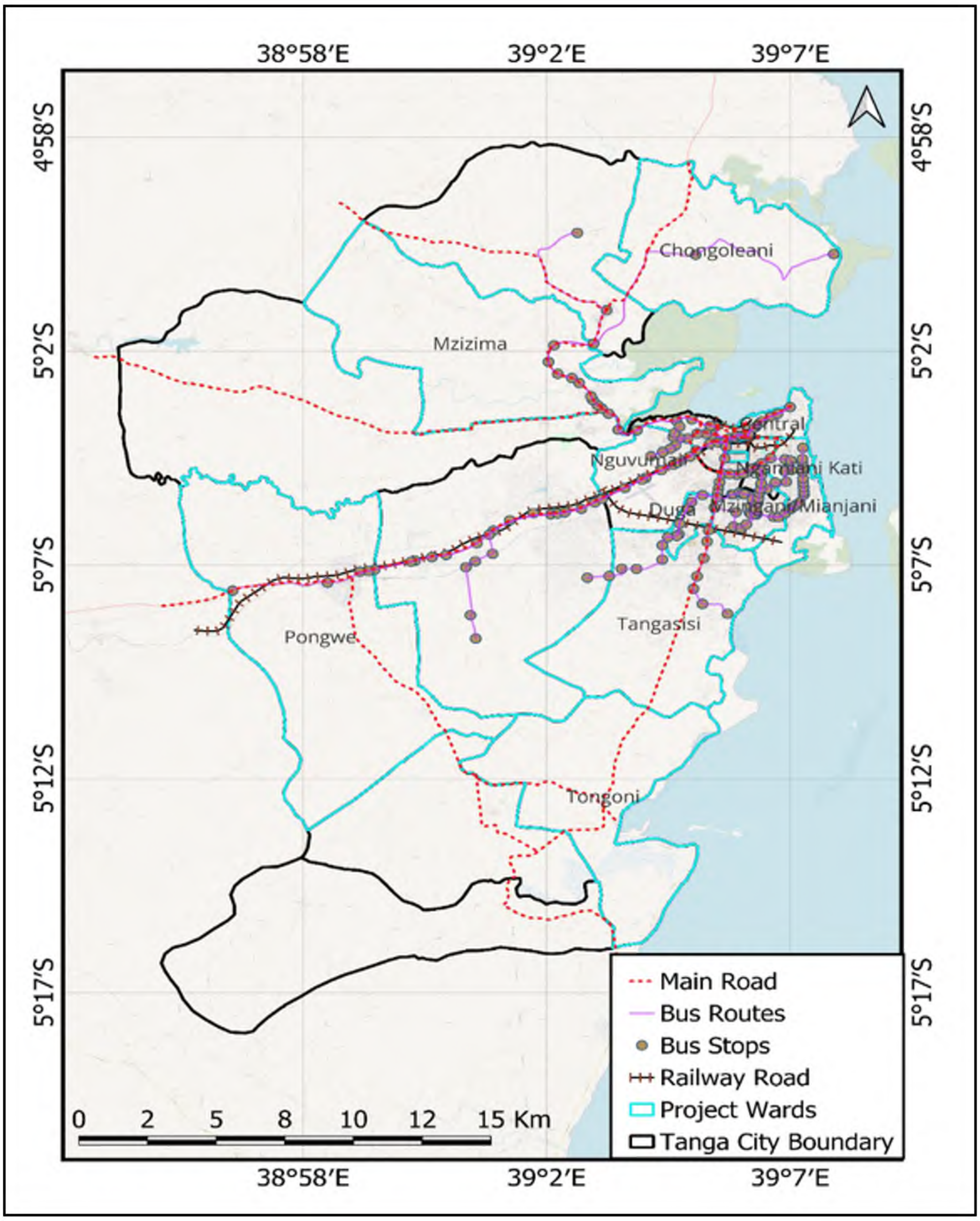

Figure 4.22: Transportation network in the project area

4.4.2 Administrative Boundaries and Offices

The analysis of administrative boundaries and offices plays a pivotal role in the project's theme, offering a detailed geospatial understanding of the governance structure and resource distribution within the study area. Through the examination of administrative boundaries, the project aims to identify jurisdictional units, enabling assessment of how climate risks and resilience efforts may vary across different administrative regions. This approach provides valuable insights into the intricacies of governance and resource allocation within the study area, enhancing the project's ability to tailor climate resilience strategies to specific administrative contexts. This analysis offers crucial insights into the accessibility of resources for climate resilience at various administrative levels. Understanding the geographic placement of these offices provides a foundation for evaluating their roles in disaster management, environmental stewardship, and municipal governance. The outcomes of this analysis will contribute to the development of targeted strategies for optimizing resource distribution and enhancing climate resilience within the governance framework of the study area. Figure 4.23 presents the Locations of Ward Administrative boundaries and offices across the Tanga City .

4.4.3 Distribution of Schools, Hospitals and Health Centers

The concurrent analysis of schools, hospitals, and health centers is crucial to the project's central theme, providing a comprehensive geospatial perspective on critical infrastructure and essential public services within the project area. By examining the distribution of schools, insights are gained into the accessibility of educational facilities and potential vulnerabilities in the education sector related to climate risks. Simultaneously, assessing the spatial arrangement of hospitals and health centers allows for an evaluation of healthcare infrastructure resilience and its capacity to respond effectively to climate-related challenges. This integrated approach ensures a holistic understanding of the spatial dynamics of key services, facilitating the development of targeted climate resilience strategies for educational and healthcare infrastructure across diverse regions in the study area.

Specifically, the study identifies Ngamiani Kati, Nguvumali, Central, and Duga as areas occupied with a large number of schools and hospitals, indicating potential areas of educational and healthcare focus. On the other hand, Chongoleani, Mzizima, Tongoni, and Pongwe are characterized by fewer schools, hospitals, and health centers. This disparity underscores the varying distribution of critical infrastructure and essential services across different regions, necessitating tailored climate resilience strategies to address the unique challenges and opportunities presented by each area. Figure 4.24 depicts the location and distribution of Schools, Hospitals and Health Centers across the Tanga City and Project Wards.

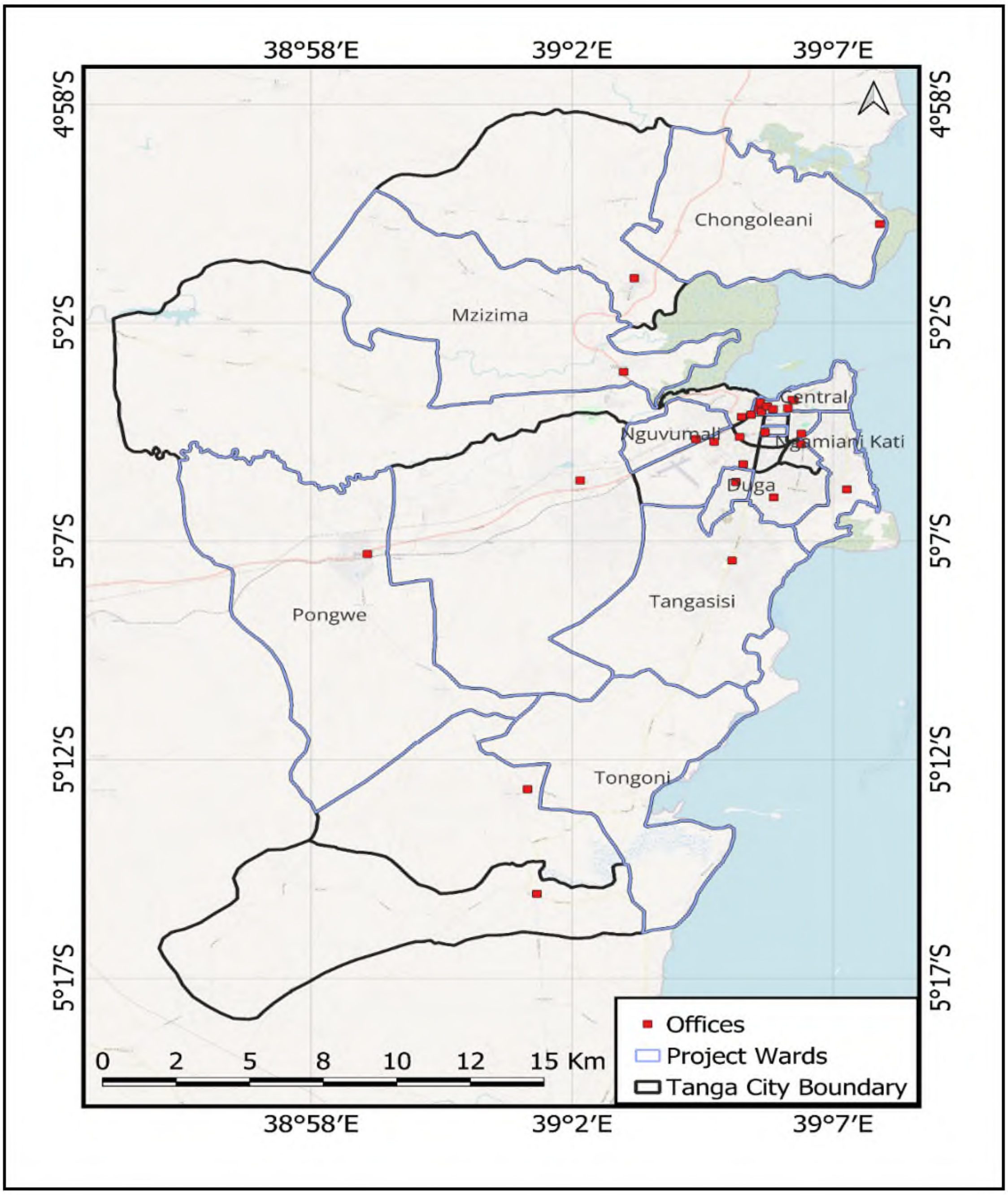

Figure 4.23: Location of Wards offices in the project area

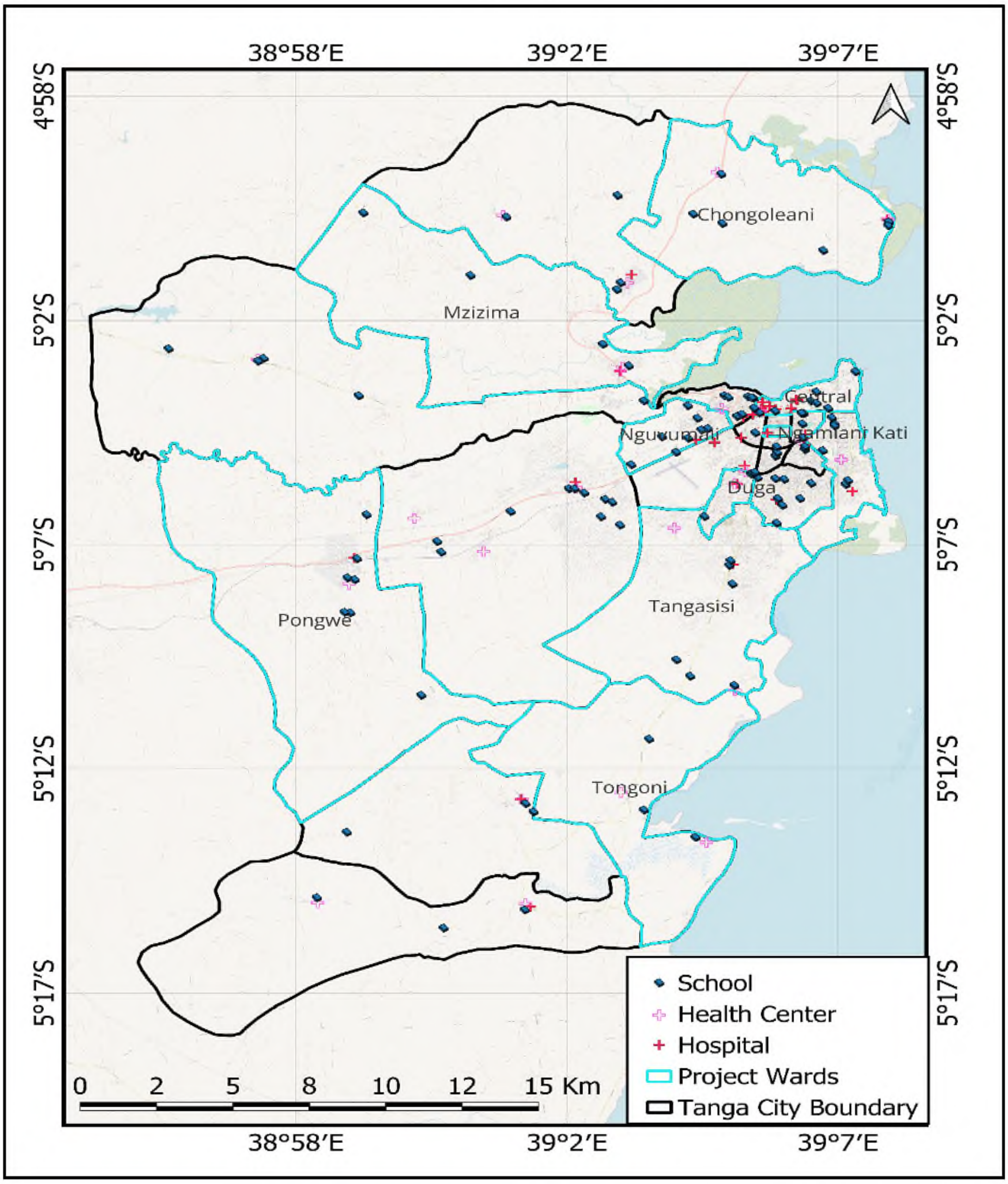

Figure 4.24: Distribution of primary school and health centers in the project area

4.4.4 Bus Stops and Accessibility

The examination of bus stops is crucial for understanding the local transportation network within the study area. By assessing the distribution and accessibility of bus stops, valuable insights are gained into the connectivity and convenience of public transportation services. This analysis helps identify areas with effective access to public transit and highlights potential gaps or areas for improvement. Understanding the spatial arrangement of bus stops is essential for crafting targeted strategies to enhance the resilience and efficiency of the public transportation system, ensuring its robustness and accessibility during various climate-related challenges.

Notably, Tongoni, Pongwe, Mzizima, and Chongoleani are identified as areas with a relatively lower number of bus stops compared to Nguvumali, Ngamiani Kati, Central, Duga, and Mzingani, which have a larger number of bus stops. This disparity in bus stop distribution underscores variations in public transportation accessibility across different regions. Tailoring strategies to address the specific needs of areas with fewer bus stops can contribute to the overall improvement of the public transportation system's resilience and effectiveness in the face of climate-related challenges. Figure 4.25 depicts the location and distribution of Bus Stops across the Tanga City and Project Wards.

4.4.5 Population Distribution and Density

In analysing Tanga city's population distribution and density across its wards, distinct patterns emerge that have implications for urban heat resilience.

Mzingani and Tangasisi are identified as areas with a high population, ranging from 24,546 to 56,276. This suggests that these locations have a relatively dense and substantial population, which may have implications for urban development, resource management, and community services. The higher population could also lead to increased demands on infrastructure and services, necessitating careful planning for sustainable growth. Conversely, Chongoleani, Mzizima, Pongwe, Nguvumali, Central, Tongoni, and Duga exhibit the lowest population, ranging from 0 to 24,545. These areas may experience lower population density, which could influence factors such as rural development, access to services, and community dynamics. The lower population may indicate a more rural or less densely populated environment. Understanding the population distribution in different regions is vital for effective urban and rural planning, resource allocation, and social development strategies

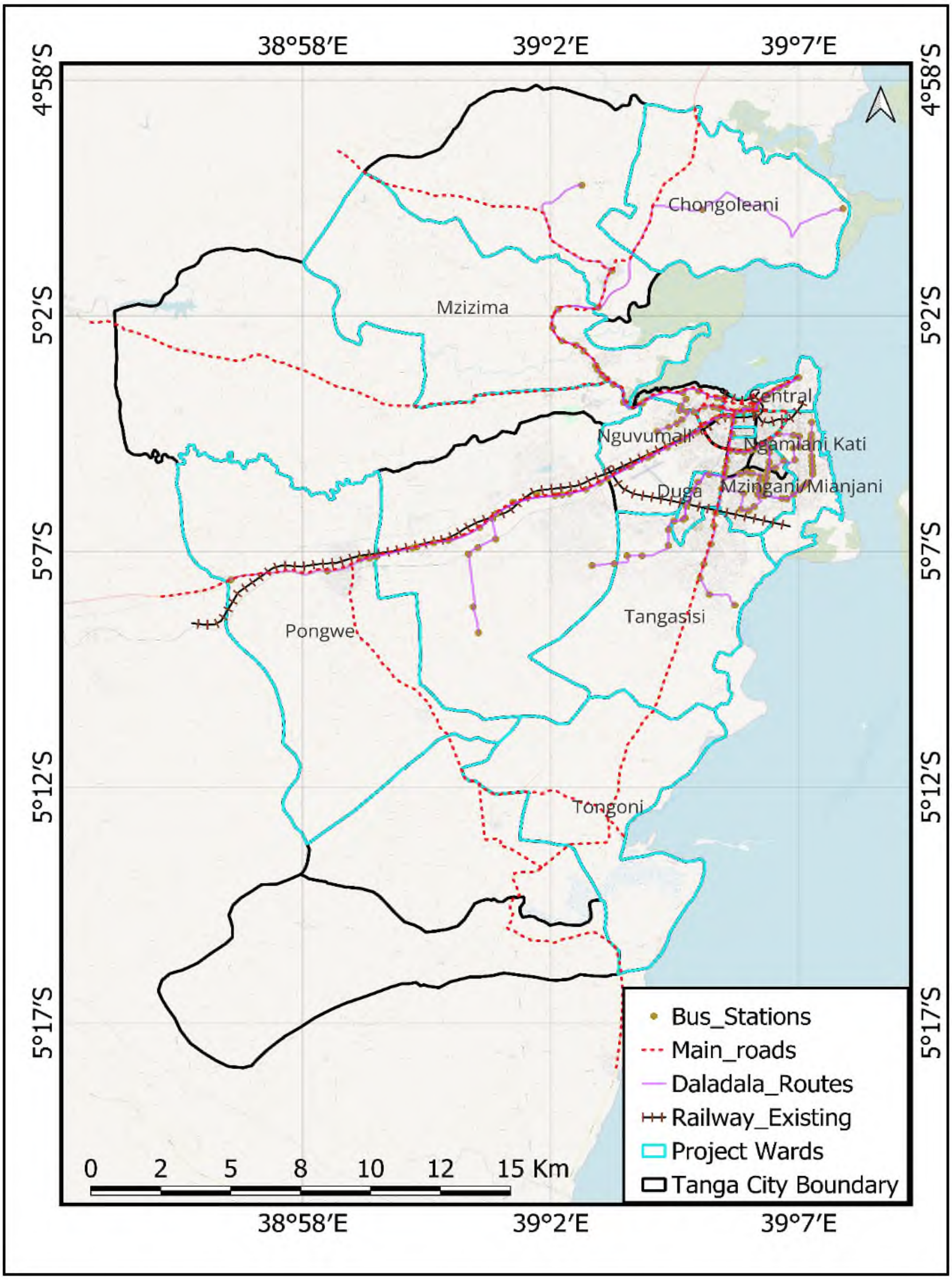

Figure 4.25: Location of Bus Stops in the project area

Wards such as Mzizima, Chongoleani, Tongoni, Tangasisi, and Mzingani exhibit low population density, ranging from 0 to 243 people per square kilometre, potentially indicating greater availability of open spaces and green areas. In contrast, Nguvumali, Duga, and Ngamiani Kati demonstrate high population density, varying from 1489 to 16126 people per square kilometre, suggesting a higher concentration of infrastructure and potentially elevated vulnerability to the Urban Heat Island effect. These variations underscore the need for targeted resilience strategies, with low-density areas benefiting from green space preservation, and high-density areas requiring interventions such as green infrastructure development and health-focused initiatives to address the specific challenges posed by their population density dynamics. Figure 4.26 present Population Distribution while Figure 4.27 depicts the Population Density across the Tanga City and Project Wards.

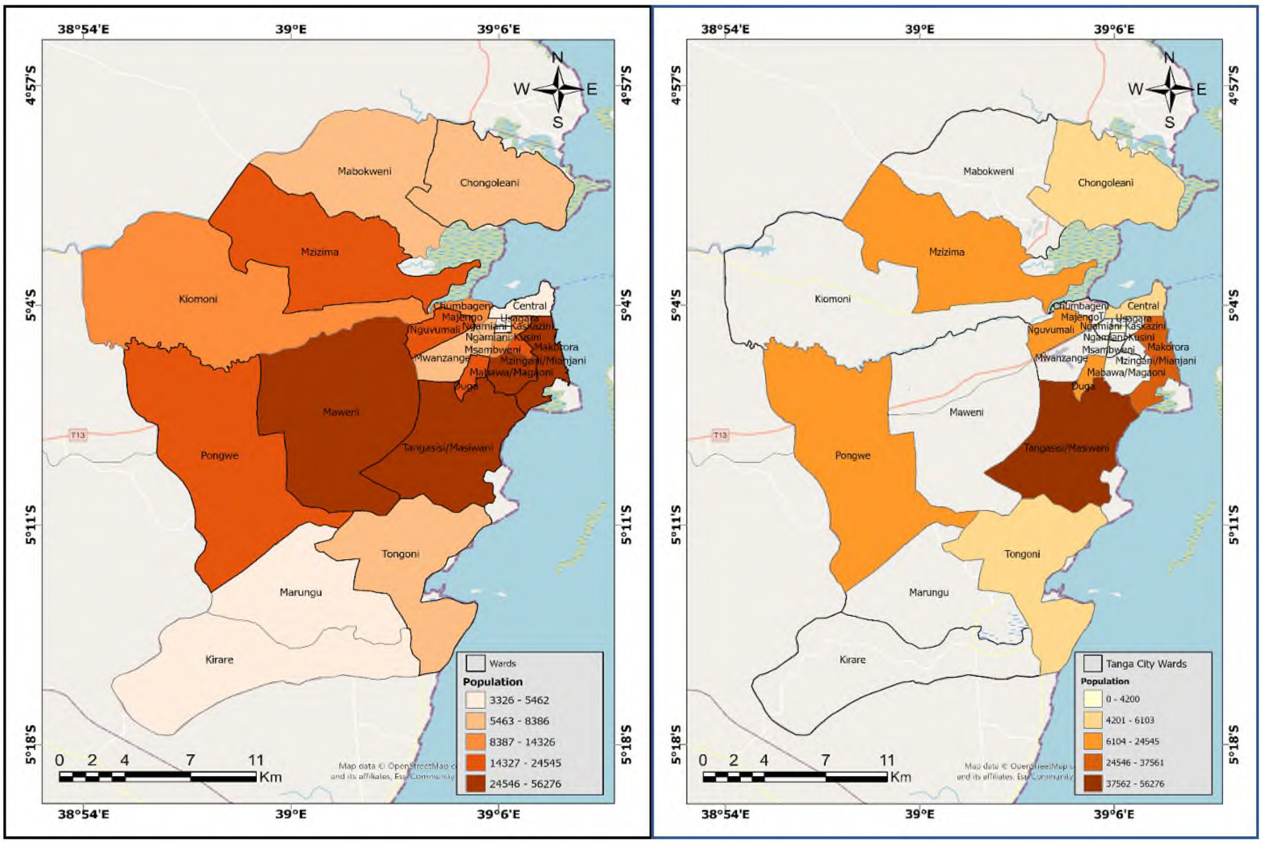

Figure 4.26: Population distribution in the project area

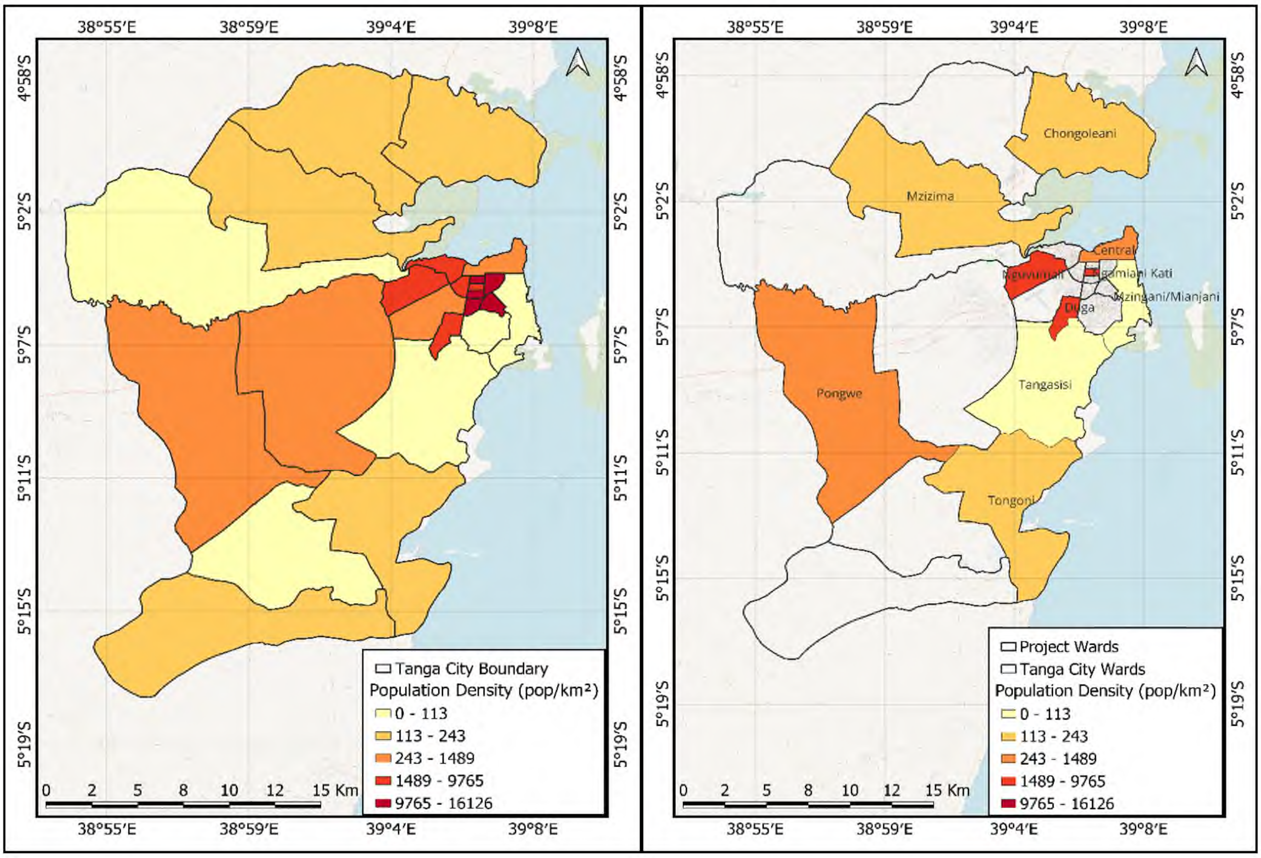

Figure 4.27: Population density in the project area

4.4.7 Heat Risk Index

The heat risk index is a measure that assesses the potential impact of heat-related conditions in specific geographical areas. In this context, several locations, including Chongoleani, Central, Mzingani, Duga, and Mzizima, exhibit a high heat index, ranging from 7.6 to 9.3. A high heat index suggests that these areas are more prone to elevated temperatures and increased heat stress, which could pose health and environmental challenges. On the other hand, Marungu, Pongwe, Tongoni, and Tangasisi are identified with the lowest values of the heat index, ranging from 5.5 to 7.6. These areas are comparatively less susceptible to extreme heat conditions, implying a lower risk of heat-related impacts. The lower heat index values in Pongwe, Tangasisi and Tongoni within the selected project wards. Figure 4.28 depicts the distribution Heat Risk Index values.

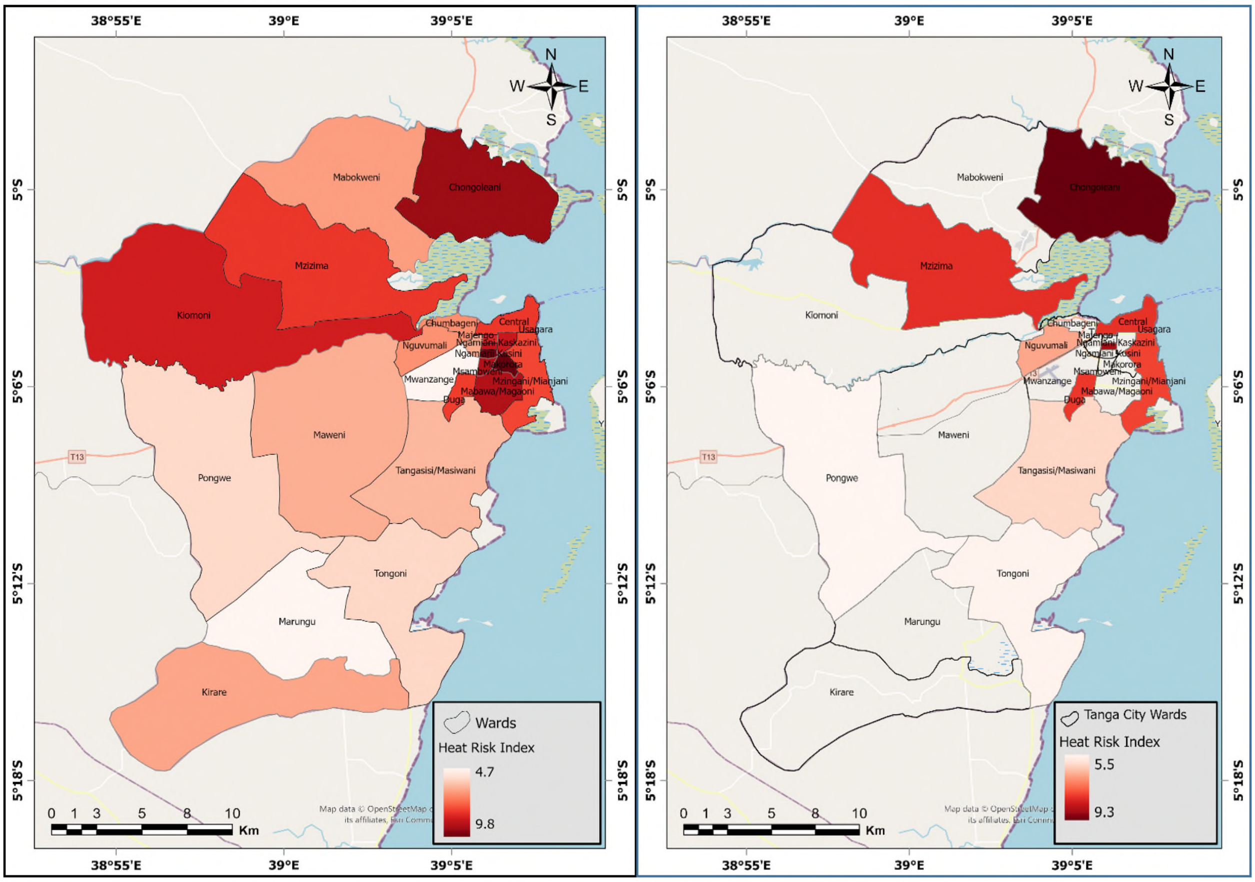

Figure 4.27: Heat Risk Index in the project area

CHAPTER FIVE

DISCUSSION

The discussion chapter provides a comprehensive analysis and interpretation of the results obtained from the study, aiming to derive meaningful insights, draw comparisons with previous studies, and highlight implications for urban planning and policy. This chapter is divided into two sub-sections: Comparison with Previous Studies and Implications for Urban Planning and Policy.

5.1 Comparison with Previous Studies

Our comparative analysis with previous studies unveils unique insights into the vulnerability and intricacies of urban areas. Aligning with broader trends in urban vulnerability, specific wards, notably Nguvumali and Central, emerge as critical infrastructure hotspots, reflecting established urban development patterns. However, our study introduces a novel dimension by revealing distinctive disparities in the distribution of schools, hospitals, and bus stops, adding granularity to our understanding of urban service accessibility.

Delving into climate-related factors, our study explores specific spatial variations, surpassing conventional analyses. The identification of Tongoni and Pongwe as areas with fewer bus stops enriches our understanding of public transportation accessibility, emphasizing nuanced perspectives often overlooked in generalized studies. This not only highlights the overarching vulnerability of urban areas but also brings to light localized intricacies that demand tailored interventions.

Furthermore, our exploration of disparities in Actual Evapotranspiration (AET), wind speed, Potential Evapotranspiration (PET), land cover, Normalized Difference Vegetation Index (NDVI), climate patterns, and humidity significantly contributes to the discourse on urban resilience. The revelation of microclimates within the study area, depicted through variations in land surface temperature and elevation, underscores the importance of localized climate adaptation strategies. Elevated AET values, particularly in wards like Chongoleani, suggest potentially stressed vegetation, influencing water demand and consumption. Disparities in wind speed across wards, such as Pongwe and Mzizima, emphasize the role of local topography in influencing atmospheric conditions and air quality. Analysis of PET values provides insights into maximum potential water demand, guiding water resource management strategies.

Moreover, distinctions in land cover and NDVI values, as observed in wards like Tongoni and Chongoleani, accentuate the need for context-specific green infrastructure initiatives. These findings not only contribute to understanding urban vulnerabilities but also refine strategies by highlighting the importance of localized variations. In this era of ongoing urbanization, recognizing the specific challenges faced by different wards becomes paramount in crafting effective climate resilience strategies. This discussion section serves as a bridge between our findings and the broader academic conversation, offering both confirmation of existing knowledge and novel insights that can inform future research, policy-making, and urban planning endeavours.

5.2 Implications for Urban Planning and Policy

The implications derived from the project underscore the paramount importance of informed urban planning and policy development, driven by a comprehensive understanding of the region's dynamics. Specific wards, notably Nguvumali and Duga, stand at the nexus of high vulnerability and limited access to essential services, demanding a strategic allocation of resources to fortify infrastructure resilience in these areas. Additionally, the identification of Tongoni and Pongwe with fewer bus stops signals the urgent need for improvements in public transportation access, especially in wards experiencing population growth.

The spatial analysis of climate-related factors, infrastructure, and administrative boundaries provides a nuanced understanding of the region's complexities. This understanding serves as a guiding beacon for policymakers, facilitating the formulation of targeted strategies for climate resilience. Disparities in land surface temperature, elevation, and vegetation cover accentuate the necessity for context-specific interventions. Proposed interventions could include the development of green infrastructure in areas with lower vegetation cover and bolstered disaster preparedness in wards susceptible to climate-related hazards.

In conclusion, this discussion chapter serves as a synthesis of the diverse results presented in earlier chapters. Through a meticulous comparison with previous studies, it establishes the distinctive climate and infrastructure landscape of the study area. The implications outlined offer actionable insights for urban planning and policy development, emphasizing the importance of tailored strategies to enhance climate resilience and promote sustainable development within the study area. The robust findings provide a foundation for addressing critical urban challenges and fostering a resilient, adaptive, and sustainable urban future.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The comprehensive analysis of Tanga City's environmental dynamics unveils the intricate interplay of climatic variables, land cover changes, elevation, soil characteristics, and geological features, offering a holistic understanding of the region's resilience to heat and responses to climate changes.

Tanga's climate, marked by temperature extremes, variable rainfall, and wind patterns, presents challenges and opportunities for agriculture, water resource management, and urban planning. The examination of Actual Evapotranspiration (AET) and Potential Evapotranspiration (PET) sheds light on water availability crucial for agricultural and ecosystem health, while variations in wind speed underscore the dynamic nature of the region's climate.

Land cover changes from 2015 to 2021 and 2022 vividly illustrate the impact of urbanization and human activities on the environment. The evaluation of Land Surface Temperature (LST) from 2002 to 2022 provides valuable insights into thermal dynamics, pinpointing areas prone to heat stress and potential Urban Heat Islands. Understanding LST variations informs decisions in urban planning, green space allocation, and climate resilience strategies. The examination of NDVI trends over the same period offers a lens into vegetation health and land cover changes, essential for biodiversity conservation and climate change adaptation in the project area.

The analysis of Heat Risk areas in Tanga city indicates that Chongoleani, Central, Mzingani, Duga, and Mzizima have higher heat risks. These areas are more prone to higher temperatures and increased heat stress, which could pose health and environmental challenges. On the other hand Pongwe, Tongoni, and Tangasisi have lower heat risks within the project wards. These areas are comparatively less susceptible to extreme heat conditions, implying a lower risk of heat-related impacts.

6.2 Recommendations

Based on the finding attained we recommend that sounding climate change mitigation and adaption plans should be formulated to support areas which have been identified to be at higher heat risks.

REFERENCE

Abatzoglou, J.T., Dobrowski, S.Z., Parks, S.A., Hegewisch, K.C. (2018). TerraClimate: Monthly Climate and Climatic Water Balance for Global Terrestrial Surfaces, University of Idaho. *Terraclimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958-2015*. Scientific Data 5:170191. doi:10.1038/sdata.2017.191.

Akhoondzadeh, M., & Saradjian, M. R. (2008). *Comparison of Land Surface Temperature Mapping Using MODIS and ASTER Images in Semi-Arid Area.* The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVII, Part B8. Beijing.

Arnfield AJ (2003) Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. Int J Climatol 23:1–26. https://doi.org/10.1002/joc.859

Bian, Y., Dai, H., Zhang, Q., Yang, L., Du, W. (2020). *Spatial Distribution of Potential Evapotranspiration Trends in the Inner Mongolia Autonomous Region (1971–2016).* Theor. Appl. Climatol. 2020, 140, 1161–1169. [Google Scholar] [CrossRef]

Chakraborty T, Sarangi C, Tripathi SN (2017) Understanding diurnality and inter-seasonality of a sub-tropical urban heat island. Boundary-Layer Meteorol 163:287–309. https://doi.org/10.1007/s10546-016-0223-0

Dodman, D, B Hayward, M Pelling, V Castan Broto, W Chow, E Chu, R Dawson, et al. 2022. "*Cities, Settlements and Key Infrastructure. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*," 907–1040. https://doi. org/10.1017/9781009325844.008.

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A., & Michaelsen, J. (2015). CHIRPS Pentad: Climate Hazards Group InfraRed Precipitation with Station Data (version 2.0 final). *The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes*. Scientific Data 2, 150066. doi:10.1038/sdata.2015.66.

Gebrechorkos, S. H., Hülsmann, S., & Bernhofer, C. (2019). Long-term trends in rainfall and temperature using high-resolution climate datasets in East Africa. Scientific Reports, 9, 11376,1-9

Han, X., Liu, W., Lin, W. (2015). *Spatiotemporal Analysis of Potential Evapotranspiration in the Changwu Tableland from 1957 to 2012*. Meteorol. App. 2015, 591, 586–591. [Google Scholar] [CrossRef]

Howard L (1833) The Climate of London: Deduced from Meteorological Observations Made in the Metropolis and at Various Places Around it. Harvey and Darton, J. and A. Arch, Longman, Hatchard, S. Highley and R. Hunter

Hu Y, Hou M, Jia G, et al (2019) *Comparison of surface and canopy urban heat islands within megacities of eastern China*. ISPRS J Photogramm Remote Sens 156:160–168. https://doi.org/10.1016/j.isprsjprs.2019.08.012

Huang, H., Han, Y., Cao, M., Song, J., Xiao, H., Cheng, W. (2015). *Spatiotemporal Characteristics of Evapotranspiration Paradox and Impact Factors in China in the Period of 1960–2013*. Adv. Meteorol. 2015, 2015, 519207.

International Federation of Red Cross and Red Crescent Societies. 2020. "*World Disasters Report 2020*." https://www.ifrc.org/document/world-disasters-report-2020.

Kalnay E, Cai M (2003) *Impact of urbanization and land-use change on climate*. Nature 425:102. https://doi.org/10.1038/nature01952

Lambin, E. F. (1997). *Modelling and monitoring land-cover change processes in tropical regions. Progress in Physical Geography*, 21(3), 375-393.

Liu, Q., Yan, C., Ju, H., Garré, S. (2018). *Impact of Climate Change on Potential Evapotranspiration under a Historical and Future Climate Scenario in the Huang-Huai-Hai Plain, China*. Theor. Appl. Climatol. 2018, 132, 387–401. [

Mahoo, H. F., Young, M. D., & Mzirai, O. B. (1999). *Rainfall Variability and its Implication for the Transferability of Experimental Results in the Semi-Arid Areas of Tanzania*. Tanzania J. Agric. Sc., Vol. 2, 127-140.

Mohajerani, Abbas, Jason Bakaric, and Tristan Jeffrey-Bailey. 2017. "*The Urban Heat Island Effect, Its Causes, and Mitigation, with Reference to the Thermal Properties of Asphalt Concrete*." Journal of Environmental Management 197 (July): 522–38. https://doi.org/10.1016/J.JENVMAN.2017.03.095.

Ngie A, Abutaleb K, Ahmed F, et al (2014) *Assessment of urban heat island using satellite remotely sensed imagery:* A review. South African Geogr J 96:198–214. https://doi.org/10.1080/03736245.2014.924864

Oke TR (1982) *The energetic basis of the urban heat island.* Q J R Meteorol Soc 108:1–24. https://doi.org/10.1002/qj.49710845502

Paavola, J. (2004). Climate change: *The ultimate grand challenge for global public policy?* International Review of Public Administration, 9(1), 53-66.

Rousel, J.W.; Haas, R.H.; Schell, J.A.; Deering, D.W. *Monitoring vegetation systems in the great plains with ERTS*. In Proceedings of the Third Earth Resources Technology Satellite—1 Symposium; NASA SP-351; NASA: Greenbelt, MD, USA, 1974; Volume 1, pp. 309–317.

Stewart, I. D. 2011. "*A Systematic Review and Scientific Critique of Methodology in Modern Urban Heat Island Literature."* International Journal of Climatology 31 (2): 200–217. https://doi.org/10.1002/ JOC.2141.

Tong, X., Yang, Y., & Xu, Y. (2012). *Spatiotemporal patterns of land use change and driving forces in China during the early 21st century*. Journal of Geographical Sciences, 22(4), 600-614.

Turner, B. L., Lambin, E. F., & Reenberg, A. (2007). *The emergence of land change science for global environmental change and sustainability*. Proceedings of the National Academy of Sciences, 104(52), 20666-20671.

United Nations Department of Economic and Social Affairs. 2019. "*World Urbanization Prospects: The 2018 Revision*." https://population.un.org/wup/publications/Files/WUP2018-Report.pdf.

Wang, Z., Xie, P., Lai, C., Chen, X., Wu, X., Zeng, Z., Li, J. (2017). *Spatiotemporal Variability of Reference Evapotranspiration and Contributing Climatic Factors in China during 1961–2013*. J. Hydrol. 2017, 544, 97–108. [Google Scholar] [CrossRef]

Wilson, R.C.L. (2000). *Weather and climate*: A guide to their phenomena (5th ed.). Oxford: Oxford University Press.

Zanaga, D., Van De Kerchove, R., De Keersmaecker, W., Souverijns, N., Brockmann, C., Quast, R., Wevers, J., Grosu, A., Paccini, A., Vergnaud, S., Cartus, O., Santoro, M., Fritz, S., Georgieva, I., Lesiv, M., Carter, S., Herold, M., Li, Linlin, Tsendbazar, N.E., Ramoino, F., Arino, O. (2021). *ESA WorldCover 10 m 2020 v100*. doi:10.5281/zenodo.5571936.

Zhang, M., Wu, J., Chen, J., & Huang, J. (2011). *Land use change and its ecological effect in a rapidly urbanizing area in the Yangtze River Delta*. Environmental Monitoring and Assessment, 177(1-4), 617-625.

Zhao, Y., Zou, X., Cao, L., Yao, Y., Fu, G. (2018). Spatiotemporal Variations of Potential Evapotranspiration and Aridity Index in Relation to Influencing Factors over Southwest China during 1960–2013. Theor. Appl. Climatol. 2018, 133, 711–726. [Google Scholar] [CrossRef]

Zhou D, Zhao S, Zhang L, et al (2015) *The footprint of urban heat island effect in China*. Sci Rep 5:1–11. https://doi.org/10.1038/srep11160

Zongxing, L., Qi, F., Wei, L., Tingting, W., Yan, G., Yamin, W., Aifang, C., Jianguo, L., Li, L. (2014). *Spatial and Temporal Trend of Potential Evapotranspiration and Related Driving Forces in Southwestern China, during 1961–2009*. Quat. Int. 2014, 336, 127–144. [Google Scholar] [CrossRef]