PLANNING IMPLICATIONS OF URBAN HEAT ISLAND EFFECT IN MOMBASA

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DECLARATION

This research project is my original work and it has never been presented nor has it been submitted for examination for the award of a degree in any university.

August 25, 2022

Signed…………………………………….…...Date…………………………………...

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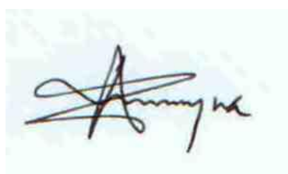
This research proposal has been submitted for examination with the approval of the candidate's university supervisors.



25th August 2022

Signed………………………………………Date…………………………………...

Supervisor: Dr. Munyua Mwaura

2022/08/25

Signed………………………………………Date…………………………………...

Supervisor: Dr. Philip Olale

DEDICATION

‘**We are nowhere near where we need to be at’**

- Barack H. Obama, 44th President of the United States of America

-

At the 2021 United Nations Climate Change Conference (COP26) hosted by the United Kingdom at the SEC Centre in Glasgow, Scotland

‘To cooling Mombasa and other tropical coastal cities of the sub-Saharan Africa’

- Mark Mbatha Mutua, Faculty of Built Environment and Design

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LIST OF ABBREVIATIONS

AUHIs	Atmospheric Urban Heat Islands
BT	Brightness Temperature
CAPA	Climate Adaptation Planning Analytics
CFCs	Chlorofluorocarbons
FbF	Forecast Based Financing
EAP	Emergency Action Plans
EMCA	Environment Management and Coordination (Amendment) Act
EM-DAT	Emergency Events Database
GHGs	Greenhouse Gas Emissions

GIS	Geographical Information Systems
GSI	Green Space Infrastructure
HFCs	Hydrofluorocarbons
HVIs	Heat Vulnerability Indexes
ICPAC	International Competition Policy Advisory Committee
ICZM	Integrated Coastal Zone Management
IFRC	International Federation of Red Cross and Red Crescent Societies
IGAD	Intergovernmental Authority on Development
IPCC	Intergovernmental Panel on Climate Change
ISUDP	Integrated Strategic Urban Development Plan
KAP	Knowledge, Attitude and Practice
LSTs	Land Surface Temperatures
MODIS	Moderate Resolution Imaging Spectroradiometer [in Terra and Aqua satellites]
NASA	National Aeronautics and Space
NASA ARSET	National Aeronautics and Space Applied Remote Sensing Training
NDBI	Normalized Difference Built-Up Index
NDVI	Normalized Difference Vegetation Index
NEMA	National Environmental Management Authority
NIHHIS	National Integrated Heat Health Information System
NOOA	National Oceanic and Atmospheric Administration
OLI	Operational Land Imagery
SDGs	Sustainable Development Goals
SUHIs	Surface Urban Heat Islands
TERI	The Energy and Resources Institute
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TOA	Top of Atmosphere
UCCRN	Urban Climate Change Research Network
UHIE	Urban Heat Island Effect
UHIs	Urban Heat Island(s)
USA	United States of America
U.S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey

ABSTRACT

Empirically, the Urban Heat Island Effect (UHIE) is a resultant of the reverberation consequences of climate change and urbanization within the built environment where hotter temperatures are acutely experienced in cities than their surrounding areas. Sadly, little is known to influence and prioritize the planning for cooler coastal cities of the tropical sub-Saharan Africa as they rapidly expand in both population size and built-up landscapes whilst simultaneously decline in green vegetation. From a spatial and temporal perspective of the sea-island of Mvita in the coastal city of Mombasa, the primary aim of the study was to empirically examine the planning implications of urban heat island effect. A subsidiary aim of the study was to propose planning interventions to enhance the mitigation of urban heat island effect in Mombasa. The study heavily depended on literature review on Earth Science; hot season diurnal satellite remote sensing for 1992, 2002 and 2022 and Geographic Information Systems (GIS) methodological approaches and over a 30-year (1990-2021) weather and climatology assessment. It utilized the proportionate stratified random sampling and 30-size rule of thumb to engage one-on-one with 68 sampled household participants and 30 sampled users of open public spaces. A visual survey and in-person interviews with 6 key informants — an urban planner, architect, public health and medical practitioner, urban climate change expert, environmental officer and a national environmental authority representative — were done. Results indicated that Mvita is a concrete jungle with a high relative humidity; more impervious surfaces, larger thermal capacity materials; less vegetation coverage; increasing vehicular, industrial, residential and commercial waste heat; moderate urban geometry and low air-conditioning systems in exposing UHIE. It is now a hotbed of hazardous land surface temperatures more than its ambient air temperatures at 2m due to its changing shift in socio-cultural, economic and political controlling interests over centuries. Economic impacts and environmental impacts of UHIE possessed a high sensitivity rating while the social impacts of urban heat islands institutional impacts of UHIE had a moderate sensitivity rating. UHIE has been broached broadly in affiliated policy guidelines, laws and regulations and institutions for mitigation in Mombasa and Kenya. Limited empirical evidences and lack of standardised health data and information systems with the urban thermal environment remains a cross-cutting challenge. Top-five prioritized heat mitigation and heat management solutions enveloped retrofitting of green walls, façades and building roofs; a green aeration and ventilation corridors programme; an urban micro-forestry programme for public parks, open spaces, residences and vacant plots; a suitable urban geometry for better wind flow and developing an urban heat resilience policy handbook. Recommended actions amounted to the establishment of an urban climate laboratory with cross-disciplinary expertise; fair funding; linking resilience theory with collaborative planning theory; virtual modelling via urban digital twin; better heat early warning and monitoring systems; heat action and heat response plans accounting provision of cooling centers; community urban heat island mapping campaigns and publication of the Kenya Spatial Biodiversity Atlas. When replicated, they can diversly serve for broader and positive social, economic, environmental and institutional ramifications — for theory, literature, methodology, policy, design, practice, monitoring, public awareness and dissemination and conservation of marine coastal ecosystems — on mitigating UHIE.

CHAPTER ONE:

INTRODUCTION

1.1 Background to the Study

Urban Heat Island Effect (UHIE) is globally a result of the dual challenges of climate change and urbanization which results to significant higher temperatures in city centers than their surrounding suburban areas and rural hinterland regions (Corneille, 2020; Li, Stringer, Chapman, & Dallimer, 2021). The description presented within the "*World Disasters Report 2020"* by the world's largest humanitarian network in the realm of disasters, risks and vulnerability, the IFRC (2020) identifies UHIE to urban areas being hotter than their proximate rural areas. These differences in temperature are caused by increasing impermeable surfaces and associated low-albedo infrastructure; limited green vegetation cover and water features; increasing anthropogenic heat and GHGs; alteration of urban morphology; calm and clear weather and climatic conditions as well as natural geographical landmarks as obstacles in towns and cities (Institut de la statistique du Québec, 2009; TERI, 2017; Foster, 2020; McCartney, et al., 2020; Climate Central, 2021). Following this account, UHIE can be investigated through observing one of the two closely coupled temperatures: surface UHIs and atmospheric UHIs (U.S. EPA, 2008; Phelan, et al., 2015; TERI, 2017; McCartney, et al., 2020).

UHIE is increasing of concern as a resultant of disastrous climate change that rises average global temperatures and increases occurrences of extreme heat days (Corneille, 2020). Largely human-induced, this climbing global mean temperatures of land and ocean surface — which preferably is to be kept below 1.5^0C pre-industrial levels — is referred to as global warming (IPCC, 2021). On the other hand, this heightening of heat events during summer/hot days and seasons — when the urban temperatures are above 37^0C — is coined as heat waves (IFRC, 2020). Coupled together, the impacts of global warming and heat waves contributes to the formation of UHIs and worsens to the overall UHI effect on health, comfort and well-being of human lives and other biodiversities (IFRC, 2020; Climate Central, 2021). The gravity of this heat stress has been alarming as the recent data monitoring in 2021 distinguished July as the world's hottest month ever, registering a global [land and ocean-surface] temperature of 0.93^0 C above the 20^{th} century average of 15.8^0C (NOOA, 2021). Consequently, the number of recorded deaths has been alarming across the globe, following 72,250 people in Europe in one deadly summer of 2003 and a global total of 70,409 people within the last decade from the 38 heatwaves recorded (IFRC, 2020). Following the case of Africa, the continent registered as the seventh-warmest in comparative ranking with Asian, European, North American, South American as well as Oceania territories in July (NOOA, 2021). The heat exposure cases of Cairo, Egypt and Lagos, Nigeria are very critical with more than half the hazard coming from the warming climate (The Energy Mix, 2021). On human health impacts, the severity of this situation stems from limited mapping and quantifying of UHIE due to the poor long-term heat data monitoring during the summer/hot day and seasons in the tropical Sub-Saharan Africa (Harrington & Otoo, 2020). The world's most authoritatively body in the domain of climate change and climate resilience, the IPCC (2014; 2021) is under high confidence that both the intensity and frequency of heatwaves will continue to increase with global warming caused indirectly or directly by human activities, in addition to natural climate variability and worsen the UHIE. Hence, there is an urgent need to develop mitigation strategies for the UHIE.

UHIE is also growing attention due to the reverberating effects of urbanization that inevitably lead to a high anthropogenic modification of the natural landscapes (Corneille, 2020; IFRC, 2020; Li, Stringer, Chapman, & Dallimer, 2021). Empirically, urbanization is transforming the world at a faster rate (UN-Habitat, 2016; Saghir & Santoro, 2018). Recent global statistics from the United Nations shows that more than half of the world's population is now living in urban areas from 751 million in 1950. UN DESA's (2018) publication, "*Revision of the World Urbanization Prospects"*, acknowledges that 55 per cent [4.2 billion] of the planet resides in urban areas. This is a recorded increment of about 1 per cent [1.2 billion] when referenced to the UN-Habitat's (2016) world cities report on "*Urbanization and Development: Emerging Future"*. The proportion of urban population is expected to rise up to 60 per cent (World Bank, 2016) by 2030 and about 68 per cent (UN DESA, 2019) by 2050, given that more people are moving to towns and cities in search for better economic opportunities annually. Recently, IFRC (2020) notes that UHIE is most acutely felt in cities that possess densely built-up neighborhoods with little or no green space. In the tropical Sub-Saharan Africa, the magnitude of this hotness is likely to occur and is seen largely because of understudied connections of urban heat islands to ecosystem services and greenery as the urban areas are rapidly urbanizing (Toit, et al., 2018).

In getting to know the magnitude of UHIE, it is important to reflect on the effect of solar radiation on human body. It is argued that since the human body temperature is approximately 37^0C (Institut de la statistique du Québec, 2009) — very high temperatures from heat-related weather and climate events and urbanization effects, proven unideal, are typically quantified above 37^0C (IFRC, 2020). Towards comfort on the urban thermal environment, Institut de la statistique du Québec (2009) is opinionated that it is possible to specify an acceptable temperature range for a high percentage of people. While acknowledging inputs from Fanger (1982) and Nikolopoulou (2004), the institute gives the acceptable thermal range between 20°C and 27°C bearing an optimal humidity rate of 35 to 60 per cent. On the other hand, differences in temperatures for urban areas and cities are can be up to 12°C higher than surrounding rural hinterland regions (Voogt, 2002; Institut de la statistique du Québec, 2009). Contemporary studies have examined peak magnitudes of heat islands as large as 6.1^0C in cities like Paris, France with some large metropolises experiencing alarming intensities up to 12^0C like Tokyo, Japan when compared to their adjacent rural regions (Phelan, et al., 2015). The UHI effect of cities often range from 5 to 9^0C warmer than their rural areas (C40 Cities Climate Leadership Group, 2019). Left unchecked, the magnitude can create negative rippling implications that are complex, in spite warming winter/cold nights and seasons seen as a notable positive impact (Phelan, et al., 2015).

Adverse impacts of UHIE can be categorized as social, economic, environmental and institutional impacts. Social effects oscillate on harms of heat stress to human comfort, health, productivity and disruption of human systems while economic effects often associate increased energy consumption (Institut de la statistique du Québec, 2009; Taru Leading Edge, 2021). On the other hand, the environmental effects revolve on elevated emissions of air pollutants and GHGs and degradation of infrastructural services like poor water supply and physical damage of built-up systems (Institut de la statistique du Québec, 2009; Taru Leading Edge, 2021). The institutional impacts of UHIE following effects of climate change and urbanization, for instance Kenya, are represented as laxity and improper translations of legislations and ratified frameworks, limited awareness and capacity building and insufficient funding for the urban thermal environment (Republic of Kenya, 2020). Going forward, the UHIE has to be addressed, informed and guided by a great deal interest from the scientists, climate researchers, health experts, architects, construction experts and designers, sustainability managers, environmentalists, urban planners as well as policy makers to aim to fill interventions towards heat resilience and sustainable cities. In this manner, using Mvita sea-island, Mombasa, Kenya as case study and both community involvement and remote sensing and GIS and as vital methodological approaches — the primary aim of this study is to examine the planning implications of urban heat island effect in coastal cities. A subsidiary aim of the study is to propose planning interventions that can enhance the mitigation of urban heat island effect in Mombasa.

1.2 Statement of the Research Problem

Following the presence of UHIE, as a result of urban climate change and urbanization, the planning for cooler coastal cities is depicted by different ideal scenarios that influences heat-resilience and sustainable development. Tropical coastal cities need to have a higher albedo for more reflectivity and emissivity of heat from urban-related impervious and infrastructural surfaces to bring cooling effects (Phelan, et al., 2015; Institut de la statistique du Québec, 2009; TERI, 2017; McCartney, et al., 2020). Second is that they require a greater share and distribution of green space infrastructure (GSI) that inculcates more shading and evapotranspiration (U.S. EPA, 2008; 2021; McCartney, et al., 2020; McCartney, et al., 2020; European Environment Agency, 2021). Third is on less release of anthropogenic heat and pollutants by the urban population, animals, vehicles, air-conditioners and energy-intensive and industrial buildings (Phelan, et al., 2015; TERI, 2017; McCartney, et al., 2020). Cooler coastal cities need also to be properly structured, spaced and zoned to present a good urban geometry/morphology that allows and increases wind aeration and ventilation contributing to cooling effects (Institut de la statistique du Québec, 2009; TERI, 2017; McCartney, et al., 2020). Further requisites of cooler coastal cities are on optimal relative humidity, decreased absorption of solar radiation, limited surface-runoff; stronger winds, more cloud covers and water bodies as well as constant supply of energy and water to moderate higher temperatures and suppress formations of UHIs (McCartney, et al., 2020).

Unfortunately, UHIs have been overlooked in the coastal cities of the tropical Sub-Saharan African countries. Harrigton and Otoo (2020) diagnoses that this situation is due to the poor long-term heat data monitoring which has even left them vulnerable to heat waves. Toit et al (2018) impressions this phenomenon to understudied connections of UHIE with greenery and ecosystem services. On further account, this occurrence is credited to the change in land use and surface cover which is a main factor of urbanization development influencing a city's microclimate (Ongoma, Muthama, & Gitau, 2013). Such aggregated reverberation effects of urbanization on the natural landscapes leaves out to wonder what can be done about it and what is the scale of this impact on temperature that is acutely higher in urban areas than outlying areas (Meriman, 2019). Sadly, little is known to influence and prioritize the planning for cooler coastal cities especially of the tropical Sub-Saharan Africa. Though not a coastal city, Kenya's capital, Nairobi, previously known as the *Green City in the Sun* for its lush environment, as put by Ongoma and Mwangi (2021), has lost 22 per cent of the city's green spaces cover period between 1988 and 2016 based on a recent study by Langsdale (2017). Such juxtaposition has been made to show the gravity of the UHIE in a more subtropical highland climate, herein, Mombasa. Being the second largest city and the primary seaport of Kenya (County Government of Mombasa & Ministry of Land, Housing and Urban Development, 2015), Mombasa County is no exceptional to this UHI phenomenon. In particular, the sea-island of Mvita is experiencing vast reverberation effects of urbanization transforming its natural landscapes into more impervious surfaces and less vegetation that potentially influences the creation of hazardous heat islands.

One study predicts more frequent and longer lasting heatwaves to be expected in Mombasa, Kenya in face of its alterations of the urban wildscapes and green spaces as a result of parallel pressures of land use developmental change by human activities and climate change (Kithia & Lyth, 2011). The severity of this situation is exacerbated by its hot tropical climatic condition that averages with about 65 per cent humidity and 32^{0}C heat temperature (Kithia & Lyth, 2011). This is likely to induce outdoor thermal discomfort in the urban environment. It is most possibly to be felt in Mvita-Sub County. This is because it houses most of the urbanization development characterized by more growth of the urban population, migration, increased socio-economic activities and varied urban morphology and land use developments per unit area than its proximate Sub-Counties of Jomvu, Kisauni, Changamwe and Nyali (County Government of Mombasa & Ministry of Land, Housing and Urban Development, 2015).

The IPCC (2014; 2021; 2022) associates a very high confidence to human-induced activities as the main driver to local warming and that further with urbanization and more frequent hot extremes will increase the severity of heatwaves. Thus, to adequately address the UHIE; social, economic, environmental and institutional resilience needs to be inculcated in the natural and the built-up ecosystems when planning for cooler coastal cities in a spatio-temporal sense towards heat resilience and sustainable development. Using the sea-island of Mvita in Mombasa, Kenya as case study and both community involvement and remote sensing and GIS and as vital methodological approaches — the primary aim of this study is to thus examine the planning implications of urban heat island effect in coastal cities. A subsidiary aim of the research study is to propose planning interventions to enhance the mitigation of urban heat island effect in Mombasa.

1.3 Research Questions

This study seeks for answers to the following key research questions;

a) What is the current profile of surface urban heat islands in Mombasa?
b) What are the causes of urban heat islands in Mombasa?
a) What are the social, economic, environmental and institutional effects of urban heat islands in Mombasa?
c) What planning interventions can be proposed from the findings in enhancing the mitigation of urban heat island effect in Mombasa?

1.4 Research Objectives

Specific research objectives of the study are as follows;

a) To map the surface urban heat islands in Mombasa.
b) To examine the causes of urban heat islands in Mombasa.
c) To assess the social, economic, environmental and institutional effects of urban heat islands in Mombasa.
d) To synthesize the findings and to analyze the implications towards formulating planning interventions for mitigating the urban heat island effect in Mombasa.

1.5 Research Hypothesis

The null hypothesis (H_o) was tested and rejected following the completion of the study, the latter is given by the alternative hypothesis (H_a). Parameters constituted the built-up area (Normalized Difference Built-up Index (NDBI), urban vegetation coverage (Normalized Difference Vegetation Index/NDVI and UHIE (Land Surface Temperature/Surface Urban Heat Islands).

$H_{o\ =}$ There is a significant relationship between urban built-up area and vegetation cover with the urban heat island effect in Mombasa.

$H_{a\ =}$ There is a significant relationship between urban built-up area and vegetation cover with the urban heat island effect in Mombasa.

1.6 Justification and Significance of the Study

The rationale of this study is derived from the need to add knowledge and fill policy gap on UHIE and its planning implications in the rapidly urbanizing coastal cities of which are often overlooked in the coastal cities of the tropical Sub-Saharan Africa. It seeks to enhance the mitigation of UHIE which has been lacking influence and prioritization in many of their urban policy domains earlier designed and planned by the colonial governments and independent city governments in realizing of heat-resilient and sustainable city systems. The significance of the study lies within proposing the planning interventions for enhancing the mitigation of urban heat island effect in Mombasa. In essence, broader planning implications proposed in the context of social, economic, environmental and institutional resilience needs to be inculcated in natural as well as built-up ecosystems when planning for cooler coastal cities of the tropical Sub-Saharan Africa. As such, it attempts to touch on climate change issues such as increased atmospheric carbon dioxide, increased temperature and storminess, sea-level rise, ocean currents, altered precipitation regime and mangrove drowning in the coastal ecosystem.

CHAPTER TWO:

LITERATURE REVIEW

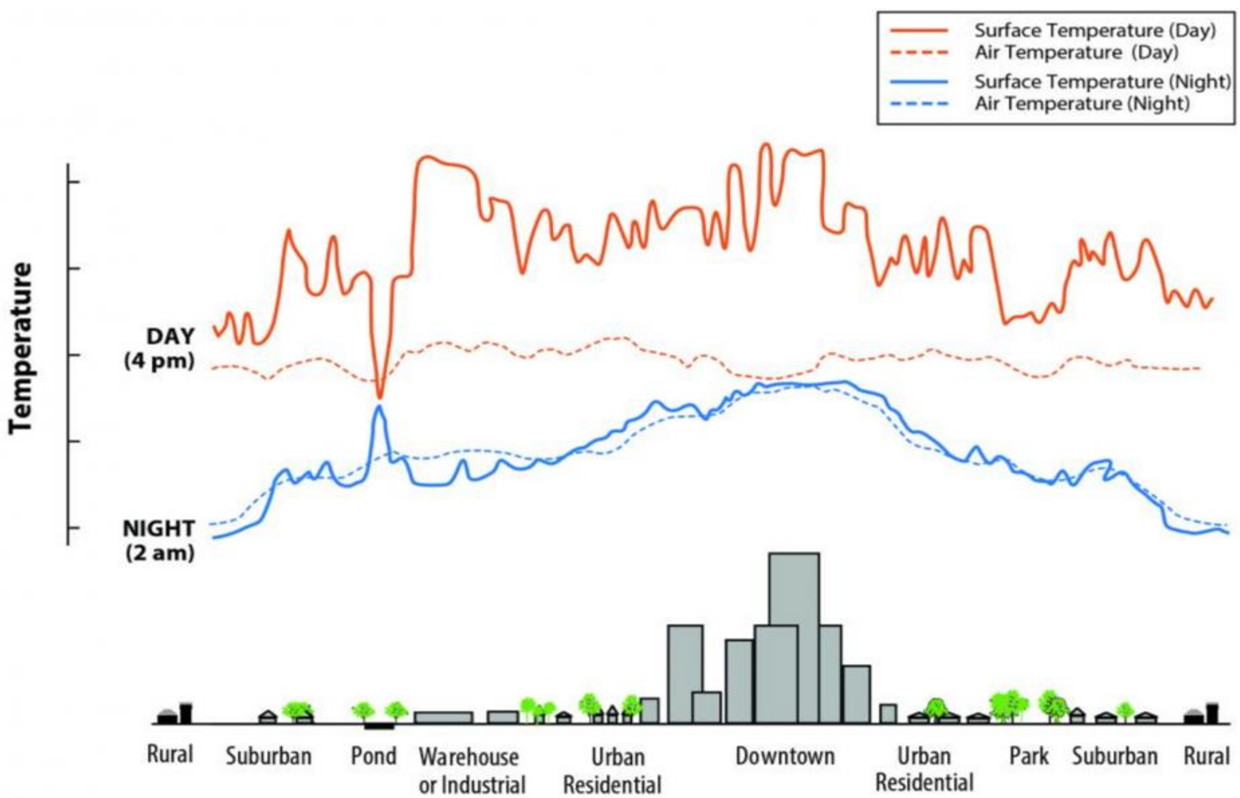
2.1 Definitional Aspects to Urban Heat Island Effect

Plainly and simply, the Urban Heat Island Effect (UHIE) is a phenomenon where urban areas are considered to experience warmer/hotter temperatures than the surrounding areas due to the dual challenges of urbanization and climate change (UCCRN, 2018; Corneille, 2020; IFRC, 2020; Li, Stringer, Chapman, & Dallimer, 2021). These observed hot zones — localized pockets/domes/ areas of higher temperatures — between urban areas and their outlying suburban and rural settings are termed as Urban Heat Islands (UHIs), with the impacts felt most during summers or hot seasons (Rohinton, 2004; Institut de la statistique du Québec, 2009; McCartney, et al., 2020; Climate Central, 2021). It is however put across by Lenzholzer (2015) that the presence of UHIs does not always holistically apply to an entire city, though they could be spatially diverse coining the term archipelago of heat islands or simply heat archipelago.

Considering that an ideal urban thermal environment ranges between 20°C and 27°C and with an average optimal humidity rate of 35 to 60 per cent (Fanger, 1982; Nikolopoulou, 2004; Institut de la statistique du Québec, 2009), heat islands in large cities can have peak magnitudes as high as 12^0C for instance, Tokyo coastal metropolis (Voogt, 2002; Phelan, et al., 2015). Nonetheless, great impacts can be adversely felt in cities experiencing heat island intensities of 5^0C to 9^0C (C40 Cities Climate Leadership Group, 2019), on the other hand as low as 1^0C to 3^0C within cities of about 1 million people (TERI, 2017). These temperatures can be found during any time of the day and night in any season, although felt the greatest at night and observed mainly in the hot seasons or summers (McCartney, et al., 2020; Climate Central, 2021). They vary widely within cities based on spatial distribution of water, soil, vegetation and hard/impervious surface in relation to various land uses (McCartney, et al., 2020; Climate Central, 2021). Figure 2.1 shows this as a graphical impression of land uses to the diurnal surface and air temperatures of the UHI phenomenon.

The definitional aspects to UHIE have been widely documented and accepted within the academic and practical circles in the 19^{th} century stemming from the London's urban thermal environment case (Howard, 1883; Oke, 1982), with only a few developments in quantifying heat islands. The notable is the inclusion of both observed air and surface temperatures to the understanding of the UHI phenomenon. As attested by different scholars and practitioners (Institut de la statistique du Québec, 2009; Phelan, et al., 2015; TERI, 2017; McCartney, et al., 2020; Climate Central, 2021), this additional development gave a more complete picture of a city's heat island, as more people continue to move in cities annually. Further into this account, while examining the coastal city of Nanjing in China, Zhang, Dong, Cheng, & Li (2021) admit that with the development of satellite remote sensing and GIS capabilities to capture the surface temperatures have curbed shortcoming of solely relying on traditional metrological stations to acquire the air temperatures. The surface radiation temperatures retrieved from satellite remote sensing and GIS are relied more in making sense and monitoring of UHIs because of their temporal advantages, high spatial resolutions and spatial continuities (McCartney, et al., 2020; Zhang, Dong, Cheng, & Li, 2021). The retrieval of land surface temperatures (LST) by using satellite remote sensing and GIS dates to interrogation of the urban thermal environment of the coastal cities in the central Pacific Ocean to ultimately to define and express UHIs (Rao, 1972).

Figure 2.1 Urban Heat Island Effect in Relation to Diurnal Temperature and Land Uses



Source: (McCartney, et al., 2020)

2.2 Types of Urban Heat Islands

2.2.1 Atmospheric Urban Heat Islands

Atmospheric UHIs — also referred to as meteorological UHIs — observes the air temperatures in the canopy layer or boundary layer (U.S. EPA, 2008; Institut de la statistique du Québec, 2009;

Phelan, et al., 2015; TERI, 2017; McCartney, et al., 2020; Climate Central, 2021). On their spatial development, atmospheric UHIs can be distinguished into two: canopy layer heat islands (CLHIs) and boundary layer heat islands (BLHIs) in urban ecosystems (Oke, 1982; Institut de la statistique du Québec, 2009; TERI, 2017; McCartney, et al., 2020). The CLHI is the layer of observed air temperature difference from ground surfaces to treetops or rooftops where most human activities occur while BLHI is the layer of observed air temperature difference extending above the treetops or rooftops of buildings where the urban landscapes no longer influence atmosphere (Oke, 1982; Institut de la statistique du Québec, 2009; TERI, 2017; McCartney, et al., 2020). The atmospheric UHIs occur due to differences in air temperatures between the urban areas and rural areas (TERI, 2017).

On their temporal development, atmospheric UHIs are small or non-existent during the day with a peak intensity variation of 1 to 3^0C and are most intensely observed in the winter, predawn or night bearing a peak intensity variation of 7 to 12^0C (TERI, 2017). They are normally measured by in-situ sensors/fixed meteorological stations and mobile transverses to identify CLHIs as well as by tall towers, radiosondes and aircraft to assess BLHIs (TERI, 2017; McCartney, et al., 2020). Fixed weather station monitors are usually located on shaded level ground often away from concrete and approximately 4 to 6 feet from the surface or rooftop ground (Climate Central, 2021). Within the academic and practical circles, the CLHIs are commonly observed and used as opposed to the BLHIs in discussions and mitigation actions as they are indirectly affected by the surface UHIs following slow release of heat emissivity or shading effect of heat from impermeable surfaces of built-up environment at the end of day (TERI, 2017; McCartney, et al., 2020). Hence, the CLHIs are weaker during the morning and more prominent in the evening than the BLHIs (McCartney, et al., 2020).

2.2.2 Surface Urban Heat Islands

Surface UHIs observes the radiated surface temperatures between the impervious surfaces of the urban landscapes and natural landscapes: urban skin temperatures (U.S. EPA, 2008; Institut de la statistique du Québec, 2009; Phelan, et al., 2015; TERI, 2017; McCartney, et al., 2020; Climate Central, 2021). On their spatial development, surface UHIs forms when sun’s heat — incoming shortwave solar radiation — is absorbed by exposed infrastructural surfaces such as rooftops and pavements which is then emitted back to atmosphere to be captured by satellite sensors (Institut de la statistique du Québec, 2009; TERI, 2017; McCartney, et al., 2020; Climate Central, 2021). On their temporal development, surface UHIs are often present at all time during the day and night bearing peak intensity variations of 10 to 15^{0}C and 5 to 10^{0}C correspondingly. They are strongest during the day and in summer/hot seasons with either clear skies to allow more solar radiation or absence of winds to withhold the atmospheric mixing (TERI, 2017; Climate Central, 2021).

Surface UHIs are measured through satellite remote sensing in the thermal infrared region of the electromagnetic spectrum to retrieve the land surface temperatures of the impervious surfaces and natural landscapes as the urban skins (Institut de la statistique du Québec, 2009; TERI, 2017; McCartney, et al., 2020). These urban skins are shown to be exposed to temperatures that are much hotter than the air (Climate Central, 2021). Figure 2.1 impressions this where surface temperatures are notably higher than air temperatures during the day, although appear lower or equivalent to air temperatures during the night. For this reason, coupled by limitation of monitoring weather stations that measures the atmospheric UHIs, surface UHIs are considered more useful and detailed spatial data for indicating UHIE (McCartney, et al., 2020).

2.2.3 Integration of Atmospheric and Surface Urban Heat Islands

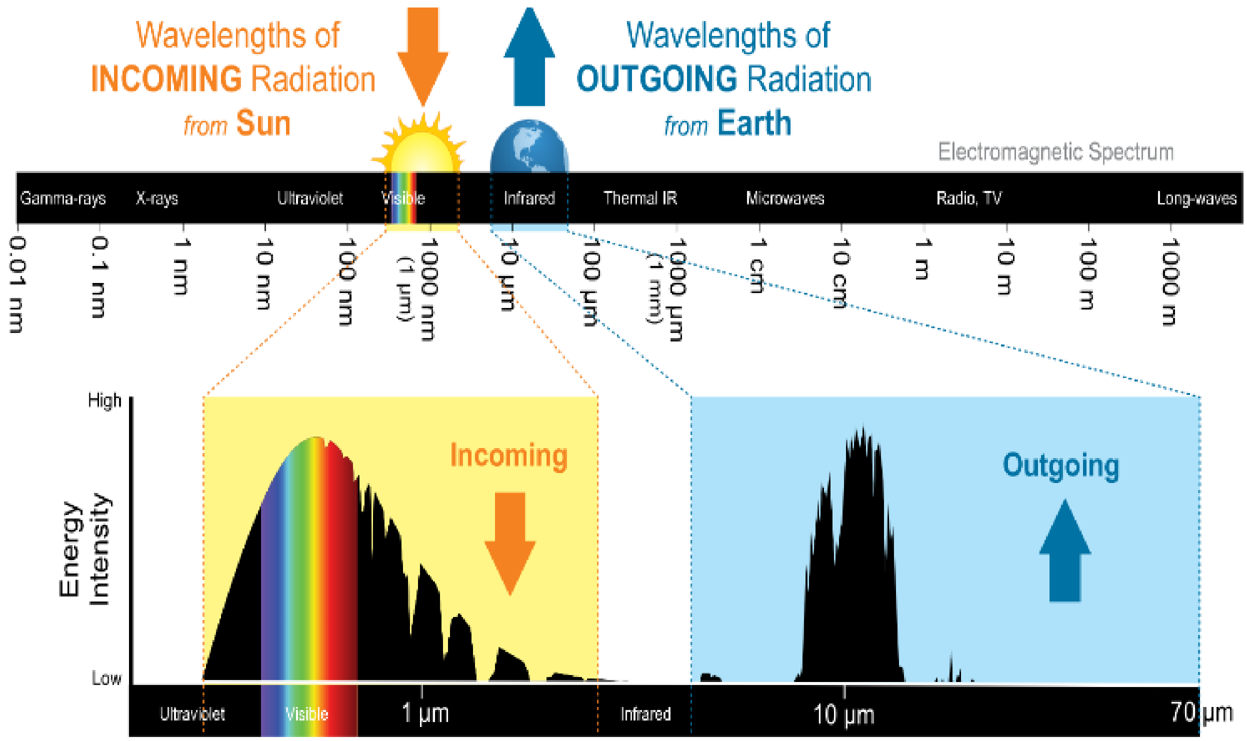
Recent studies have demonstrated the practicability of mainstreaming air temperature data from monitoring in-situ stations or mobile transverses and the surface temperature data from satellites can be used to generate a more complete composite of a city's heat island (McCartney, et al., 2020; Climate Central, 2021). Integration of atmospheric and surface UHIs has been necessitated by two reasons: understanding of the study evolution of UHIE as well as the awareness of Earth science. Historically, as pin-pointed earlier on the definitional aspect to UHIE, contemporary research and practice stemmed from the initial study of the UHIs at the city of London, England (Howard, 1883; Oke, 1982). Other studies in earlier cities are Paris, France by È. Renou in 1868 and by L. Besson in 1931 and Tokyo, Japan by K. Sasakura in 1931. In addition, I. Kayane in 1960; Nairobi, Kenya by K. Nakamura in 1966 and Johannesburg, South Africa by Y. Goldreich in the 1970 (McCartney, et al., 2020). Such researches oriented to just observing the temperature differences between cities and their surrounding areas. This approach was by use of traditional meteorological methods such as in-situ stations to acquire data on air temperatures as well as humidity (McCartney, et al., 2020; Zhang, Dong, Cheng, & Li, 2021).

Recent study motivations have evolved to the current assessment of root causes and temperature deviations within and across cities through the use of the Earth science by remote sensing and GIS mapping capabilities to acquire land surface temperatures (McCartney, et al., 2020; Zhang, Dong, Cheng, & Li, 2021). The initial landmark in research was carried by Rao (1972) whom interrogated the urban thermal environment of the coastal cities in the central Pacific. Overtime, modern studies from scholars such as Shandas, Voelkel, Williams and Hoffman et al (2019) and practictioners like the National Oceanic and Atmospheric Administration (NOAA's Climate Program Office, 2014); NASA Applied Remote Sensing Training Program (McCartney, et al., 2020) and the U.S. National Integrated Heat Health Information System (NIHHIS, 2021) have indeed demostrated the capacity to acquire ground measurements of air temperatures and humidity data with use of mobile traverses via community engagement. Subsequently, they integrate them with satellite surface data to predict a more complete picture of hot spots in cities (Climate Central, 2021). Further into the awareness of the Earth science is the process of energy budget that is essential in predicting UHI phenomenon (Oke, 1982; 1998; McCartney, et al., 2020), as it relates to heat energy flows when examining the sun's heating of the Earth's atmosphere and its surface.

In understanding this heat energy balance, the incoming sun's energy — shortwave radiation from visible light and near infrared portion of electromagnetic spectrum — passes through space to the Earth warming its surface and air which gives off heat — outgoing long-wave radiation from the infrared region of the electromagnetic spectrum — back the atmospheric windows (Institut de la statistique du Québec, 2009; TERI, 2017). In the incoming shortwave radiation budget, the heat is absorbed by the atmosphere and the Earth's ecosystem while some of it is reflected by clouds (Phelan, et al., 2015; McCartney, et al., 2020). Alternatively, in the outgoing long-wave radiation budget, the heat is reflected by the lower atmosphere and Earth's surface back to the troposphere and stratosphere where the CFCs and HFCs traps them and radiates the heat back towards the Earth in a continuous cycle (Phelan, et al., 2015; McCartney, et al., 2020). That said, four forms of heat find their way into the urban ecosystem and built-up environment. Namely, ground heat that warms the surface by conduction; sensible heat that warms the air by convention around us and latent heat which comes from the evaporation and transpiration (Phelan, et al., 2015; McCartney, et al., 2020). Anthropogenic heat constitutes as the fourth form, albeit is viewed as negligible to the environment but significant since it emitted from the vehicles, heating/air-cooling systems, lighting, buildings, human metabolism and animal metabolism (Institut de la statistique du Québec, 2009; Phelan, et al., 2015; TERI, 2017).

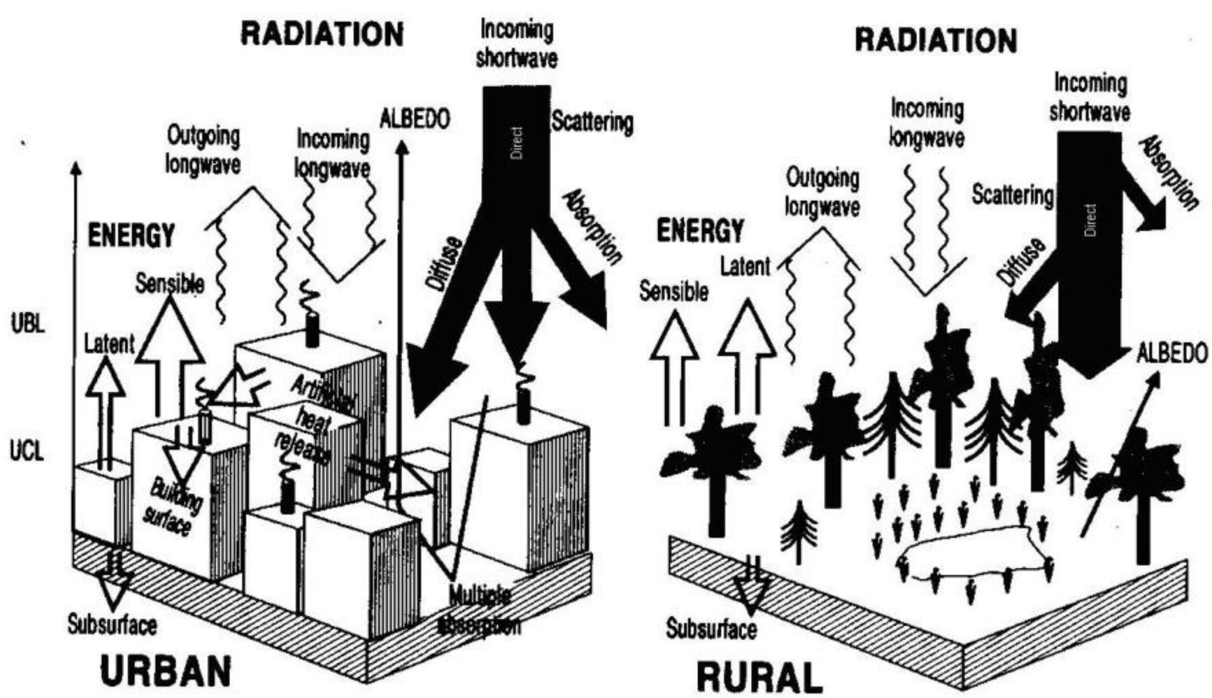
Figure 2.2a and 2.2b impressions the incoming energy from the sun and outgoing energy from the earth relative to electromagnetic spectrum and relative to built environment in understanding earth science and consequently UHI formation.

Figure 2.2a Heat Energy Balance: Electromagnetic Spectrum in the Atmospheric Window



Source: (NOAA, 2021)

Figure 2.2b Heat Energy Balance: Relative to the Urban and Rural Built Environment



Source: (TERI, 2017)

This comprehensive understanding of the study evolution of UHIE relative to interrogative needs and awareness of Earth science connected with remote sensing and GIS, community involvement and interplay of the urban heat energy budget have led to substantive progress in measuring of the heat island effect through surface UHIs and atmospheric UHIs within cities. As argued by Climate Central (2021), on one hand, they have established the contributing heat intensity score variables in cities that include the albedo level, percentage of greenery, population density, building height and the average width of streets and irregularities in that order. On the other hand, McCartney et al (2020) acknowledge that effective applications of findings of surface and air temperatures have really opened up to urban planning tools and design guidelines for mitigation and climate change adaptation options. Thereby, it can be established from this review that UHIE can be investigated through observing one of the following two closely coupled temperature: atmospheric UHIs and the surface UHIs (U.S. EPA, 2008; Institut de la statistique du Québec, 2009; Phelan, et al., 2015; TERI, 2017; McCartney, et al., 2020; Climate Central, 2021).

2.3 Causes of Urban Heat Islands

2.3.1 Increase of Impermeable Surfaces and Low-Albedo Infrastructure

Globally, regionally and locally, the intensification of urbanization causes changes on landscapes that tremendously influences the urban surface characteristics when absorbing, reflecting and re-emitting solar energy (Institut de la statistique du Québec, 2009; TERI, 2017). The urban surface characteristics viewed as ground cover changes are interpreted in two-fold to the UHI formation. One is the increment of impermeable surfaces and thermal properties of infrastructural materials whereas the other leading change is the reduction of green vegetation areas and water features in the urban settings (Institut de la statistique du Québec, 2009; TERI, 2017; Foster, 2020; Climate Central, 2021). It is observed that impermeability of paved urban surfaces and building materials such as asphalts, concrete and bricks curtails water infiltration and ground absorption functions, therefore, altering the natural hydrological cooling processes (Institut de la statistique du Québec, 2009) and impairing the water quality through thermally polluted run-offs (Phelan, et al., 2015). Thermal properties of materials that have low-albedo — less percentage of solar energy reflected by the paved and impermeable surfaces — absorbs and retains heat during the day and releases it vastly during the night (Institut de la statistique du Québec, 2009; Phelan, et al., 2015; McCartney, et al., 2020), reaching up to 80^0C in summer. Herein, primary contributing variables to determining the impermeability and thermal proprieties of materials to the UHI formation are the percentage of albedo; the population density and the share and distribution of the urban built-up areas or urban built-up footprints (Climate Central, 2021).

2.3.2 Inadequate Green Vegetation Cover and Water Features

Secondly, promoting emergence and intensification of UHIs in cities is the gradual loss of urban greenery — green spaces, trees and vegetation — due to urbanization that contributes to reduced cooling effects normally by shading and evapotranspiration (Institut de la statistique du Québec, 2009; TERI, 2017; Foster, 2020; McCartney, et al., 2020; Climate Central, 2021). The amount of evaporation and soil moisture are usually lower in the urban areas than rural areas, hence adding the former higher temperatures (Climate Central, 2021). In addition, limited water characteristics in urban areas like the fountains, springs, lakes or seas minimizes the cooling process needed to moderate heat energy from the air (McCartney, et al., 2020). As such, less vegetation and water features have exasperating outcomes on heat generation and heat stress as consequents of UHIE. In Northern America, this has been the case for Mexicali, a city located in the sub-tropical zone in Mexico whose green space is a mere 1.11 per cent (2.43 m^2/inhabitant), of which 1.27 m^2 is active vegetation (Saiz-Rodríguez, Salazar-Briones, Ruiz-Gibert, Moctezuma, & Lomeli-Banda, 2021). In Africa, such have been the cases of the Greater Cairo Area, Egypt having 3.85 per cent of green areas (Kafafy & Al-Betawi, n.d) and Lagos, Nigeria laden with three decades of intensified urban heat islands (Bassett, Young, Blair, Samreen, & Simm, 2020) having approximate 3 per cent share of urban green spaces of its city's landmass (Oduwaye, 2013; Sawyer, 2013). Other critical cases of the tropical coastal cities of the Sub-Saharan Africa have been documented by White, Turpie and Letley (2017) highlighting Dakar, Senegal with 34 per cent loss of green spaces over twenty-year period between 1988 and 2008; Luanda, Angola bearing less than 1m^2 urban green spaces per inhabitant as well as Durban Bay estuary, South Africa with only 3 per cent of mangrove forest.

Underlying variables for this causality to UHIs formation are usually demonstrated in the context of green space infrastructure (GSI): the share of green urban areas and distribution of green urban areas (Climate Central, 2021; European Environment Agency, 2021; U.S. EPA, 2021). Urban GSI is an umbrella term that spans a range of all forms and vegetation types across both the public and private realms: urban forests, street trees, open parks and gardens, waterways and habitat corridors, the active recreation areas, green roofs, walls and facades, water sensitive urban design treatments and other vegetated streetside treatments (Bush, 2017). In this manner, other contributing authors have expressed the urban GSI as a strategically planned multifunctional network of all natural and semi-natural areas entailing of vegetated green and blue spaces designed and managed in planning to deliver ecosystem services (Monteiro, Ferreira, & Antunes, 2020; Forest Research, 2021). Such a network constitutes different types of green spaces which together enable delivery of multiple benefits as goods and services at all spatial scales (Forest Research, 2021).

2.3.3 Increase of Anthropogenic Heat and Greenhouse Gas Emissions

Despite numerous circles within the academia and practice depicting the two main factors to the formation of UHIs: increased of impermeable surfaces and low-albedo infrastructure and limited reduction green vegetation cover and water features, studies of UHIE have identified that there are still more human-created heat emissions. These heat emissions are termed as anthropogenic heat coming from manufacturing facilities and energy-intensive buildings; the fuel fossils; heat rejected dissipated from cooling by air-conditioners; human metabolism and animal metabolism (MDDEP, 2006; Institut de la statistique du Québec, 2009; Phelan, et al., 2015; TERI, 2017). Studies identify resulting GHGs also causes of UHI phenomenon in cities that cumulatively lead to global climate change by warming the atmosphere (Institut de la statistique du Québec, 2009; TERI, 2017).

Although vital, Phelan et al (2015) states that anthropogenic heat and GHGs are negligible relative to other heat sources in adding to the UHIE. Nonetheless, they might worsen the presence of heat waves and the impact of global warming in the planet, currently kept under 1.5^0C pre-industrial levels (IPCC, 2021). Largely human-induced, the gravity of this situation is alarming since recent data monitoring in 2021 distinguished July as the world's hottest month ever, registering a global [land and ocean-surface] temperature of about 0.93^0 C above the 20^{th} century average of 15.8^0C (NOOA, 2021). Though, this surface temperature is merely 0.01°C higher than the previous 2016's record (NOOA, 2021). Following the case of Africa, it registered as the seventh-warmest continent in July amidst comparative ranking with the Asian, European, North American, South American and Oceania territories (NOOA, 2021). The exposure cases of Cairo, Egypt and Lagos, Nigeria are very critical with more than half the hazard coming from the warming climate (The Energy Mix, 2021). That said, the predominant variables in examining the anthropogenic heat and GHGs to the UHI phenomenon are the types of land uses and population density in understanding the various human-created heat emissions (TERI, 2017; Climate Central, 2021).

2.3.4 Poor Alteration of the Urban Geometry in a City

The contribution of the urban spatial geometry — urban morphology and city size with regard to the spacing dimensions of the built-up environment — to UHIE is when they are altered to trap more heat in the vicinity (Institut de la statistique du Québec, 2009; TERI, 2017; Zhou, Rybski, & Kropp, 2017; Foster, 2020). TERI (2017) mention that this alteration may directly influence wind movements, shading patterns, heat absorption and the ability of surfaces to emit outgoing long-wave radiation back to space. Created UHI phenomenon is distinct in the urban canyons/enclosures created by streets and building irregularities within the cities (TERI, 2017; McCartney, et al., 2020; Climate Central, 2021). Particularly, although tall buildings and narrow streets may provide shade and reduce surface temperature, they may act as obstacles of wind flow and ventilation increasing air temperatures due to radiation trappings and reduced cooling effects (TERI, 2017; McCartney, et al., 2020; Climate Central, 2021). With this in mind, the notable variables of the urban geometry to the UHI formation include the different widths and heights of streets and buildings respectively based on the urban canyons.

2.3.5 Calm and Clear Weather and Climatic Conditions

The stream of the solar energy reaching urban surfaces is maximized when the weather is typically calm and clear (McCartney, et al., 2020). Further, strong winds and cloud cover, on the other hand, prevent heat islands from forming in cities (McCartney, et al., 2020). Main variables under study to the UHI formation are weather and climate trends, especially of wind patterns and cloud covers (McCartney, et al., 2020; Climate Central, 2021). This root cause has necessitated the case reviews of Stuggart in Germany on its mild climate and air quality (Kazmierczak, 2010; Climate-ADAPT, 2016) and Hanoi in Vietnam on heat waves forecasts (Taru Leading Edge, 2021; Anticipation Hub, 2021).

2.3.6 Natural Geographical Landmarks as Obstacles

UHI formation in cities is also influenced by geography (McCartney, et al., 2020). Large bodies of water can help to moderate surface and air temperatures, while adjacent mountains can help to block wind or create wind patterns that travel through it (McCartney, et al., 2020)**.** This causality has necessitated the case review of the water-wise spray parks in Cape Town, South Africa that is widely typified its table mountains (CapeTownMagazine, 2016; Taru Leading Edge, 2021).

2.4 Impacts of Urban Heat Islands

2.4.1 Social Impacts of Urban Heat Islands

It relates to those effects manifested on people whom includes the city residents with the vulnerable population/groups suffering more from the associated heat stress of the UHIs (Taru Leading Edge, 2021). Social effects oscillate on the harmful consequences of heat stress to human comfort, health, productivity and disruption of human systems while the economic effects often associate increased energy consumption (Institut de la statistique du Québec, 2009; Taru Leading Edge, 2021). It cut across health impacts in particular prevalence of heat illnesses as direct impacts and increased need for health services as indirect impacts during summer/hot seasons on the urban population (Taru Leading Edge, 2021). The types of heat illnesses are human thermal discomfort; body weakness; dehydration; unconsciousness; cramps; fainting; heat stroke; heat rash and illnesses such as air borne and water borne diseases; chronic diseases; respiratory diseases; cardiovascular diseases and renal diseases, especially to the vulnerable population (Institut de la statistique du Québec, 2009; Taru Leading Edge, 2021). Vulnerable groups include infants, school children, homeless people, laborers, disabled people, street vendors, traffic police, senior citizens and animals experiencing increased risk of heat-related morbidity and even mortality (Taru Leading Edge, 2021). The gravity of UHIE across the world has been alarming with the worsening of heat waves on the number of recorded deaths, following 72,250 people in Europe in one deadly summer of 2003 and a global total of 70,409 people within the last decade from 38 heatwaves recorded (IFRC, 2020). On health services, heat stress induces increment of the number of hospitalized patients, need for emergency services and amount call-outs for ambulance and fire-brigades (Phelan, et al., 2015; Taru Leading Edge, 2021). Hence, the need to mitigate the social impacts of UHIs.

2.4.2 Economic Impacts of Urban Heat Islands

On economy, the impact of heat stress indirectly reduces both activity and productivity, contributes to infrastructural damage and damage due to heat waves and global warming (Taru Leading Edge, 2021). Increases in expenditure on health services and expenditure on energy consumption from electric-colling devices constituted as indirect economic implications of UHIs (Phelan, et al., 2015; Taru Leading Edge, 2021). Heat islands are known to elevate both overall electricity demand and peak energy demand (McCartney, et al., 2020). There is thus the need to mitigate the economic impacts of UHIs, as it is noted that extreme heat weather related and climate change events causes overload systems that necessitates utility controls through rolling brownouts or blackouts to curtail power outages (McCartney, et al., 2020).

2.4.3 Environmental Impacts of Urban Heat Islands

Despite of the notable advantage of warming winter/cold nights and seasons (Phelan, et al., 2015), heat islands have adverse direct effects to the natural ecosystems and built-up ecosystems. On the natural environment, the environmental effects revolve on elevated emissions of air pollutants and GHGs leading to deterioration of indoor and outdoor air quality; frequent forest fires; degradation of crops and agriculture; increased rate of evapotranspiration, humidity, precipitation, floods and disasters and deterioration of fauna and green vegetation (Institut de la statistique du Québec, 2009; McCartney, et al., 2020; Taru Leading Edge, 2021). The built-up environment focuses more the negative impacts of heat stress on infrastructural services and it direct corelates to the impacts of heat stress on the economy. These are notably impairment of water quality by thermal pollution; increased electric-energy demand for air-cooling and refrigeration; increased demand of potable water for cooling; shortage of water and electricity; power failures either as brownouts or blackouts as well as melting of tar roads and damage to street pavements, buildings and piped infrastructure (McCartney, et al., 2020; Taru Leading Edge, 2021). Therefore, the need to mitigate the economic impacts of UHIs.

2.4.4 Institutional Impacts of Urban Heat Islands

It encompasses the inequities of the actors, policy frameworks and legislations and monetary and capacity funding to properly deal with the urban thermal environment (Taru Leading Edge, 2021). Following climate change and urbanization, the concern of UHIs have been lacking influence and prioritization to city-wide systems especially in Sub-Saharan Africa such as Nigeria, Angola and Kenya and Southern Asian countries such as India and Indonesia. For instance, Kenya has been represented by laxity and improper translations of legislations and ratified frameworks, limited awareness and insufficient capacity building, inadequate funding for deal with challenges of the urban thermal environment (Republic of Kenya, 2020).

2.5 Planning Implications of the Urban Heat Island Effect

2.5.1 Mainstreaming Urban Thermal Environment into Urban Planning

The comprehensive understanding of the examination of the indicators, root causes and effects of UHIs and mitigation solutions (Climate Central, 2021); use of Earth science with satellite remote sensing and GIS capabilities (McCartney, et al., 2020) and community engagement are indeed paramount on the road to heat resilience and sustainable development (NOAA's Climate Program Office, 2014; Taru Leading Edge, 2021). At city level, it is imperative that the thermal environment be studied in cities whilst reflecting on the urbanization [built-up footprint and population scale] and climate change [heat waves and global warming] to clearly inform and guide decision-making during the planning for cooler cities (Zhang, Dong, Cheng, & Li, 2021). In particular, on reducing heat islands; improving thermal comfort; decreasing risks of heat-related mortality and morbidity; increasing greenery; enhancing air and water quality; promoting energy efficiency in relation to air-conditioning; reducing GHGs emissions and reducing peak electricity demand (Institut de la statistique du Québec, 2009; Phelan, et al., 2015; TERI, 2017; C40 Cities Climate Leadership Group, 2019; Climate Central, 2021). Interrogation of archipelago of heat islands necessitates planning implications on albedo and infrastructure services, vegetation, anthropogenic heat, urban morphology, weather and micro-climate and urban geography in relation to blue spaces, landmarks and winds (McCartney, et al., 2020). Therefore, planning implications of UHIE can be expressed as the necessitations of policy and practical approaches that acts as potential cooling remedies in realm of urban planning to enhance the mitigation of heat islands within cities (Phelan, et al., 2015; TERI, 2017; C40 Cities Climate Leadership Group, 2019). Careful urban planning is therefore an imperative strategy on tackling adverse impacts of sprawling, compacting as well as intensifying human activities to subsequently improve the urban climate and human health (Stone, Hess, & Frumkin, 2010; Imran, Kala, Ng, & Muthukumaran, 2019).

2.5.2 Social Resilience for Urban Heat Island Effect

Going forward in attaining a higher position of social adaptive capacity for UHIE, people ought to be engaged in thermal comfort awareness and mitigation of heat-related mortality and morbidity (McCartney, et al., 2020; Stevens, 2020; NIHHIS, 2021). Social resilience for UHIE induces social protection that cut across low-income, middle-income and high-income neighborhoods, with the former given more prime importance in inculcating better working conditions and maintaining a constant supply food availability and water supply (Taru Leading Edge, 2021). The latter has been represented under the case study of spray parks for cooling in Cape Town, South Africa where the population have aquatic facilities. The use of social media can also be very effective in addressing and spreading awareness regarding impacts on heat illnesses and health services in cities (Taru Leading Edge, 2021).

Cutting across social resilience for UHIE is anthropogenic heat-reduction strategy that connotes to inducing adaptive capacity to human related activities. The objective this strategy is to enhance both energy and electricity efficiency, reduce their demands and GHGs and promotes ventilation (Institut de la statistique du Québec, 2009; Phelan, et al., 2015). Key measures under this strategy envelopes social protection. They include use of compact fluorescent light bulbs; energy-efficient equipment in offices as well as houses; energy-efficient household appliances; natural ventilation; controlled mechanical ventilation; ground-coupled heat exchanger; solar air-conditioning as well as radiant cooling systems (Institut de la statistique du Québec, 2009; Phelan, et al., 2015). The cooling centres of Hanoi, Vietnam impressions this type of social resilience, conversed under the case studies. Other effective measures include reduction in the number of vehicles in urban centres and development of bicycle and pedestrian corridors notably applied in Ottawa, Canada (Institut de la statistique du Québec, 2009).

2.5.3 Economic Resilience for Urban Heat Island Effect

In inducing a higher position of economic adaptive capacity, application of smart and sustainable urban-related infrastructure cuts across not only in mitigating affiliated economic impacts but also built-up environmental impacts of UHIs, particularly for the property owners as well as corporates on energy saving. C40 Cities (2019) indicates that there is a need to make the cool surface business case to property owners and corporate cool options with other long-term infrastructure projects. To complement this strategy, C40 Cities (2019) highlights undertaking public outreach awareness raising; identifying co-paired measures for cooling; offering incentives for implementation of cool solutions and developing policy and legislation requiring cool components of the same. Smart and sustainable urban-related infrastructure strategy for energy savings has been effectively applied in Tokyo, Japan on its Thermal Barrier Coating and Water-retentive Pavement Project, New York, USA (C40 Cities Climate Leadership Group, 2019). Moreover, applied in Indore, India on its Cooling Roofing Projects and Hanoi, Vietnam on Heat Forecasting Technologies and Cooling Tents (Taru Leading Edge, 2021).

In relating to uses and designs of buildings, roads and other components of the built environment, the objective of the smart and sustainable urban-related infrastructure strategy is to increase level of albedo, energy and electricity peak efficiencies, performance and air-circulation (Institut de la statistique du Québec, 2009; Phelan, et al., 2015; TERI, 2017; C40 Cities Climate Leadership Group, 2019; Climate Central, 2021). There has to be utility controls through rolling brownouts or blackouts (McCartney, et al., 2020). The emphasis of heat reductions under this strategy are on the incorporation of reflective materials for buildings; building insulations; cool roofs (white or foam coated) as an alternative to air-conditioners (Phelan, et al., 2015; C40 Cities Climate Leadership Group, 2019; Climate Central, 2021); good thermal inertia materials such as wood, bricks and stone (Institut de la statistique du Québec, 2009) and water installation features such as waterfalls, fountains, spraying parks, pools and ponds (Institut de la statistique du Québec, 2009; C40 Cities Climate Leadership Group, 2019; Taru Leading Edge, 2021). Installations of high-performance widows and shading devices for windows constitutes as emphasis of heat reductions on buildings (Institut de la statistique du Québec, 2009). Heat monitoring technologies to assist in forecast (Taru Leading Edge, 2021) and cool pavements put emphasis on having smart city-wide practices (Phelan, et al., 2015; TERI, 2017; C40 Cities Climate Leadership Group, 2019; Climate Central, 2021). Others include high-albedo paints for vehicles; well-ventilated urban morphology and up-wind parks (Institut de la statistique du Québec, 2009).

2.5.4 Environmental Resilience for Urban Heat Island Effect

Besides affiliation to smart and sustainable urban-related infrastructure, environmental resilience for UHIE is attached with having a higher position of adaptive capacity on the natural ecosystems. It offers a cross-cutting pathway to cooling cities with zoning by institutions. Often, environmental resilience envelopes urban greening strategy, sustainable blue spaces and stormwater management strategy. The objective of the urban greening strategy is to enhance the share and distribution of greenery in cities as the main indicators of GSI (European Environment Agency, 2021; U.S. EPA, 2008). Therefore, increasing a city's total vegetation index or GSI per capita value (Institut de la statistique du Québec, 2009; Mwasi & Goro, 2017). Into this account, WHO (2012) recommends the provision and availability of GSI should be a minimum of $9m^2$ of green space per individual with an ideal urban green space value of $50m^2$ per capita. When holistically seen as a percentage of a city's land mass, the share and distribution of greenery is simply suggested by the UN-Habitat (2018) to be an average of 15-20 per cent of the city land area. GSI forms a critical component of the ecosystem since they provide a range of mental and physical health as well as social economic, biophysical and environmental services that improve the quality of lives in cities as acknowledged by UHIE studies in Melbourne, Australia by Bush (2017) and Eldoret, Kenya by Mwasi and Goro (2017).

On one hand, the case for these multifunctionalities essentially contributes to urban liveability as well as cooling effects while on other hand prioritizes retention and maximization of green areas (Norton, et al., 2015; Bush, 2017; Mwasi & Goro, 2017). Bush (2017) underscores that the value of green spaces in planning for cooler cities is as a matter of policy and legislation perspectives. This warrants provision of urban greening strategies at macro-scale, meso-scale and micro-scale to mitigate UHIE, as cities undergo environmental modification due to urbanization and climate change (Norton, et al., 2015; Bush, 2017). Notably, selective planting of trees and vegetation along the transportation corridors, public property and private property; greening parking lots; increasing vegetation density around buildings and retrofitting of green walls/façades and green roofs (Institut de la statistique du Québec, 2009; TERI, 2017; C40 Cities Climate Leadership Group, 2019; Climate Central, 2021). In this manner, tropical coastal cities of the Sub-Saharan Africa could learn and adopt these best practices in planning for cooler cities. This urban greening strategy has been applied in in Stuggart, Germany on its Green Aeration Project (Kapp, 2017); Greater London, England on its Greening Business Improvements Districts Project (C40 Cities Climate Leadership Group, 2019); Tokyo Plan 2000 (TERI, 2017); 21-signed Sub-Saharan Africa countries on their

Great Green Wall Project, albeit in motion (Kelly, Butscher, & van der Werf, 2021) and Kampala, Uganda on its Tree Audit and Forest Management Plan (Taru Leading Edge, 2021).

The consideration of water in cities creates additional cooling through evaporation and improved evapotranspiration of vegetation (Institut de la statistique du Québec, 2009; C40 Cities Climate Leadership Group, 2019). In coastal cities as well as wetlands-fronted cities with lakes and rivers, the sea breezes during the day and land breezes at the night aids in the thermal regulation (Bush, 2017). Key considerations under sustainable blue spaces to the heat islands mitigation are protection of riparian reserves from built environment and human activities and synergetic greening arrangements with existing blue spaces: the wetlands and rivers, lakes, seas and oceans (Gunawardena, Wells, & Kershaw, 2017). In Kenya, a setback of 30m from the highest water mark often accounts for river riparian reserves (Republic of Kenya, 1989; 2006b) and a setback of 60m also from the highest tidal water mark accounts for oceans and lakes (Republic of Kenya, 2017a). Applicable example of this strategy is seen in the island of Mombasa, Kenya where green and blue spaces exist together credited to its wildscapes, Haller Park [Lafarge Ecosystems] and mangroves, though mitigation as well as adaptation approaches that account for the full value of these urban landscapes are needed (Kithia & Lyth, 2011). On the other hand, key measures under sustainable stormwater management strategy comprises the permeable surfaces; rain gardens; retention ponds; dry wells; infiltration trenches; reservoir pavements and watering of pavements with recycled water (Institut de la statistique du Québec, 2009). This strategy has been applied in the Netherlands where population generally live with water and New Orleans, USA on instituting flood-defence tactics (Kazmierczak, 2010).

2.5.5 Institutional Resilience for Urban Heat Island Effect

Going forward in attaining a higher position of institutional adaptive capacity for UHIE, there has to be more awareness among the stakeholders on the root causes of UHIs; comprehension of Earth Science and physics of heat transfer and more data availability and analysis to identify the relevant challenges and develop suitable solutions (McCartney, et al., 2020; Taru Leading Edge, 2021). Adequate institutional capacity for data analysis and interpretation for implementing the solutions inclusive of physical planners, architects, construction designers, environmental managers, climate researchers, health experts and donors or funders forms the road to institutional resilience for UHIs (McCartney, et al., 2020; Taru Leading Edge, 2021). Urban heat island mapping campaigns across 13 cities, USA and heat wave forecasts monitoring systems in Hanoi, Vietnam underpins as some of the best practices on institutional resilience, conversed under the case studies. A collaborative understanding among the professionals in the public and private sector within natural and built-up ecosystems; environmental managers and policy makers whereas more efforts for community participation is undertaken should underpin all intersectoral and cross-cutting issues in mitigating the institutional impacts of UHIs (McCartney, et al., 2020; Taru Leading Edge, 2021).

The latter, in the context of thermal stakeholder participation and engagement, entailed as part and parcel of good practice to enhance the mitigation of UHIE. Under this strategy, a vital tool used is the heat watch engagement model advocated by the CAPA Heat Watch to assist the communities and organizations in identifying various areas for action and mitigation to enhance the protection of people from the impacts of heat stress (McCartney, et al., 2020; Stevens, 2020). Ground-based assessments are usually done with custom-engineered temperature and humidity sensors mounted on bicycles and vehicles or with walking traverses, depending the city geographical area to be able to predict a diurnal temperature and humidity pattern (McCartney, et al., 2020; Stevens, 2020). Observations are often based in the morning (possibly 6am), afternoon (3pm) and evening (7pm) for one hour and all within a day or a week at most, given on the conditions of the local site most effectively during hot seasons/summers for accuracy as both the temperature and humidity keep shifting (McCartney, et al., 2020; NIHHIS, 2021).

The final products from these community science field campaigns are a set of high-resolution air temperature, humidity data and map report that are presented back to the community to know the spatial distribution and the intensity of heat exposure during the morning, afternoon and evening (McCartney, et al., 2020; NIHHIS, 2021). Consequently, creating a deepened engagement in the identification of heat mitigation actions for human health and well-being, future development and infrastructure changes (McCartney, et al., 2020; Stevens, 2020; NIHHIS, 2021). In spite of such anticipated benefits, limitations of UHI mapping campaigns still revolve on funding applications that are very costly. Currently, a baseline cost of a campaign by NOOA applied across the 13 US cities — conversed under the case study — ranges between $10,000 for small-sized cities of less than 260 sq. km and $30,000 for large-sized cities of about 1295 sq. km (NIHHIS, 2021). Hence, higher cost implications for the coastal cities of the tropical Sub-African Africa when carried out.

2.6 Case Studies on Enhancing the Mitigation of Urban Heat Island Effect

2.6.1 Green Aeration Corridors for Heat and Air Quality Control in Stuggart, Germany

Although not a coastal city, the location of Stuggart with its wide river Neckar valley basin, steep hill slopes around the city, mild climate, industrial activity and incremental volume of traffic has made it vulnerable to poor air quality since 1970s (Kazmierczak, 2010; Climate-ADAPT, 2016).

These challenges when coupled by the low-speed winds led to heat island effect (Kazmierczak, 2010; Climate-ADAPT, 2016). The planning solutions were presented as a five-building block strategy (Kapp, 2017), constructively driven by municipal planning, landscaping and adjustment zoning changes in the application of the German Building Code and other national, regional and local regulations in the city (Kazmierczak, 2010; Climate-ADAPT, 2016).

First is the Climate Atlas 2008, revision from the 1992 version (Kazmierczak, 2010) and Climate Booklet for Urban Development Online 2012 guiding planners in climatic optimisation, retention and maximization of green-blue space infrastructure and mitigation of poor air quality and the UHIE (Kapp, 2017; Climate-ADAPT, 2016). Second block is the green aeration and blue space infrastructure while the third is implementation of the 2010 Land Use Plan in guiding brownfield development rather than greenfield development (Kapp, 2017). The fourth strategy is the use of the KlippS project as an evaluation tool to aid examine areas and plan actions against urban heat stress vulnerability (Kapp, 2017). The fifth building solution is the stakeholder partnerships of the Office for Urban Planning and Urban Renewal; the Office for Environmental Protection; city residents and other financial donors underscoring success of the whole strategy (Kazmierczak, 2010; Kapp, 2017). Plate 2.1 illustrates this successful case of Stuggart, Germany.

The benefits included enhanced air quality, lowered city temperatures, improved recreation, urban aesthetics and public health, reduced energy demand for indoor climate controls and created and preserved wildlife habitats within the socio-ecological systems of the city (Kazmierczak, 2010). Greenery in the city now covers more than 60 per cent (Kapp, 2017; Climate-ADAPT, 2016). It comprises of 5000 ha of forests and woodland; 65,000 trees in parks and open spaces with some cooling water fountains; 35,000 street trees; 300,000 sq. m of green rooftops and 63 out of 273 km of green tram tracks of oligotrophic grasses (Climate-ADAPT, 2016). Building developments have been curtailed in hills surrounding the city to allow proper exchange of air flows that are free from obstacles (Climate-ADAPT, 2016). Nonetheless, limitations in uncertainty about future climate change, urbanization impacts and the shortage of staff and organizational capabilities for climate mitigation and financial resources still lingers in the implementation process (Kazmierczak, 2010).

Plate 2.1 Distribution of Green Areas and Green Aeration Corridors in Stuggart, Germany

Panoramic View of the Inner City of Stuggart

Green Corridor with Green Tram Tracks

Source: (Kapp, 2017)

2.6.2 Urban Heat Island Mapping Campaigns Across 13 Cities, USA

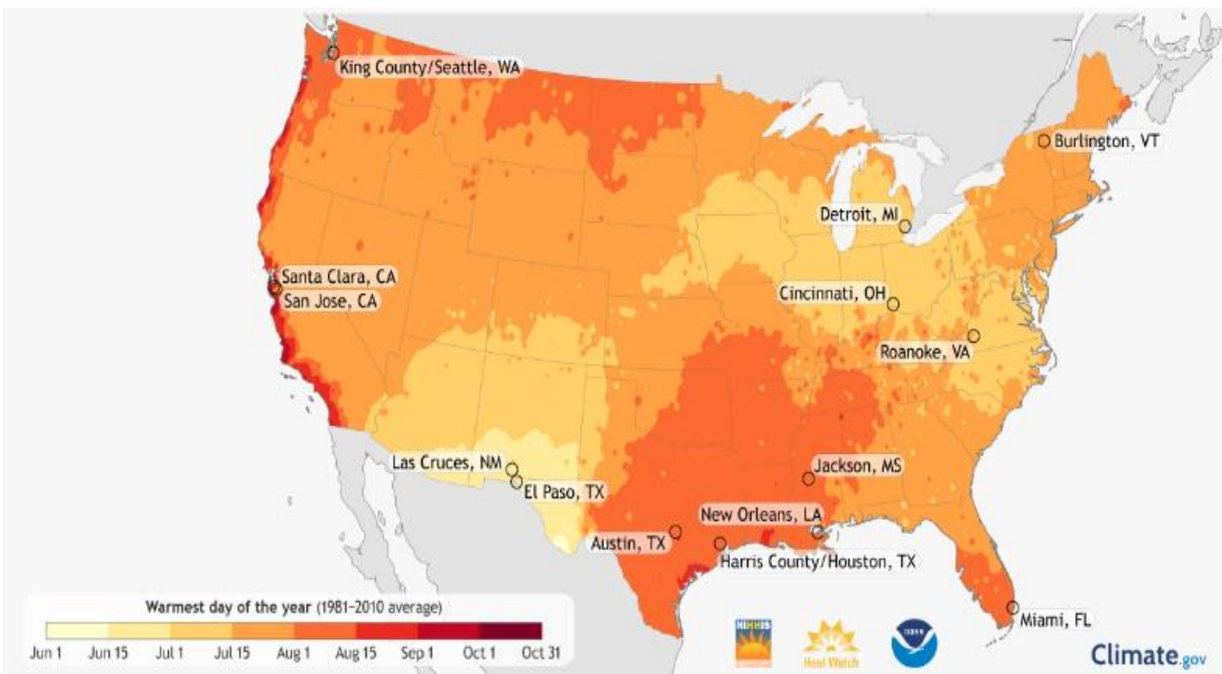
In 2020, 13 US cities — Miami, New Orleans, Houston, Jackson, Austin, El Paso, Las Cruces, San Jose/Santa Clara, Seattle, Detroit, Cincinnati, Roanoke and Burlington — undertook UHI mapping campaigns (Stevens, 2020). This collaborative project was essentially supported by the NOAA's Climate Program Office, National Integrated Heat Health Information System (NIHHIS) and the Climate Adaptation Planning and Analytics (CAPA) Strategies (Stevens, 2020). Along these lines, using the case of Miami, Florida when presenting during NASA Applied Remote Sensing Training Program (McCartney, et al., 2020), the necessitation of UHI mapping campaign was to perform ground-based measurements of air temperature and humidity data by community science/citizen science field participation. These observations were integrated with satellite imagery for a robust and holistic decision-making process in the mitigation of urban heat island effect. Seconding this approach was the articulation of the NIHHIS on engaging with the city residents in the scientific process while teaching them about UHI phenomenon across the mentioned 13 cities, as the more than 600 people in the United States have succumbed to extreme heat every year as put by the Centers for Disease Control and Prevention (Stevens, 2020). Plate 2.2 and Map 2.1 demonstrates the urban heat island mapping campaigns in USA.

Plate 2.2 Typical Community Science Field Awareness on Heat Watch in USA

Source (Stevens, 2020)

Source (McCartney, et al., 2020)

Map 2.1 Urban Heat Island Mapping Campaigns in USA



Source (Stevens, 2020)

2.6.3 Heat Wave Forecasts and Cooling Centres in Hanoi City, Vietnam

Financial capacity building efforts of the Vietnam Red Cross Society with the German Red Cross, the Red Cross Red Crescent Climate Centre and close collaboration with the Vietnam Institute of Meteorology, Hydrology and Climate Change, heatwave forecasting system was co-created (Taru Leading Edge, 2021; Anticipation Hub, 2021). It was based on the FbF (Forecast Based Financing) Vietnam project — that commenced in January 2018 and finished in March 2021 — encompassing extensive Knowledge, Attitude and Practice (KAP) survey of the target populations in 12 districts of Hanoi for anticipatory humanitarian actions for the frequent urban heat waves on the vulnerable population (Anticipation Hub, 2021). This KAP survey was further complemented by stakeholder identification analysis to pin point the potential partners for their valuable information for the Emergency Action Plans (EAP) on the heat waves and with the GIS mapping to identify locations of the vulnerable people (Taru Leading Edge, 2021; Anticipation Hub, 2021). Plate 2.3 shows FbF project impressions in Hanoi City, Vietnam.

Plate 2.3 Project Impressions on Heat Wave Forecasts and Cooling in Hanoi City, Vietnam

KAP Survey with a Builder Construction

Workers in a Cooling Tent

Source: (Anticipation Hub, 2021)

In 2019, a heightened heat wave with a heat index of 47.5°C in Hanoi enabled the Vietnam Institute of Meteorology, Hydrology and Climate Change to use the forecasting system to issue warnings (Taru Leading Edge, 2021). Subsequently, the Vietnam Red Cross Society and partners provided various cooling centres/tents for communities, towels in cooling buses, cooling fans with ice tanks for use during night and household retrofitting like covering tin roofs with white plastic tarpaulin and using sprinklers during the daytime as some of valuable early actions for change (Taru Leading Edge, 2021; Anticipation Hub, 2021).

2.6.4 Spray Parks for Cooling in Cape Town, South Africa

Through creation of environmentally friendly aquatic systems (CapeTownMagazine, 2016), the coastal city of Cape Town has been championing the mitigation of UHIE in the tropical Sub-Saharan Africa. The city has inadequate access of air-conditioning or swimming pools to help its community residents to cope up with heat, albeit its vast sandy beaches provide opportunities for swimming, limited knowledgeable swimmers (Taru Leading Edge, 2021). To adequately address such heat challenges due to the increasing impermeable surfaces and high number of very hot days, the Mayoral Committee for Community Services of Cape Town developed new green-blue space infrastructure: water-wise spray parks and accompanying facilities (CapeTownMagazine, 2016). They are to be free, safe and inclusive to infants, toddlers, teens, youths, adults and people with disabilities. Plate 2.4 showcases the project impressions for water-wise spray parks in Cape Town, South Africa.

Plate 2.4 Water-Wise Spray Parks in Cape Town, South Africa

Source: (CapeTownMagazine, 2016)

There are about five of them situated within Ocean View, Nyanga, Valhalla Park, Scottsville and Khayelitsha (CapeTownMagazine, 2016). The spray parks are not swimming pools but amusement parks and cooling centres that only use about 15-20 per cent of water equivalent to medium-size municipal pools. Henceforth, having less water consumptions which earlier on were broached as a limitation (CapeTownMagazine, 2016; Taru Leading Edge, 2021). These spray parks serve as a suitable way of integrating green-blue infrastructure: recreational spaces and aquatic environment system in staying cool during the summer or hot days (CapeTownMagazine, 2016).

2.7 Synthesis of the Lessons Learnt and Existing Gaps

UHIE is concerned about differences in temperature between urban areas and rural hinterlands. In this manner, UHI is an urbanized area that is warmer than its surrounding area. The main cause is the modification of land surfaces. Urban surface accumulates heat and thus causes the increase of air temperature. Other causes are the increase of surface temperature/friction; decrease of relative humidity; increase of the absorption of solar radiation; decrease of evapotranspiration; release of anthropogenic heat; poor aeration and ventilation; increase of surface run-off and intensified urban morphology and land use activities. In dynamically quantifying the heat island effect in cities, the surface UHIs are represented by the land surface temperature (LST) obtained by satellite data to show the varied urban areas and non-urban areas as well as hot spots and cool spots in cities. It thus proves useful to urban planners within the physical and land use planning domain when assessing the impervious surfaces and vegetation cover and their scale impact to temperature. Literature review established that the use of satellite thermal remote sensing measures to acquire surface UHIs gives consistent and repeatable observations of the Earth's surface. However, the integration of atmospheric UHIs from ground measurements — costly and subject to community heat mapping campaigns — and climate change parameters like air temperatures; humidity; wind speed and direction; ventilation channels; cloud coverage; precipitation and atmospheric pressure often may reinforce satellite-based measurements to predict more accurate extreme urban heat distributions and depiction of UHIE.

UHIE in cities is observed to vary with human activities in both space and time. Hence, the use of remote sensing and GIS provides ability to study the urban thermal environment at various spatial and temporal scales on examining LST on impervious surfaces and vegetation cover as the coupled primary contributors to UHIE. Emerging gaps on UHIE revolve on the poor translation of policy and legislations on the urban thermal environment; understudied connections of the UHIs to GSI and ecosystem services and insufficient heat monitoring systems. A three-pronged challenge of limited awareness, capacity building and funding on the institutional aspect to the urban thermal environment have fueled further impacts of UHIs considered a problem because of increased risk of heat-related mortality and morbidity, increased energy-consumption, elevated emissions of air pollutants and impaired of water quality. On that account, this study uses resilience theory to adequately address UHIE and further inculcate social, economic, environmental and institutional resilience needs in the natural and built-up ecosystems when planning for cooler coastal cities in a spatio-temporal sense to enhance heat resilience and sustainable development. Using the sea-island of Mvita in Mombasa, Kenya as case study and both community involvement and remote sensing and GIS and as vital methodological approaches — the main aim of this study is to thus examine the planning implications of urban heat island effect in coastal cities. A subsidiary aim of the study is to propose planning interventions that can enhance the mitigation of urban heat island effect in Mombasa. The replication of the proposals is set to form broader implications to having cooler coastal cities in the tropical Sub-Saharan Africa countries.

CHAPTER THREE:

RESEARCH METHODOLOGY AND DESIGN

3.1 Analytical Framework

This section underpins the theoretical and conceptual framework to the study.

3.1.1 Theoretical Framework

The basis of this study draws on the application of resilience theory by Canadian ecologist, C.S Holling (1973) by bringing together ecology and systems theory within socio-ecological systems as a coherent theoretical framing towards heat resilient and sustainable cities. Following the effects of urbanization and climate change on the natural landscapes and resulting impacts on temperature, resilience theory provides a way of thinking that is rooted in understanding of the city as a complex adaptive socio-ecological panarchy (Holling, 1973; 2001; Harrison, et al., 2014). This intelligent acting leads to building adaptive capacity and attaining sustainability (Harrison, et al., 2014).

A city as a socio-ecological panarchy signifies the nested as well as co-evolving aspect of complex hierarchical structures of nature, humans, human-nature and management in never-ending adaptive change cycles and continuity of growth, accumulation, restructuring and renewal (Holling, 2001). Incorporation of ecology in the theory addresses the constant need of change across the different scales in cities as a panarchy (Holling, 1973; 2001). Conversely, the embedded systems theory serves to respond to these changes by correcting feedbacks (Harrison, et al., 2014). Pioneered in the 1930s by Ludwig von Bertalanffy (1950; 1968), systems theory has been evolving from its numerous recognitions in the field of science, cybernetics, engineering to now communication in the management of cities as complex adaptive socio-ecological systems. As such, in planning for cooler cities, the application of resilience theory consequents to enhance the mitigation of UHIE that is caused by urbanization and climate change. In this fashion, the most authoritative body in climate change and associated human-induced activities, the IPCC (2014; 2021) has been drawing significantly on resilience theory following its Fifth Assessment Report and multiple background documents to its recently Sixth Assessment Report in spearheading heat-resilient and sustainable cities.

Resilience theory has been recently gaining popularity in policy and planning circles in spite of its origin in the 1970s (Harrison, et al., 2014). However, this is not to replace or change the idea of sustainable development also widely applied worldwide since the 1970s, but fulfill it. As put by Walker and Salt (2006),*"resilience is the key to sustainability"*. In this manner, a city is affirmed to be sustainable (Harrison, et al., 2014), when it has attained a higher position of adaptive capacity or resilience in the face of unpredictable changes, disturbances or disasters inclusive of the UHI phenomenon. Under the extreme heat category, the Emergency Events Database (EM-DAT) labels UHIs as silent killers in the taxonomy of disasters due to their hazardous nature on health and well-being and worsening of heat waves and global warming (IFRC, 2020). As such, the application of resilience theory can essentially serve cities through creation of synergies in the strategies and policy interventions; improvement of air quality; reduction of urban heat stress vulnerability and fourth as promotion of multi-functional benefits to biodiversity (Bush, 2017).

Limitations on application of resilience theory have largely been from the critique impressions of Davoudi (2012) who cautions that the underlying resilience idea might lose its confidence be just another popularized catch phrase out there. On one hand, she warns that its theoretical construct might be prone to simplistic insights on mainstarteaming of ecology and social sciences, hence, cautionary care is necessary when translating the ecology panarchy into human world (Davoudi, 2012; Harrison, et al., 2014). Thus, urban planners need to tread carefully when enhancing the mitigation of UHIE, resultant of the dual challenges of climate change and urbanization. On the other hand, she calls attention to the power blind nature of the theoretical construct which might not be always be positive and could foster unjust rewards in polices and plans (Davoudi, 2012; Harrison, et al., 2014). Therefore, when achieving the adaptive capacity and mitigation, Davoudi (2012) suggest on paying more attention to the question of justice, fairness and to the distribution of benefits and ends as paramount as resilience for some might mean absence of resilience for others. To this insight, a careful understanding and awareness of the types, root causes and impacts of the UHIs and its mitigation solutions (Climate Central, 2021); the use of Earth science — heat energy flows — with the aid of satellite remote sensing and GIS (McCartney, et al., 2020) and community participation and engagement are essentially imperative to the road to heat resilient and sustainable cities (NOAA’s Climate Program Office, 2014; Taru Leading Edge, 2021).

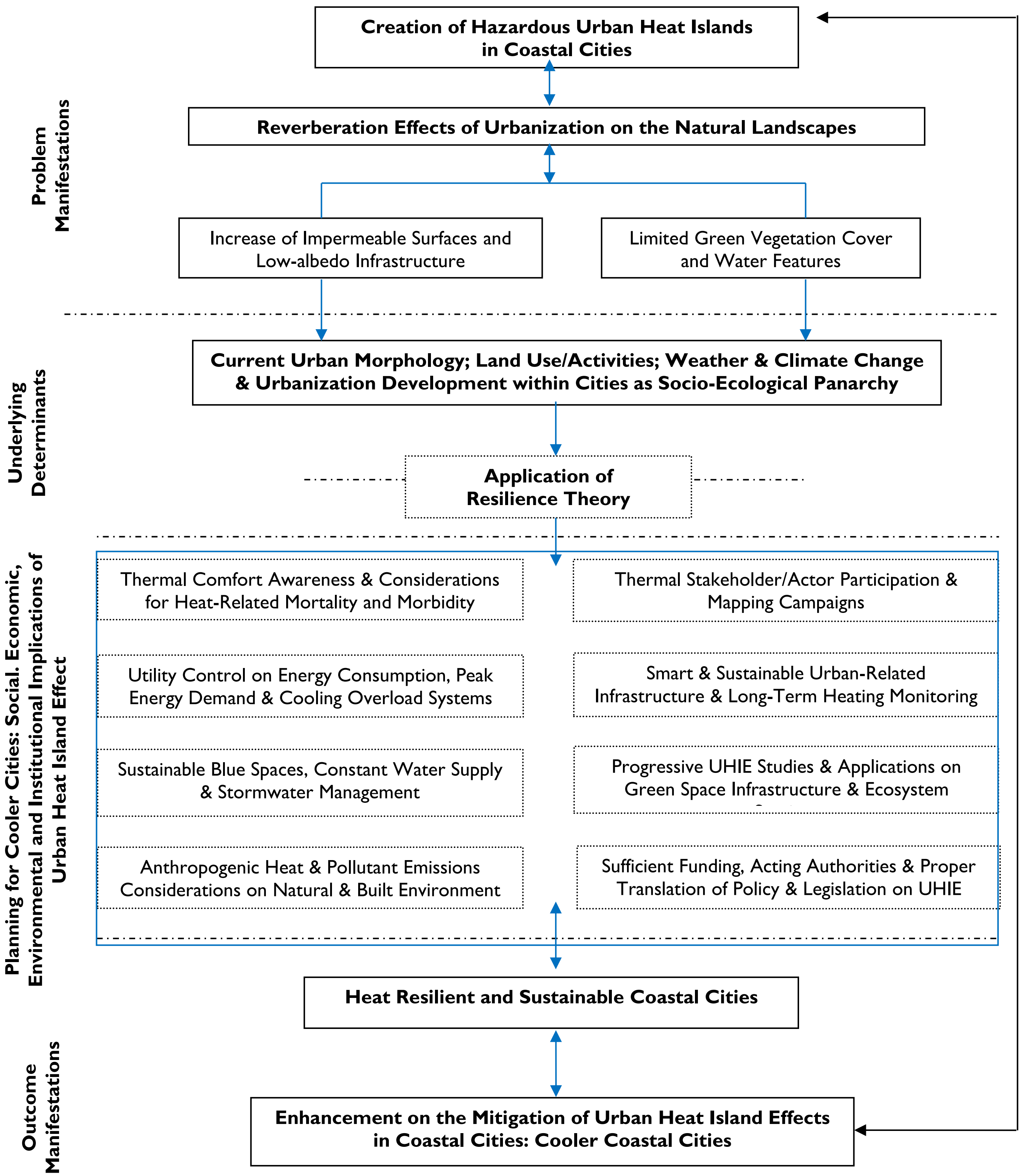
3.1.2 Conceptual Framework

There are multiple conceptual framings in the understanding the root causes, effects and potential mitigation in the field of climate researchers, health experts, architects and urban planners. With this in mind, when planning for cooler cities, the place of urban planners has been attached to the influence of human activities on land in both space and time. Figure 2.1 has clearly demonstrated heat island effect in relation to diurnal temperature and land uses whereas Figure 2.3 shows this study’s conceptual framework. The scope of study focuses on the effects of rapid urbanization on natural landscapes that coastal cities of the Sub-Saharan African are experiencing. It elucidates on how and what can be done about it to mitigate their scale impact on temperature, acutely higher in their urban areas than outlying areas: the UHIE.

Indeed, the literature review has established that heat island effect are phenomena where urban areas experience hotter temperatures than their surrounding hinterland areas. Primarily, this is a consequent of the reverberation effects of urbanization that have profound impact on landscape modification: increase of impermeable surfaces and low-albedo infrastructural materials as well as limited GSI. Effects on climate change such as heat waves and global warming are secondary, however, the association of climate change and urbanisation culminate to the influence of human activities. As such, the UHIE varies with land uses and activities in cities. Others being their urban geometry, weather, climate and landmarks existing and interacting in socio-ecological panarchy of cities.

In this conjunction, application of resilience theory proves essential in understanding as well as making planning considerations as it indelibly links heat resilience and sustainable development when planning for cooler cities. As potentially noted in tropical Sub-Sharan Africa, the literature review has pointed out that there is a poor translation of policy and legislation on heat island effect; understudied connections of UHI to GSI and ecosystem services and a lack of heat monitoring systems following slow ratification process of East African Community Protocol on Cooperation in Meteorological Services. Still, limitations in awareness, capacity building and funding lingers. Coastal cities, especially of the tropical Sub-Saharan Africa could learn a great deal of interest following good practices and case studies tackled in the literature review to make informed and sound decisions after assessing both atmospheric and surface UHIs.

Figure 2.3 Conceptual Framework



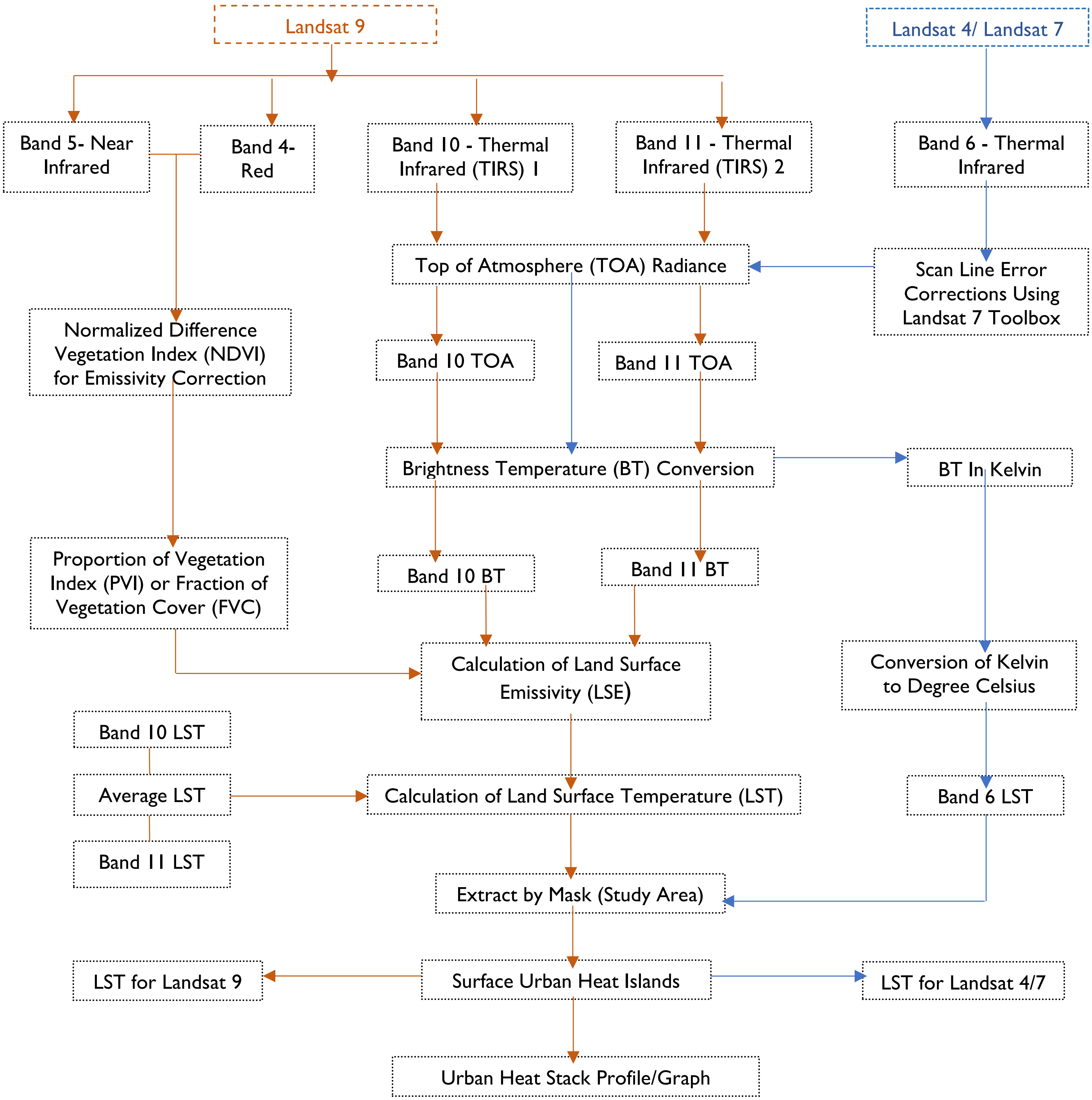
Source: (Author, 2022)

3.2 Research Design

The study adopted a mixed multi-stage research design. On one hand, it applied the panel survey design, also known as the time series design study ranging between 1992 and 2022, a 30-year panel survey. Sources of data are based on satellite remote sensing, GIS tools and techniques, desktop survey techniques and library literature reviews. Data needs entailed a spatio-temporal analysis of the Landsat land surface temperature, built-up area and urban density index, population density, vegetation coverage and previous physical planning and land use developments. Ancillary weather and climatology parameters included the air temperature, earth skin temperature, all-sky surface albedo, relative humidity, cloud cover, precipitation as well as wind speed and direction sourced from the Data Access Viewer under NASA Prediction of Worldwide Energy Sources website.

The use of Landsat series of satellites possesses the potential to provide estimation of surface urban heat islands at a high spatial resolution for small-scale studies and a rather vital facet of the Earth's energy balance, closely connected to sensible and latent heat fluxes mentioned in literature review. Thus, a procedural methodology on the retrieval of surface urban heat islands constituted the study using computerized system on satellite remote sensing system from the United States Geological Survey (USGS) Earth Explorer website and GIS capabilities from the ArcGIS Desktop and ArcGIS Pro *– See Figure 3.1a, Table 3.1 and Map 3.1*. Mapping of the surface urban heat island involved the land surface temperature (LST) estimation process for the Landsat-4 imagery retrieved on the 24th June 1992, Landsat-7 acquired on the 22nd July 2002 and Landsat-9 retrieved on the 8th April 2022 in Mombasa. The months were chosen to be within and/or in close proximity between the months of 18th December and 15th April that are normally the hottest months in Mombasa County, each year. Moreover, they were selected due to their availability and minimal cloud coverage of 0 to 30 per cent. The Landsat series of satellites were based on Landsat Collection 2 Level 1 from the USGS EarthExplorer website to enable the calculation of the Top of the Atmosphere (TOA) radiance and Brightness Temperature (BT). Although, Landsat 9 has higher high-quality and medium-resolution images of Earth's landscapes and coastal regions every eight days with improved atmospheric corrections, than Landsat 8, its Operational Land Imager (OLI)-2 design is still a copy of Landsat 8's OLI, and will provide imagery consistent with previous Landsat spectral, spatial, radiometric and geometric qualities (USGS Landsat Missions, 2021). Hence, correction values for Landsat 8 were still used for the Landsat 9. Landsat 9 was launched on September 27, 2021.

Figure 3.1a Processing Chain Methodology on Retrieval of Surface Urban Heat Islands



Source: (Author, 2022) Adapted from Literature Review

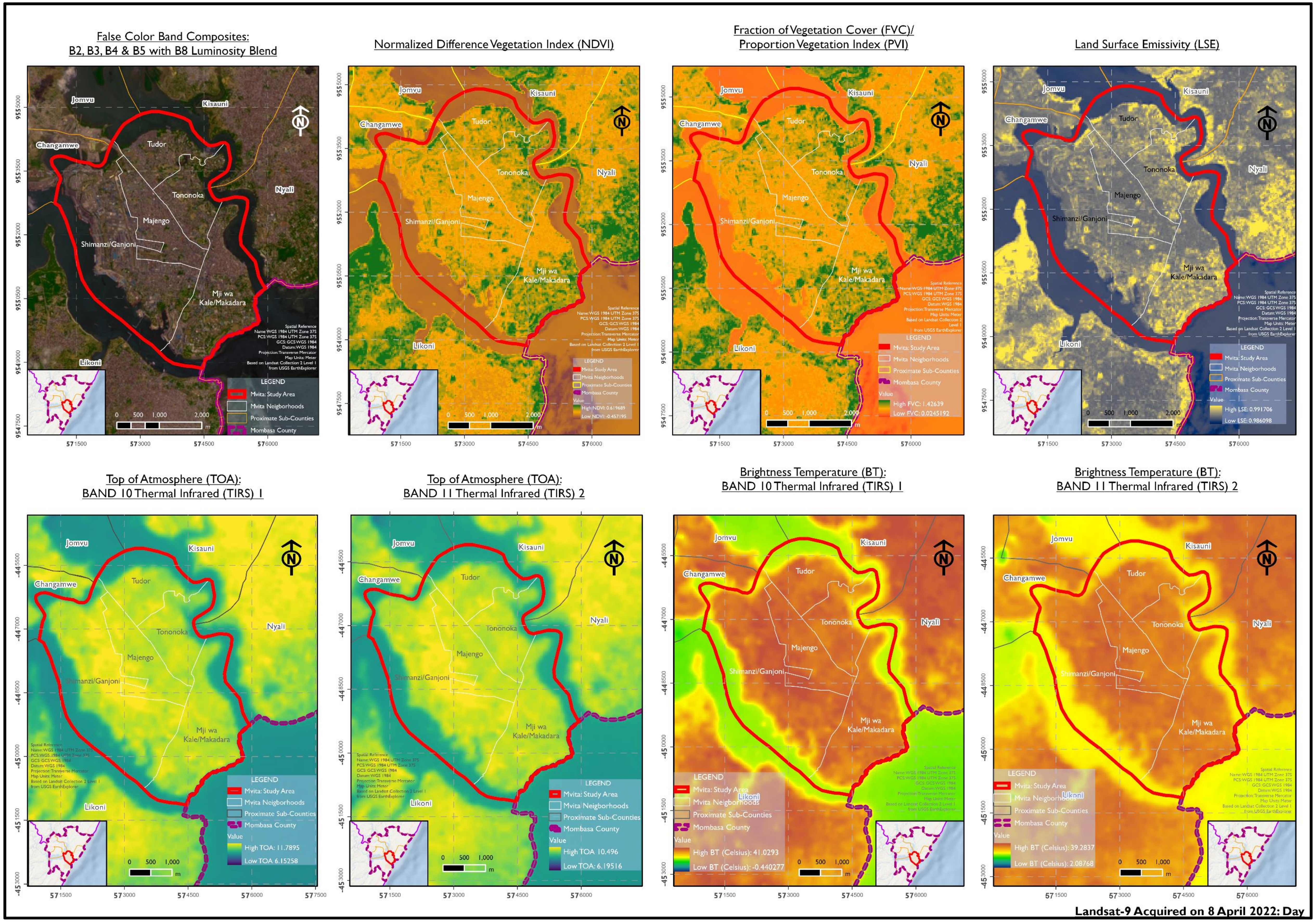
Table 3.1 Calculation of the Land Surface Temperature Using Remote Sensing and GIS Analysis

Processing Chain Methodology	Calculation of LST via Landsat-9 Metadata	Calculation of LST via Landsat-4 and Landsat-7 Metadata
Top of Atmosphere (TOA) Spectral Radiance	TOA (Lλ) = ML * Qcal + AL - Qi Band 10 TOA = 0.0003342 * "B10.TIF" +0.1 -0.29 Band 11 TOA = 0.0003342 * "B10.TIF" +0.1 -0.51 *TOA (Lλ)* Total Spectral Radiance *ML* represents the band specific Multiplicative Rescaling Factor *Qcal* is the Band 10 of Landsat 8 for Landsat 9 *AL* is Band-Specific Additive Rescaling Factor Qi is Correction Value for Band 10 of Landsat 8 for Landsat 9	Landsat 7 TOA= ((17.040- 0.000) / (255- 1)) * ("CorrectedBand6.TIF" -1) +0.000 Landsat 4 TOA= ((15.303- 1.238) / (255- 1)) * ("CorrectedBand6.TIF" -1) +1.238
TOA to Brightness Temperature (BT) Conversion	BT = K2 / Ln ((K1 / TOA) + 1)) − 273.15 Band 10 BT= (1321.0789 / Ln ((774.8853 /"10TOA") +1)) -273.15 Band 11 BT= (1201.1442 / Ln ((480.8883/"11TOA") +1)) -273.15 *BT* Top of Atmosphere Brightness Temperature *Lλ* Total Spectral Radiance *K1* CONSTANT_BAND 10_BAND 11 *K2* CONSTANT_BAND 10_BAND 11	Landsat 7 BT Kelvin= 1282.71 / Ln (666.09 /"TOA" +1) Landsat 7 BT Celsius= 1282.71 / Ln (666.09 /"TOA" +1) -273.15 Landsat 4 BT Kelvin= (1284.30 / Ln (671.62 /"TOA" +1)) Landsat 4 BT Celsius= (1284.30 / Ln (671.62 /"TOA" +1)) -273.15
Normalized Difference Vegetation Index (NDVI) Method for Emissivity Correction	NDVI = Float (Band 5 – Band 4) / Float (Band 5 + Band 4)	-
Calculation of Proportion of Vegetation Index (PVI) or Fraction of Vegetation Cover (FVC)	PVI= Square ((NDVI – NDVImin) / (NDVImax – NDVImin)) PVI = Square (("NDVI" +0.58835) / (0.58835 +0.374091))	-

	Pv Proportion of Vegetation *NDVI* Normalized Difference Vegetation Index *NDVImin* Refer the Previous Result of NDVI minimum value *NDVImax* Refer the Previous Result of NDVI maximum value	
Calculate Land Surface Emissivity (LSE) (ε)	ε =0.004 * Pv + 0.986 ε = Land Surface Emissivity Pv = Proportion of Vegetation 0.986 correction value for the equation	-
Calculate the Land Surface Temperature. LST is calculated using BT (Brightness Temperature), NDVI, LSE (Land Surface Emissivity)	T_S = BT / ((1+ (λ * BT/ ρ) * Ln (ε))) Band 10 LST = "10BT"/ (1 +((10.895 * "10BT" / 14388) * Ln("LSE"))) Band 11 LST ="11BT"/ (1 +((12.005 * "11BT" / 14388) * Ln("LSE"))) Average (AVG) LST = ("10LST" + "11LST") /2 BT Top of Atmosphere Brightness Temperature λ Wave length – Emitted Radiance (λ is 10.895) ε Land Surface Emissivity, ρ = 1.438 ×10−2 m K, = 14388 $\rho = h\frac{c}{\sigma}$ *c* is Boltzmann constant (1.38×10−23 J/K), ***σ*** is s the velocity of light (2.998×108 m/s) and *h* is Planck's constant (6.626×10−34J s)	-

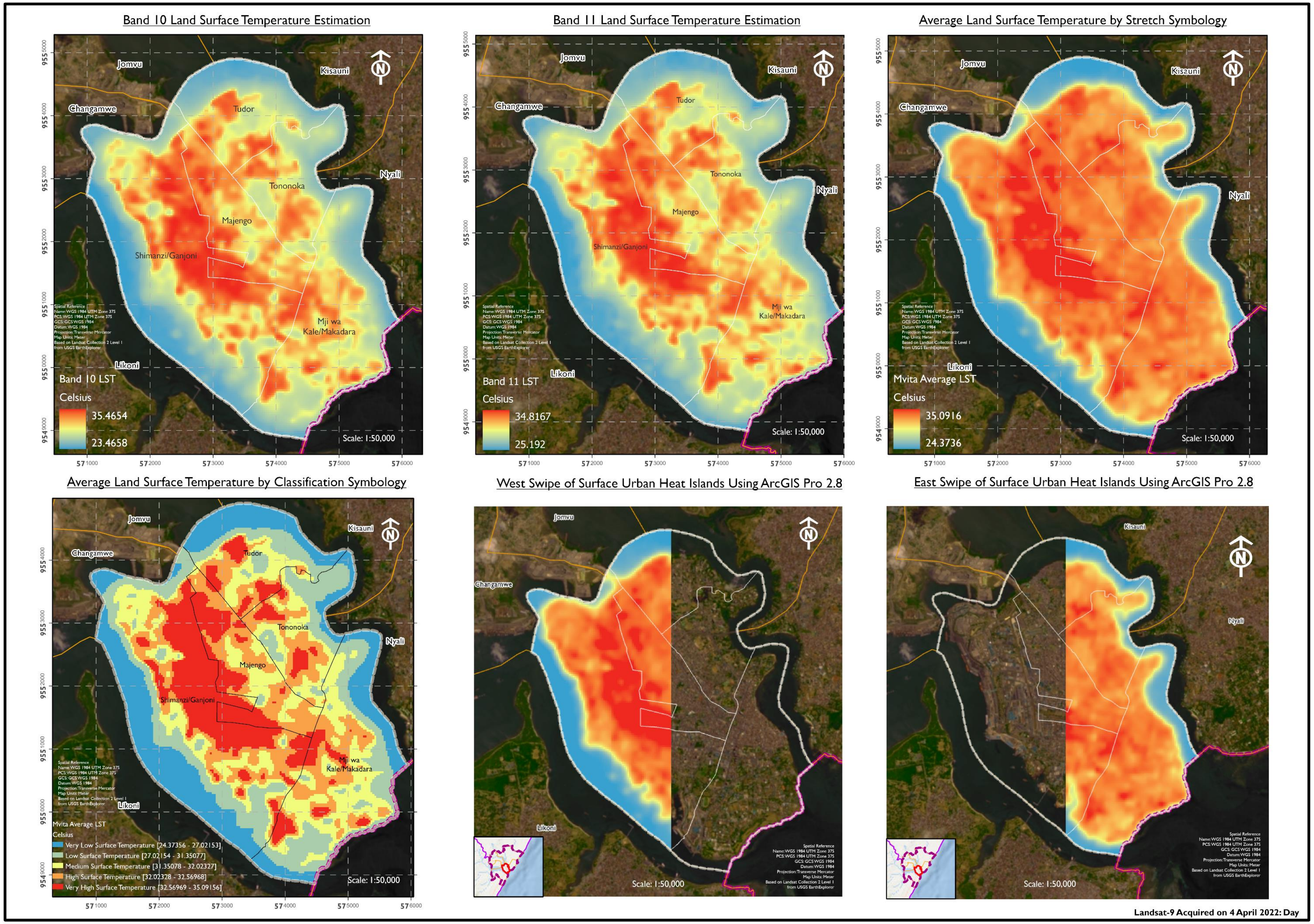
Source: (Avdan & Jovanovska, 2016; Wang & Ientilucci, 2018; USGS Landsat Missions, 2021) Adapted from ArcGIS Pro and ArcGIS Desktop @A3

Map 3.1 Typical Spatial Illustration from the Calculated Chain Methodology for Landsat-9



Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

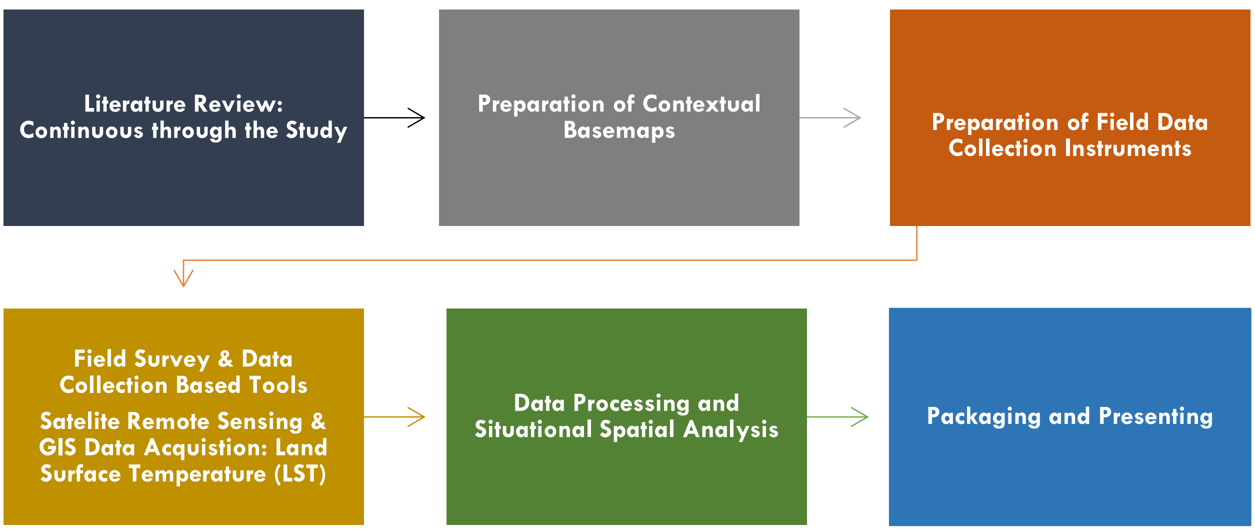
Map 3.2 Typical Spatial Illustration of Generated Surface Urban Heat Island Mapping for Landsat-9



Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

On the other hand, the study encompassed the cross-sectional design, conducted over a period of days in a week between 29th March 2022 and 2nd April 2022. It was based on rapid appraisal via interviewing of key informants, conducting indoor household comfort survey and outdoor thermal survey as well as structured direct observations. Such was to understand the root causes of urban heat islands, identifying solutions and prioritize various issues on social, economic, environmental and institutional implications on urban planning. Holistically, the execution of the entire research design was guided by literature review; preparation of contextual basemaps; preparation of field data collection instruments; actual field research, data acquisition and gathering; data processing and situational spatial analysis as well as packaging and presentation - *See Figure 3.1b.*

Figure 3.1b Summary of the Methodological Approach of the Entire Study



Source: (Author, 2022)

3.3 Description of Study Area

3.3.1 The Sea-Island of Mvita, Mombasa

The geographical scope of study is Mvita Sub-County in Mombasa. It is located at approximately 4°03'11.9"S and 39°39'50.5"E. Mvita is a sea-island and the urban core for Mombasa County — the second largest city in Kenya with an urban population of 1,208,333, after Nairobi City (KNBS, 2019). It has an urban population of 154,171 and a total land area of 14.6 km^2 (KNBS, 2019). Mombasa Vision 2035 gives Mvita a land area of 14.16km^2 in close proximity to that of the Kenya National Bureau of Statistics (KNBS). The total island area, however, inclusive of landmass and water mass from the digitized boundary puts Mvita Sub-County with an area of 19.19km^2 of which this study adopted.

Compared to its proximate areas of Likoni, Changamwe, Jomvu, Kisauni and Nyali Sub-Counties, it houses most of the urbanization development. Such is typified by the growth of urban population, rural-urban migration, increased socio-economic activities and changes in urban morphology as well as land use developments per unit area (County Government of Mombasa & Ministry of Land, Housing and Urban Development, 2015). It underpins the basis of this study reflected in problem statement that Mvita Island is experiencing much significant reverberation effects of urbanization that have been transforming natural landscapes into more impervious surfaces and less vegetation coverage to create hazardous urban heat islands in the city. Coupled further, Mombasa County as the larger geographical context of this study is often characterized by a tropical climate with hot and wet seasons averaging 65 per cent humidity and 32^0 C heat temperature (Kithia & Lyth, 2011). One study predicts that more frequent longer lasting heatwaves are bound to cause outdoor thermal discomfort in face of alterations of the urban wildscapes and green spaces of Mombasa (Kithia & Lyth, 2011). Such is as a result of parallel pressures of land use developmental change by human activities and climate change (Kithia & Lyth, 2011).

3.3.2 Justification of the Study Area

Sadly, little is known to influence as well as prioritize planning interventions for enhancing the mitigation of UHIE in Mombasa that is currently lacking within the ISUDP Mombasa 2035. Thus, planning for a cooler city such as Mombasa and in particular Mvita Sub-County while rapidly-urbanizing is left wanting and alarming due to the potential thermal discomfort from influences of intensifying urbanization coupled by heat-related weather events and climate change. This is in spite of Mvita been surrounded by large volumes of waterways, namely; Tudor Creek to the north and east, Indian Ocean to the south east and Kilindini Port/Harbor to the west that induces sea breezes during the day and land breezes at the night aiding in cooling its core built-up area: the sea-island of Mvita Sub-County. In this manner, since the UHI phenomenon is acutely felt more in the urban built-up area than their proximate suburban areas and countrysides, Mvita-Sub-County is chosen precisely as the study area in relation to its surrounding Sub-Counties in Mombasa – *See Map 4.2.*

Simply, the study focuses on planning for cooler coastal cities of the tropical sub-Saharan Africa. Mombasa, Kenya was therefore selected for the study. Mvita was chosen for its strategic position as well as comparison to its proximate environs of Likoni, Changamwe, Jomvu, Kisauni and Nyali Sub-Counties in Mombasa in relation to UHIE. The principal researcher wanted to assess whether the tropical paradise is now a hotbed of UHIs which are seen as silent killers under the taxonomy of disasters as noted by Emergency Events Database (EM-DAT) due to their hazardous nature on health, wellbeing and the exacerbation of heat waves and glob warming. This study is set to be the first in kind at the Department of Urban and Regional Planning, University of Nairobi in attempting to contribute the existing body of literature on urbanization and climate change related to UHIE at a coastal city. It breaks the monotony of conducting related research studies done numerous in the city of Nairobi and its environs.

3.3.3 Limitations of the Study

On the outdoor thermal engagement, the study uses five outdoor spaces only: Uhuru Gardens, Fort Jesus Park, Mama Ngina Waterfront Park/Azania Drive Avenue, Mombasa Road and Moi Avenue. The justification of the outdoor public spaces is that they are very common, frequented and notable spaces and places in the sea-island of Mvita, Mombasa. The narrowing to the five outdoor public spaces also came as an impromptu notice from supervisors during the field work and because of limited time schedule and budget for the fieldwork.

The study's assessment of UHIE is limited to the daytime surface UHIs and not nocturnal surface UHIs. It has not included the atmospheric UHIs and Heat Vulnerability Indexes (HVIs). Although it has well presented the weather and climatology evaluation between 1991 to 2021 on ambient air temperature at 2m and perceptions on heat exposure, sensitivity and adaptive capacity as a function of vulnerability under the causes, effects and planning interventions of the UHIE respectively. Last but not least, the study converses broadly on climate change issues like coastal flooding, mangrove drowning and sea level rise.

3.4 Data Needs Matrix

Table 3.1 illustrates data needs matrix based on the four research objectives.

Table 3.1 Data Need Matrix of the Study

Research Objective	Data Needs	Sources of Data	Methods of Data Collection	Methods of Data Analysis	Expected Outputs
To map the surface urban heat islands in Mombasa.	Landsat-9 imagery retrieved within 18th December, 2022 and 15th April, 2022 as the hottest months in Mombasa. The study used Landsat-9 Operational Land Image (OLI) and Thermal Infrared Sensor (TIRS) acquired on 8th April 2022, Day with less cloud coverage of 0-30 percent. A 30-year interval of spatio-temporal trend analysis of the Normalized Difference Built-Up Index (NDBI), Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature in 1992, 2002 and 2022. The study used Landsat-4 Thematic Mapper (TM) acquired on 24 June 1992, Day and Landsat-7 Enhanced Thematic Mapper Plus (ETM+) acquired on 22 July 2002. June and July were settled on the formative years as their respective days presented a less cloud coverage of 0- 30 percent and are in close proximity to April as one of hottest months in Mombasa, over the years.	USGS EarthExplorer website	Spatio-temporal collection of Landsat series of satellite imagery with less cloud coverage of 0-30 percent: Landsat 4 (1992), Landsat 7 (2002) and Landsat 9 (2022), a 30-year time-span.	Spatio-temporal analysis of the vegetation coverage, built-up and land surface temperature using ArcGIS Pro and ArcGIS Desktop. Correlation trend analysis of built area and vegetation coverage with the land surface temperature to test the research hypothesis. Content analysis	Profiling of the urban density index, population density, normalized difference vegetation index and surface urban heat islands using Landsat series of satellites from USGS EarthExplorer website
To examine the causes of urban heat islands in Mombasa.	Urbanization and urban development assessment; urban thermal environment assessment; weather conditions and climatology assessment [January 1990 to December 2021 — a 30+ years' time series examination] as well as legal and policy issues assessment on urban heat island effect. Others include urban morphology assessment and release of anthropogenic heat.	Actual field survey and visual survey. Secondary data from the USGS EarthExplorer, NASA Prediction of Worldwide Energy Sources (POWER) Data Access Viewer, Google Earth Pro, County Government of Mombasa, NEMA and KNBS.	Time series data collection, indoor household and outdoor thermal comfort surveys using KoboCollect, interview schedule guides, visual survey recording checklist and desktop reviews.	Spatio-temporal analysis, time series analysis, content analysis and pictorial descriptions. Qualitative and quantitative analysis. Web Kobo Toolbox result findings repository.	Understanding the risk exposures on the root causes of urban heat islands according to the context of the city.

To assess the social, economic, environmental and institutional effects of urban heat islands in Mombasa.	Social, economic, environmental and institutional impacts of urban heat islands	Actual field survey and visual survey. Desktop surveys and library literature reviews.	Comfort surveys to households and users of public spaces via KoboCollect, interview schedule guides and visual survey recording checklist.	Content and thematic analysis of the impacts. Qualitative and quantitative analysis. Web Kobo Toolbox result findings repository	Understanding the sensitivity rating on the impacts of urban heat islands in the socio-ecological panarchy.
To propose planning interventions for enhancing the mitigation of urban heat island effect in Mombasa.	Social resilience strategy, economic resilience strategy, environmental resilience strategy and institutional resilience strategies divided into the legislative, policy, actors and financial aspects.	Aggregated insights from actual field survey and visual survey. Desktop surveys and library literature reviews.	Aggregated insights from actual field survey and visual survey. Desktop surveys and library literature reviews	Deductions from literature review, field surveys based on Web Kobo Toolbox findings repository, interview schedules, observation matrix and spatio-temporal analysis and content analysis of the previous objectives.	Identification and prioritization of the planning solutions on social, economy, environment and institutional aspects

Source: (Author, 2022) Adapted from Literature Review and Fieldwork @A3

3.5 Sampling Procedure

The study employed a combination of non-probability and probability sampling procedures. On the former, purposive sampling was used for the key informant interviews at the national and sub-national levels of the government. Namely, a County Physical Planner at the Department of Lands, Planning and Housing; a County Architect at the Department of Transport, Infrastructure & Public Works; a Public Health Practitioner at the Coast General Teaching & Referral Hospital; a County Climate Change Expert at the Department of Climate Change; a County Environment Officer at the Department of Environment Compliance and a National Environmental Officer at the National Environmental Management Authority. A total of six key informants were interviewed.

On the latter, this study applied proportionate stratified random sampling to obtain responses from the households and users of public spaces using the prepared participatory household and outdoor thermal comfort surveys/questionnaires in Mvita Island. The locational strata used were the four wards/neighborhoods of Mvita Sub-County which include Shimanzi/Ganjoni, Majengo, Tudor, Tononoka and Mji wa Kale/Makadara – *See Map 4.3*. The structured direct observations were also centered on these neighborhoods. Collectively, the adopted mixed sampling procedures brought together insights from community residents, users of public spaces within the public green spaces and streets, an urban planner, architect, environmental experts, a public health expert and a climate change expert.

3.5.1 Delimitation of Study and Sample Size

The study area location was Mvita Sub-County, Mombasa County. This sea-island delimited into four wards were characterized as neighborhoods and served as the locational strata in proportionate stratified random sampling for administration of the comfort surveys. The selection of households was chosen randomly based on the four locational strata. The sampling frame was all the target households of Mvita Sub-County is 38,995. The chosen confidence level is 95 per cent while the margin of error was 12. Using the online Cochran's sample size formula provided at the survey monkey website, a sample size of 67 cases of households was obtained on the chosen confidence level and margin of error – *See Table 3.2*. The sampling fraction for the random sample sizes from each stratum was provided by the calculated sample size [67] divided by the population, herein, as total households [38,995] then, multiplied by each of the household population stratum. A total of 67 comfort surveys/questionnaires for the households were to be administered during field work with approximately 10 in Shimanzi; 19 in Majengo; 20 in Tudor; 11 in Tononoka and 7 in Mji wa Kale using KoboCollect. Ultimately, indoor households amounted to 68 with the additional sample been administered in Tudor Ward. The distribution of the households was also in line with the places/settlements given by the neighborhood context of Mvita- *See Map 3.3 and 4.3*.

Table 3.2 Delimitation of Study and Sample Size: Proportionate Stratified Random Sampling

Neighborhoods/ Locational Strata	**Total Households [38,995]**	**Sample Size [67] ***
Shimanzi/Ganjoni [Inclusive of Railway]	6,060	10
Majengo [Inclusive of Mwembe Tayari]	10,925	19
Tudor	11,640	20
Tononoka	6,340	11
Mji wa Kale/Makadara	4,030	7
Total	38,995	67

* Rounded off

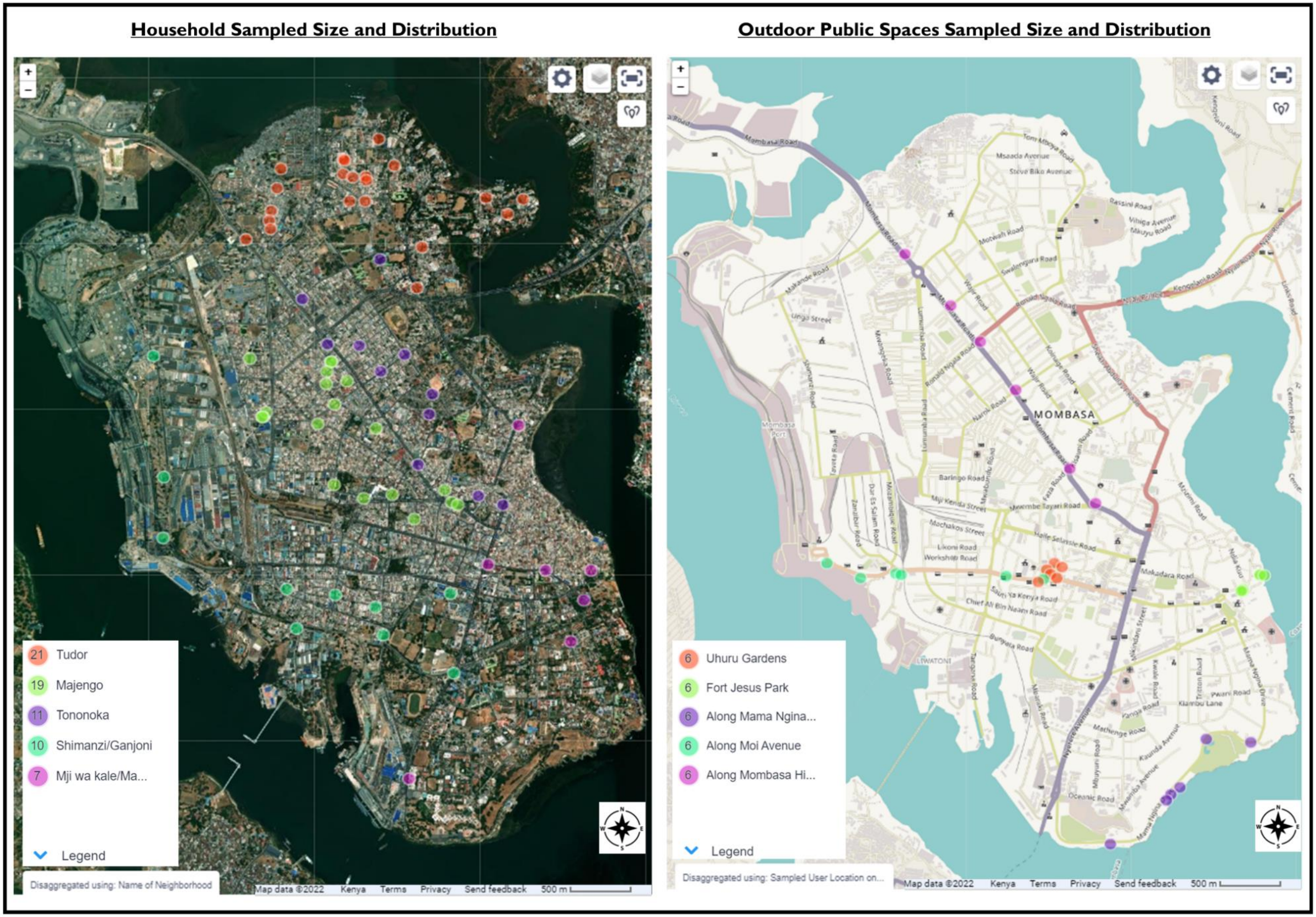
Source: (KNBS, 2019) Based on Sampling Fraction

On the outdoor thermal survey, a total of 30 users of public spaces were conducted evenly in six locations: Mombasa Road, Moi Avenue, Fort Jesus Park, Mama Ngina Waterfront Park and Uhuru Gardens *– See Map 3.3.* In entirety, the study accommodated the views and insights of 98 persons and 6 key informants. The sampling procedure for the study utilized the 30-sample rule-of-thumb which justifies the minimum selection of sample size of 30 and above as advocated by William Gosset, a statistician as well as Head Brewer of Guinness, in his 1908 article published under the pseudonym of Student, *Probable error of a correlation coefficient* (Student, 1908). It also attempts to cancel effects of skewness and higher margin of error because its rationale is based on the central limit theorem (Morte, 2016) and at least 28-30 and above questionnaires as per Sekran & Bougie (2010) would be considered for right and appropriate for a post-graduate study.

3.5.2 Sampling Techniques

The interviews from the six key informants the study employed purposive sampling technique. On the other hand, the participatory comfort surveys to the community households were based on proportionate stratified random sampling technique.

Map 3.3 Spatial Distribution of the Household and Outdoor Participatory Thermal Comfort Survey



Source: (Author, 2022) Adapted from Web KoboToolbox Map Repository

On the outdoor thermal survey, the study opted to concentrate common and often frequented Mombasa Road, Moi Avenue, Fort Jesus Park, Mama Ngina Waterfront Park and the Uhuru Gardens.

3.6 Data Collection Methods

The study encompassed collection of both primary and secondary methods of data collection. Primary data collection entailed actual field survey as well as questionnaire administrations for household and outdoor thermal comfort surveys with open-ended and closed-ended questions that were prepared from the Web Kobo Toolbox Repository. Moreover, taking of photographs and face-to-face interviews with six key informants were undertaken. The prepared contextual base maps also aided in the primary collection of data - *See Map 4.1 to Map 4.4*. The instruments were developed to address the four research objectives on the planning implication of urban heat island effect in Mombasa - *See Annex I.* The primary data collection was undertaken between 29th March 2022 and 2nd April 2022.

In the collection of secondary data, the study heavily depended on satellite remote sensing and GIS tools and techniques within the realm of Earth Science using USGS Earth Explorer, NASA Power Data Access Viewer, ArcGIS Desktop 10.8 and ArcGIS Pro 2.8. Moreover, published literature reviews and case studies based on social, economic, environmental and institutional resilience were entailed on the planning implication of urban heat island effect in Mombasa. Read published materials were mainly the journals, reports, books and internet sources. The search terms used for the literature study oscillated on urban heat islands, urban heat island effect, urbanization, climate change, urban planning, planning implications, Mvita Island, tropical coastal city of Mombasa and varied combinations. Geographically provided shapefiles were based on IEBC data as well as from Mombasa Vision 2035, an ISUDP Plan for the County Government of Mombasa. Moreover, self-created shapefiles, raster data sets as imageries through ArcGIS 10.8 and ArcGIS 2.8 Pro, Map Puzzle, Google Maps, Google Earth Pro and Google Earth Engine were constituted in creation of maps and graphic displays based on the spatio-temporal data acquisitions.

3.7 Data Analysis and Presentation

Data analysis involved a mixture of qualitative and quantitative techniques as well as spatio-temporal analysis. Qualitative analysis techniques entailed photographic description as well as content analysis to highlight insights and concerns from the literature review, key informants, household participants and users of public spaces. Quantitative analysis techniques included use of numerical values from the USGS Earth Explorer, NASA Power Data Access Viewer, ArcGIS Desktop 10.8, ArcGIS Pro 2.8, Web Kobo Toolbox and Microsoft Excel from research objectives. Data presentation in this study comprised display of variety of maps, photographic descriptions, tables, figures, PowerPoint presentation and this dossier.

3.8. Expected Outputs

Table 3.1 highlights the expected outputs of this study. However, a key expected output was in testing the null hypothesis that interrogated that there isn't a significant relationship between the urban built-up area and vegetation coverage with the urban heat island effect. The result findings rejected this null hypothesis. This follows as a Pearson Correlation was performed to test if there is a relationship between the Normalized Difference Built-Up Index (NDBI) and Normalized Difference Vegetation Index (NDVI) of Mvita Island and Mombasa County with the Land Surface Temperature (LST) in 2022, 2002 and 1992, a 30-year period. The results indicated that there was a significant positive association, upward trend association, between the NDBI and LST as well as the NDVI and LST. As the built-up areas increases, the vegetation coverage reduces which in turn caused the increase of the urban heat islands over the 30-year interval, from 1992 to 2022 in Mvita Island and Mombasa. The physical and land use planning of the city has made Mvita a concrete jungle with less vegetation potentially credited to its changing shift in socio-cultural, economic and political controlling interests over the centuries. In this manner, based on the result findings in chapter four and five, the research hypothesis reads that there is significant relationship between the urban built-up area and vegetation coverage with the urban heat island effect.

3.9. Quality of The Study

The study employed the rule of thumb for obtaining a sample size of 30 and above. The study also applied content validity to accurate represent research objectives on the used instruments based on the data needs matrix *- See Table 3.1*. The study was propelled by the directions of the supervisors. Graphical visual aids such as basemap and neighborhood context maps were used to break the ice on information gathering. On the Landsat series of satellites, the dates of the months were chosen to be within close proximity between the months of 18th December and 15th April that are normally the hottest months in Mombasa County, each year.

The Landsat series of satellite (Landsat 4, Landsat 7 and Landsat 9) were based on Landsat Collection 2 Level 1 from United States Geological Survey (USGS) EarthExplorer website to enable calculation of Top of the Atmosphere (TOA) radiance and Brightness Temperature (BT). Although Landsat 9 has higher high-quality and medium-resolution images of Earth's landscapes and coastal regions every eight days with improved atmospheric corrections than Landsat 8, its Operational Land Imager (OLI)-2 design is still a copy of Landsat 8's OLI. It will still provide imagery consistent with previous Landsat spectral, spatial, radiometric and geometric qualities (USGS Landsat Missions, 2021). As a result, correction values for Landsat 8 were still used for the Landsat 9. Landsat 9 was launched on Sept. 27, 2021.

3.10. Ethical Considerations

Research permits from Department of Urban and Regional Planning, University of Nairobi and County Secretary, County Government of Mombasa; school and national identification cards were carried throughout this research study. In respecting the anonymity and confidentiality of the identified key informants relevant to urban thermal environment, the principal investigator used the participant information sheet, though none of the key infants signed on it. Uprightness and sincerity in data analysis and presentation were earnestly executed.

CHAPTER FOUR:

PROFILE OF SURFACE URBAN HEAT ISLANDS IN MOMBASA

4.1 Contextual Background of the Study Area

4.1.1 Historical Profile of Mvita Sea-Island

Mombasa stems from an Arabic name *"Manbasa"* and a Swahili name of "*Kisiwa Cha Mvita"* meaning *"Island of War"* as a result of its numerous changes of ownership and administration. The urban thermal environment has long been in existent in Mvita Island and Mombasa in its entirety since the 1st century AD, until now 21st century due to its tropical hot and wet climate. The sea-island is linked to its adjacent mainland of Changamwe, Kisauni, Likoni and Jomvu which comprises as the tropical coastal city of Mombasa - *See Map 4.2*. The original inhabitants of Mombasa town, before it cemented its municipality and city status and a chief sea-port along the Kenyan coastline were the Bantu-speaking population whom grew and diversified more with Swahili and Mijikenda people following the dominance of Arabic influence through trade and inter-marriages. The strategic position of Mvita Island, then considered as Mombasa town, experienced a changing shift in socio-cultural, economic and political controlling interests from the Arabs, Persians, Portuguese and Turks until the middle 19th century; Sultanate of Zanzibar till late 19th century, British administration until Kenyan independence on the 12th December 1963. Within the 20th century, Mombasa town remained the capital of the British East Africa Protectorate around 1907; became the capital of the Coastal British Protectorate in 1920; later a municipality in 1928 and assumed council status in 1959. In the early 21st century, Mombasa was elevated to a city status.

Such historical account of Mombasa saw transformation of the construction materials from just clay with mangrove structures as well as walls with mangrove structures to newly industrialized materials such as glass, steel and concrete. The neighborhoods of the Old town and Majengo in Mvita Island were initially settled on and still do bear similar artisanal construction materials, urban morphology and retained ownership from the historical account. Thus, until now houses are still closely packed in Old Town and Majengo often casting shade on each other. The use of window bays in creating canopy design in Old Town and Mombasa Central Business District — transitioning between Majengo and Mji wa Kale Ward where Old Town is situated — cast shade on the streets as a cooling measure for the urban thermal environment. Majengo and Mji wa Kale still possesses this Swahili architecture – *See Plate 4.1*. Shimanzi Ward grew as a result of the newly developed Kilindini Harbor Port to the West of Mvita Island as the location had more available space for expansion. This is because the services around the former Old Port in Old Town were mainly of residential nature and did not adequately serve industrial needs of the Island – *See Plate 4.2*. The city of Mombasa grew and developed from the South East of Mvita Island, particularly, in Mji wa Kale and spread out to Majengo, Tononoka, Shimanzi eventual Tudor Ward. The three former wards often have low-income earners to middle-income earners and are now undergoing urban renewal in making urban development more regulated whereas the latter two are mostly of low-density developments with high-income earners and have more conventional planning standards than the Old Town, Majengo and Tononoka Wards.

Plate 4.1 Swahili Architecture in Mvita Island, Mombasa

The Old Town, Mji wa Kale with window bays, narrow streets and closely packed houses

Ziwani, Majengo with old and closely packed houses with narrow streets

Source: (Author, 2022) Adapted from Field Survey

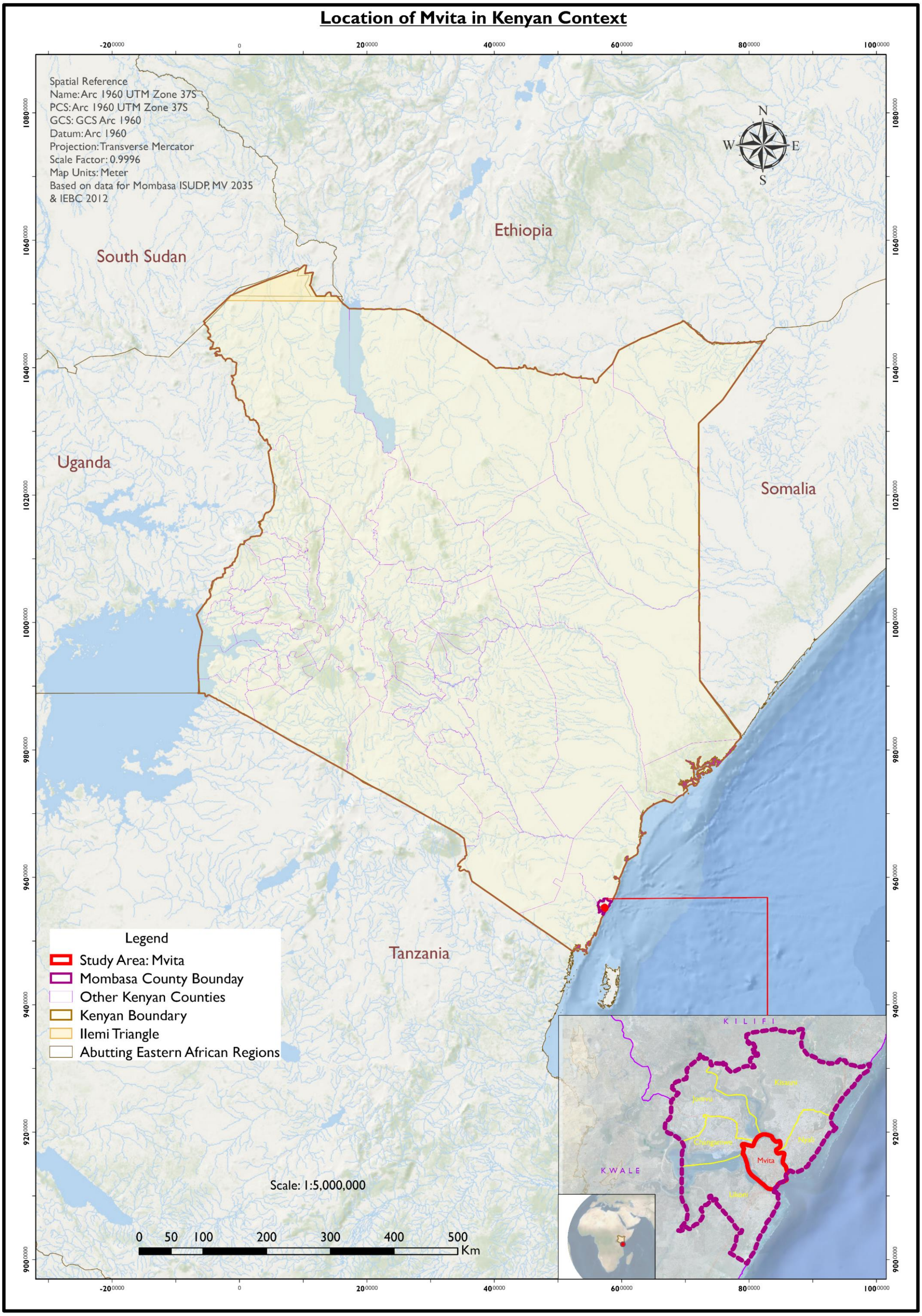
Plate 4.2 The Mombasa Old Town Signage at Old Port, Mji wa Kale

A joint preparation by MOTCO (Mombasa Old Town Conservation Office- National Museum of Kenya and CRATerre-ENSAF (France) with support from the French Embassy in Nairobi.

Source: (Author, 2022) Adapted from Field Survey

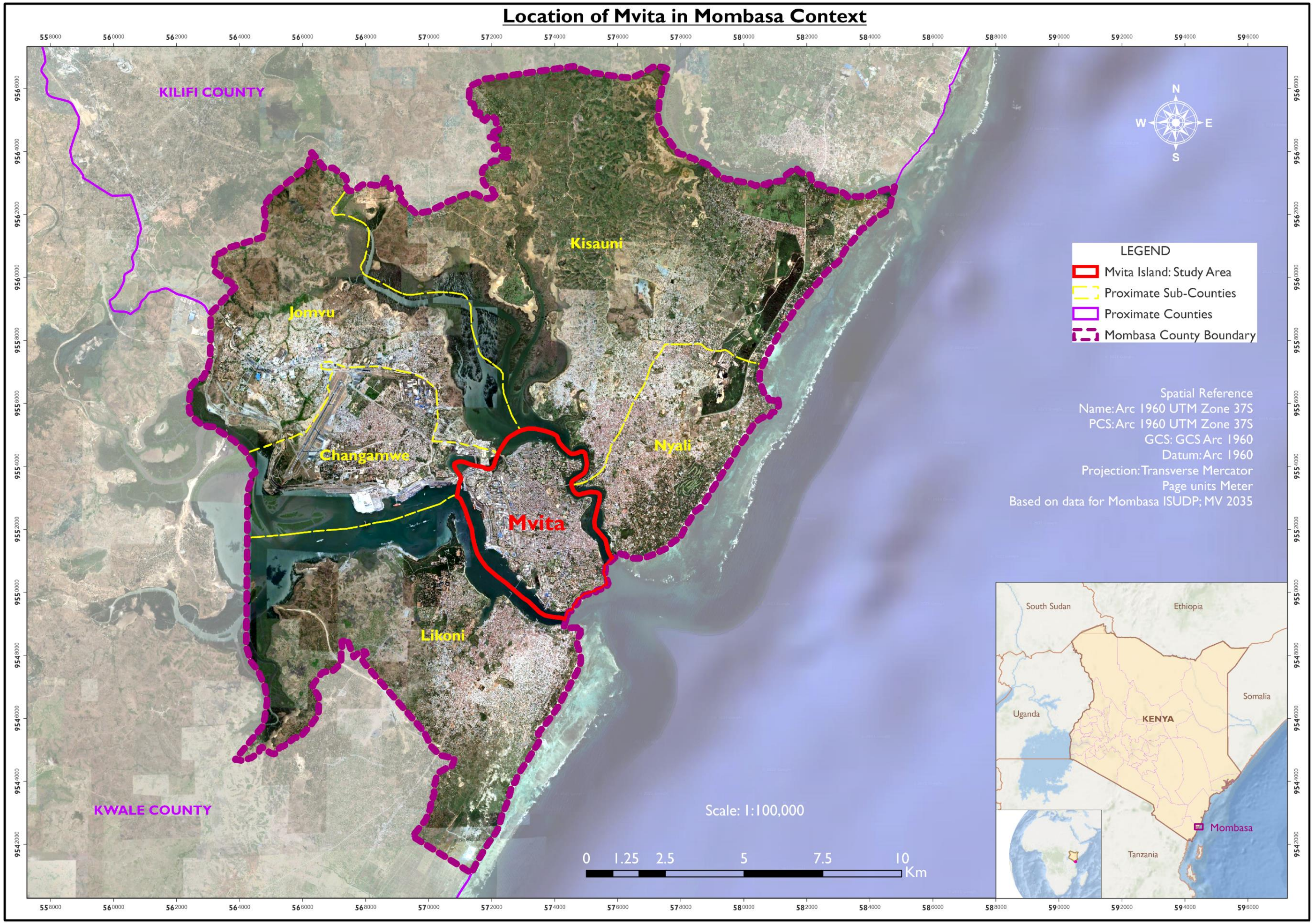
4.1.2 Locational Context of the Study Area

Map 4.1 Mvita Island in National Context



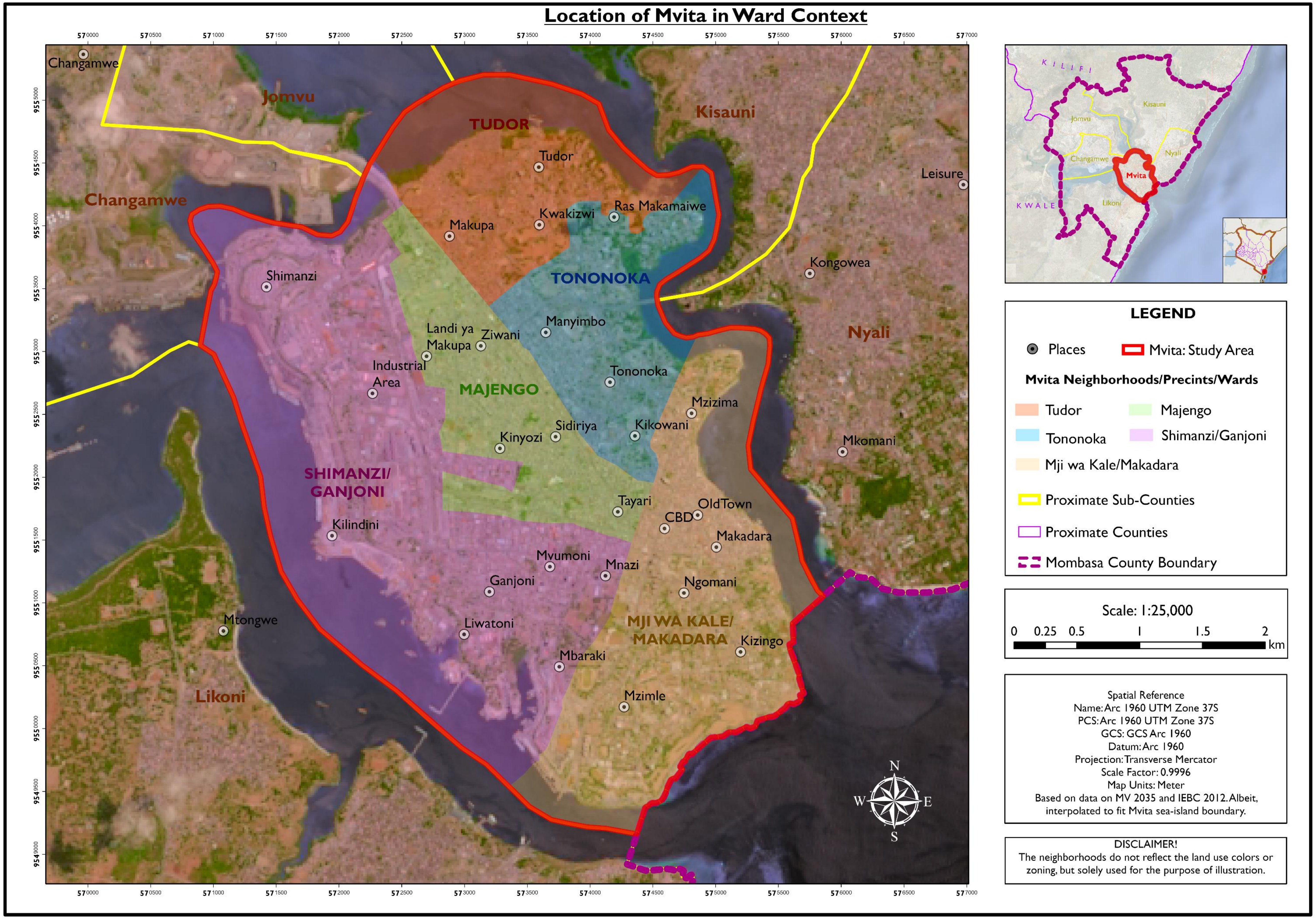
Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

Map 4.2 Mvita Island in County Context



Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

Map 4.3 Mvita Island in Neighborhood Context



Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

Map 4.4 Mvita Island in Detailed Context

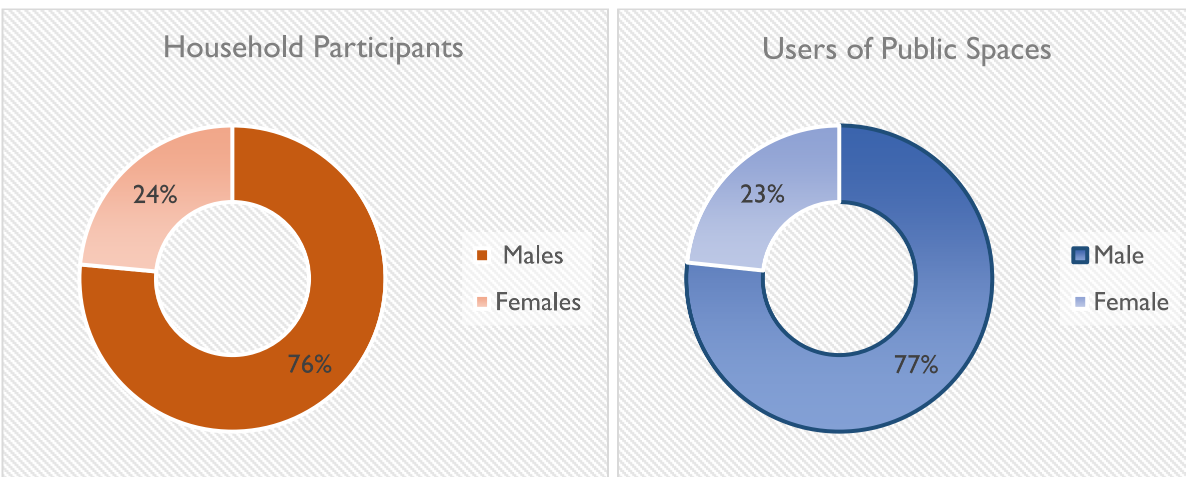
Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

4.2 Brief Background of the Sampled Participants

4.2.1 Gender Profile for Household Participants and Users of Public Spaces

Figure 4.1 shows gender profile for household participants and users of public spaces in Mvita Island, Mombasa. A total of 68 household participants were involved on the administration of the indoor household participatory thermal comfort survey while an aggregate of 30 users of public spaces participated on the administration of the outdoor participatory thermal comfort survey using KoboCollect. On the former, about 76 per cent of the household participants were males while 24 per cent were females. On the latter, about 77 percent of the users of public spaces engaged were males and the remaining 23 per cent were females. Such gender profile gives an inference to the level of involvement and engagement on the males and females encountered during the actual field thermal survey.

Figure 4.1 Gender Profile for Household Participants and Users of Public Spaces

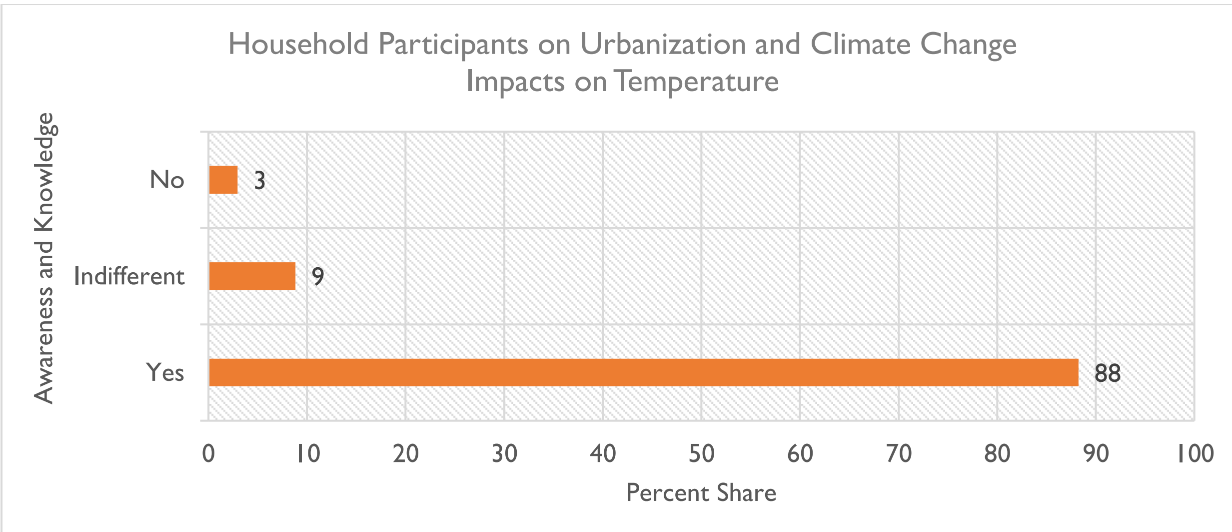


Source: (Author, 2022) Adapted from Field Work

4.2.2 Awareness of Urbanization and Climate Change Impacts on Temperature

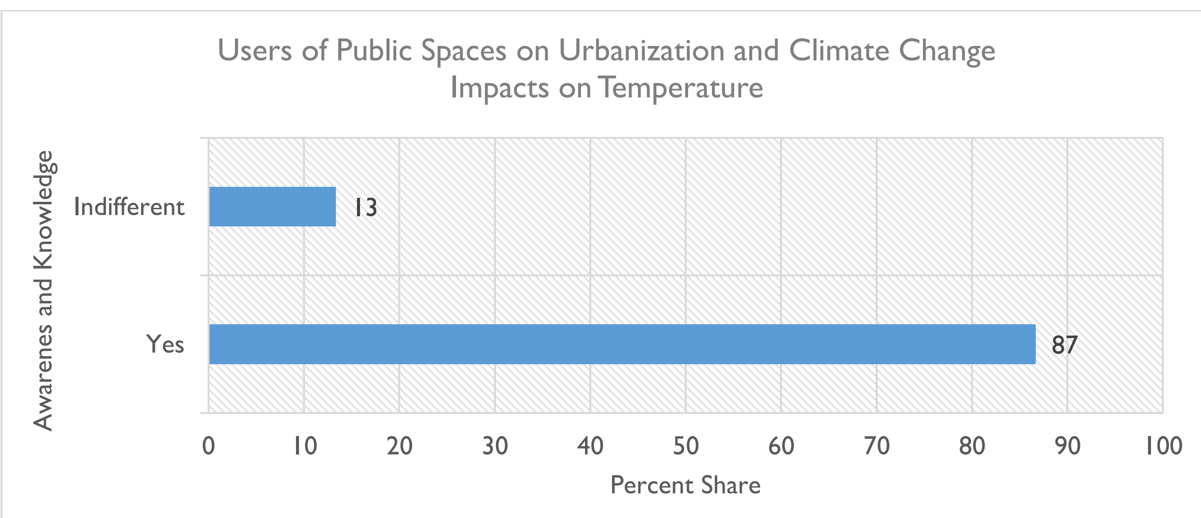
All the six key informants engaged were well aware and knowledgeable about climate change and urbanization impacts on the urban thermal environment. These were the County Physical Planner, County Architect; Public Health Practitioner, Urban Climate Change Expert, County Environment Officer and National Environmental Management Authority Officer. A larger share of household participants [88 per cent] and users of public spaces [87 per cent] affirmed that they aware about climate change and urbanization impacts on temperature. Nevertheless, there is still need for more awareness as well as knowledge about urbanization and climate change effects on the thermal environment by the remaining smaller representative samples of the target population. This is paramount in attaining a higher position of institutional adaptive capacity in Mvita, Mombasa. Figure 4.2a and Figure 4.2b illustrates about awareness and knowledge of urbanization and climate change impacts on temperature for household participants and users of public spaces in Mvita Island, Mombasa respectively.

Figure 4.2a Household Participants: Thermal Awareness on Urbanization and Climate Change



Source: (Author, 2022) Adapted from Field Work

Figure 4.2b Users of Public Spaces: Thermal Awareness on Urbanization and Climate Change



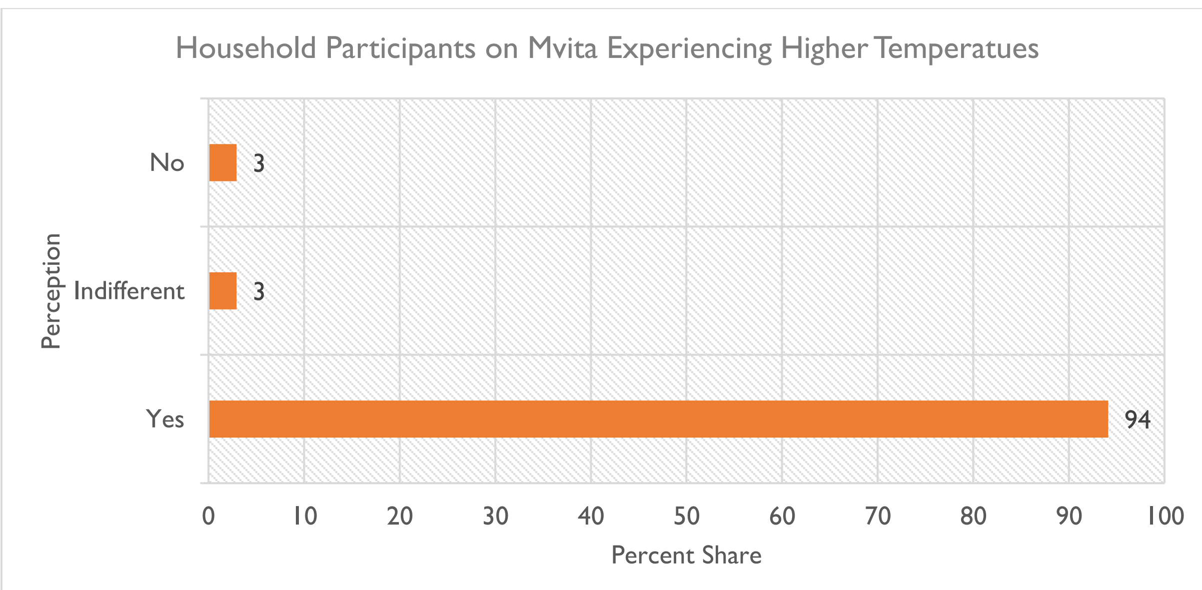
Source: (Author, 2022) Adapted from Field Work

4.2.3 Perception on the Urban Heat Island Effect in Mombasa

Each interviewed key informant affirmed that perceive that there are higher/warmer temperatures experienced in Mvita that outlying areas of Changamwe and Jomvu to the north, Kisauni and Nyali to the east and Likoni to the west. Namely; the County Physical Planner, County Architect; County Public Health Practitioner, County Climate Change Expert; County Environment Officer as well as the National Environmental Management Authority Officer.

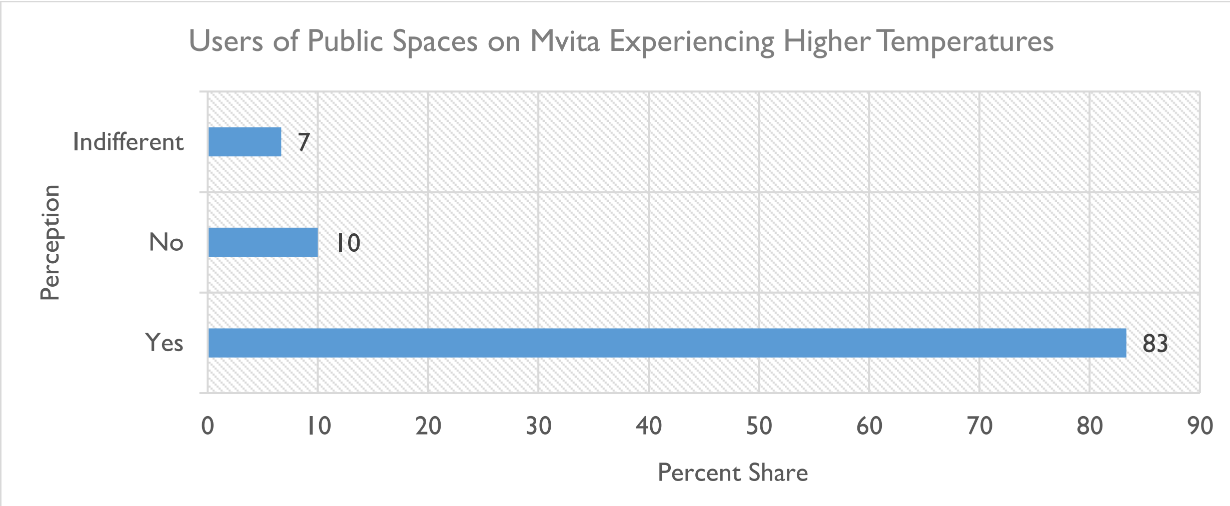
A greater proportion of household participants [94 per cent] and the users of public spaces [83 per cent] perceived also that the island experiences warmer temperatures than outlying areas. Such perception acknowledges the presence of the urban heat island effect in Mvita, that necessitates the undertaking this research study. To mention a few, understanding of the root causes of urban heat islands; effects of urban heat islands as well as adaptive capacity needed on feasible mitigation options to plan for cooler coastal cities. Figure 4.3a and Figure 4.3b demonstrates the perception of higher temperatures in Mvita Island than for household participants and users of public spaces respectively.

Figure 4.3a Perception of Higher Temperatures in Mvita Island than Outlying Areas



Source: (Author, 2022) Adapted from Field Work

Figure 4.3b Perception of Higher Temperatures in Mvita Island than Outlying Areas



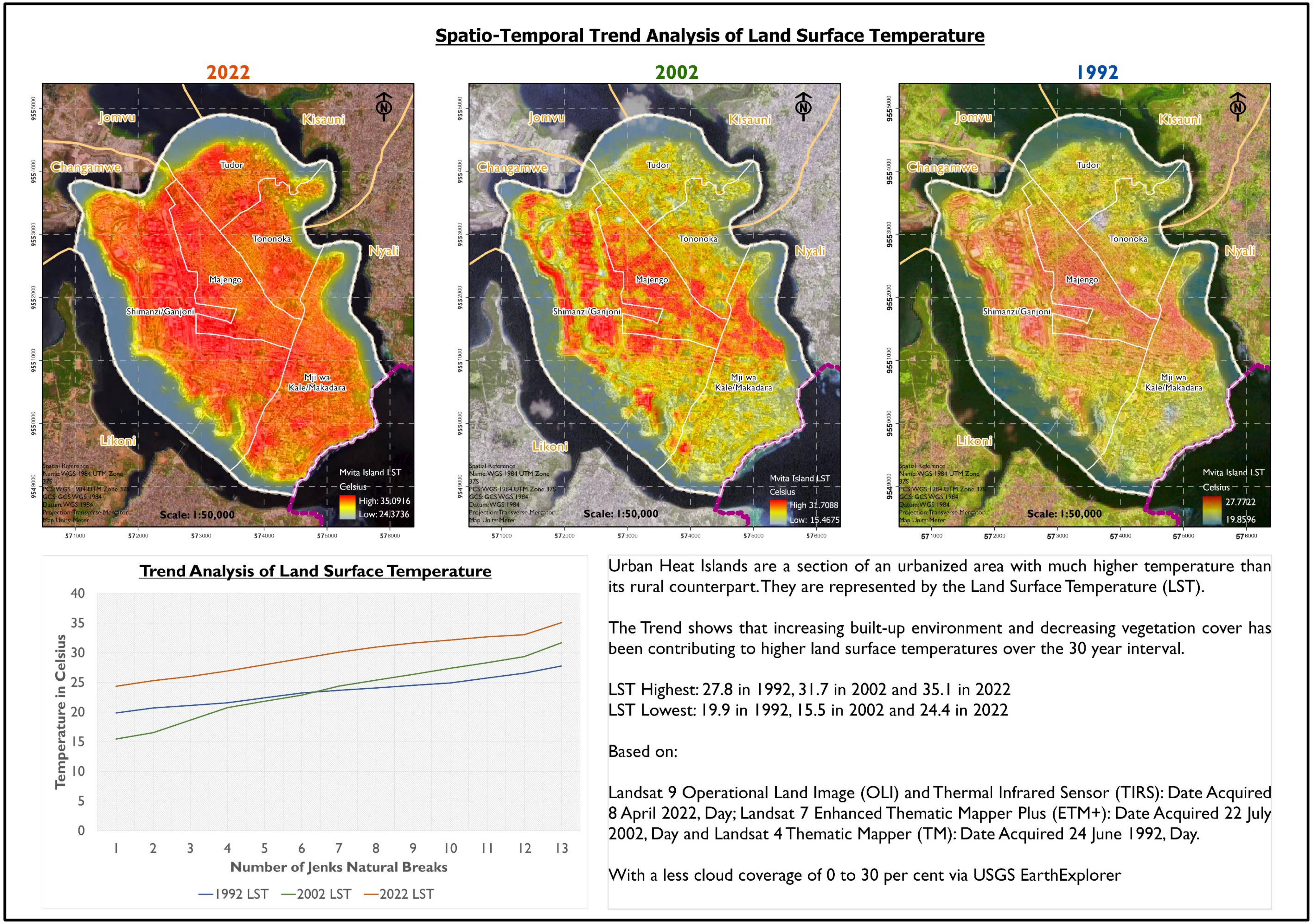
Source: (Author, 2022) Adapted from Field Work

4.3 Mapping of Surface Urban Heat Islands in Mombasa

Surface urban heat islands aided in the understanding the differences of LST in urban areas relative to peri-urban and rural hinterland areas, on one hand and identification of hot-spots and cool-spots of the island. The LST was chosen for this study to map the surface urban heat islands, during the day. Nighttime surface urban heat islands were not calculated and is therefore constituted under areas of further research. A spatio-temporal analysis of the Land Surface Temperature (LST) in Mvita Island was carried out for 1992, 2021 and 2022 correspondingly from Landsat 4 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM+) as well as the Landsat 9 Operational Land Image (OLI) and Thermal Infrared Sensor (TIRS) acquired daytime - *See Map 4.5*. Surface urban heat islands have been increasing over the 30-years. The highest average LST recorded in 1992 was 27.77^{0}C while in 2022 was monitored at 35.09^{0}C in Mvita Island. Currently, for the Mombasa County is 37.77^{0}C - *See Map 4.6*. Based on the classification symbology, the average LST in 2022 for Mvita ranges the very low surface temperature as 24.4 to 27.01^{0}C; low as 27.01 to 31.35^{0}C and medium as 31.03 to 32.02^{0}C, which are alarming, considering an acceptable urban thermal environment is between 20 and 27°C.

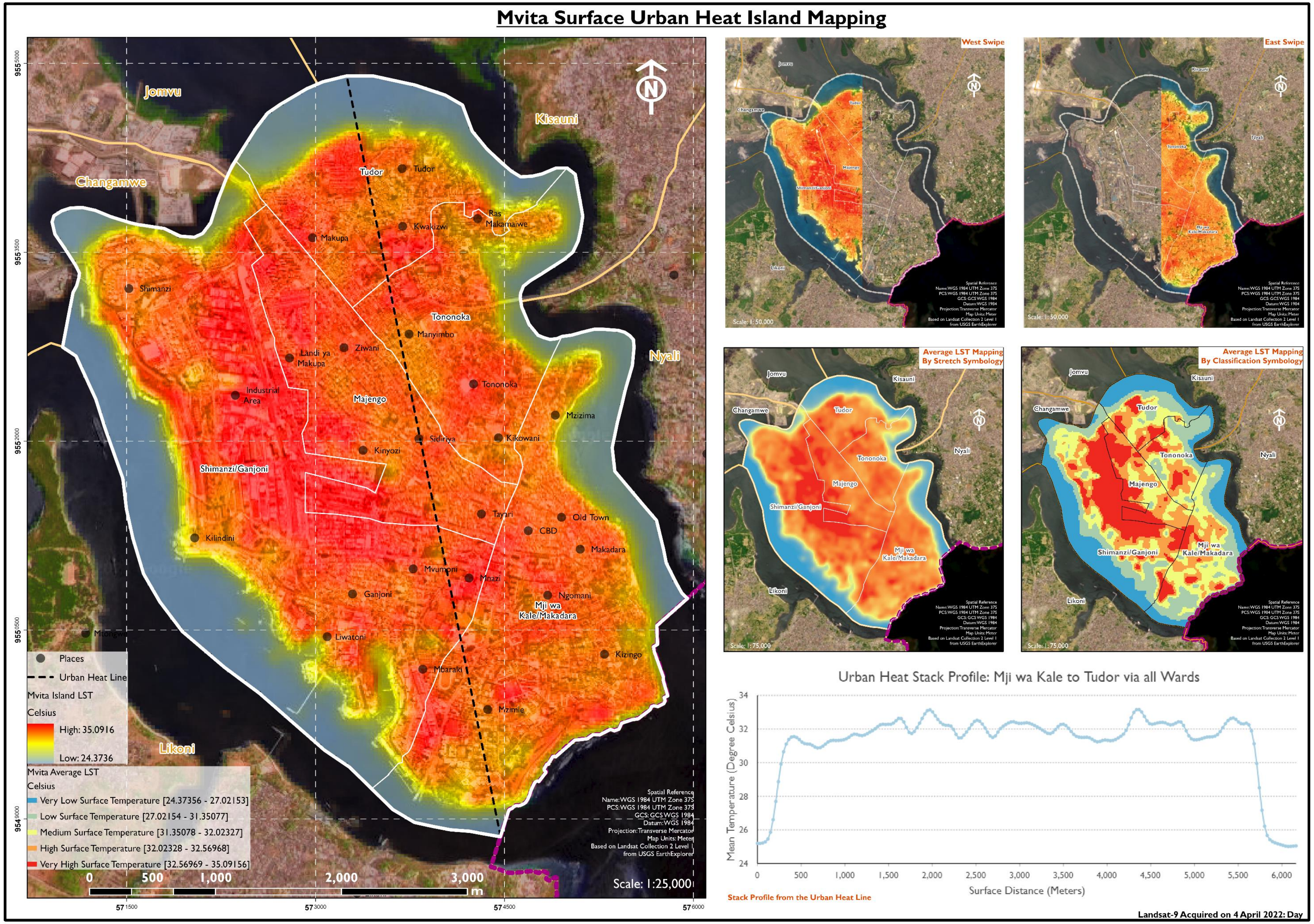
Surface urban heat islands are more pronounced at sunset due to the slow release of heat from impervious surfaces especially in deep canyons. This explains the higher temperatures registered by the intensified red colour on the 2022 LST. Largely, this is attributed to the shallow geometry of urban canyons that tend to have more exposed impervious surfaces in areas such as the Shimanzi industrial area — that absorbs more incoming solar radiation than those places with deep canyons during the day like Old Town and Majengo. The industrial emissions also contribute to the addition of heat in the atmosphere. The frequent prevailing winds from the south and south-south-east helps cool Mji wa Kale. Within the island, Mvita bears peak surface urban heat islands with intensity variations of 8.2 to 10.7^{0}C during the day whereas Mombasa County bears peak surface urban heat islands with intensity variations of 21.4 to 26.2^{0}C - *See Map 4.6 and 4.7 respectively*. On adjacent areas, Mvita has higher surface temperatures than sub-counties of Changamwe, Jomvu and Likoni by 2.1 to 3.5^{0}C - *See Map 4.7*. Nonetheless, the outlying areas Nyali and Kisauni are quite hotter than Mvita Island by 1.4 to 6.3^{0}C due to having a higher population density as well as urban density index. Higher temperatures in Kisauni and Nyali are a function of the soil cover, bare ground and built-up areas - *See Map 4.7.*

Map 4.5 Spatio-Temporal Trend Analysis of the Land Surface Temperature in Mvita



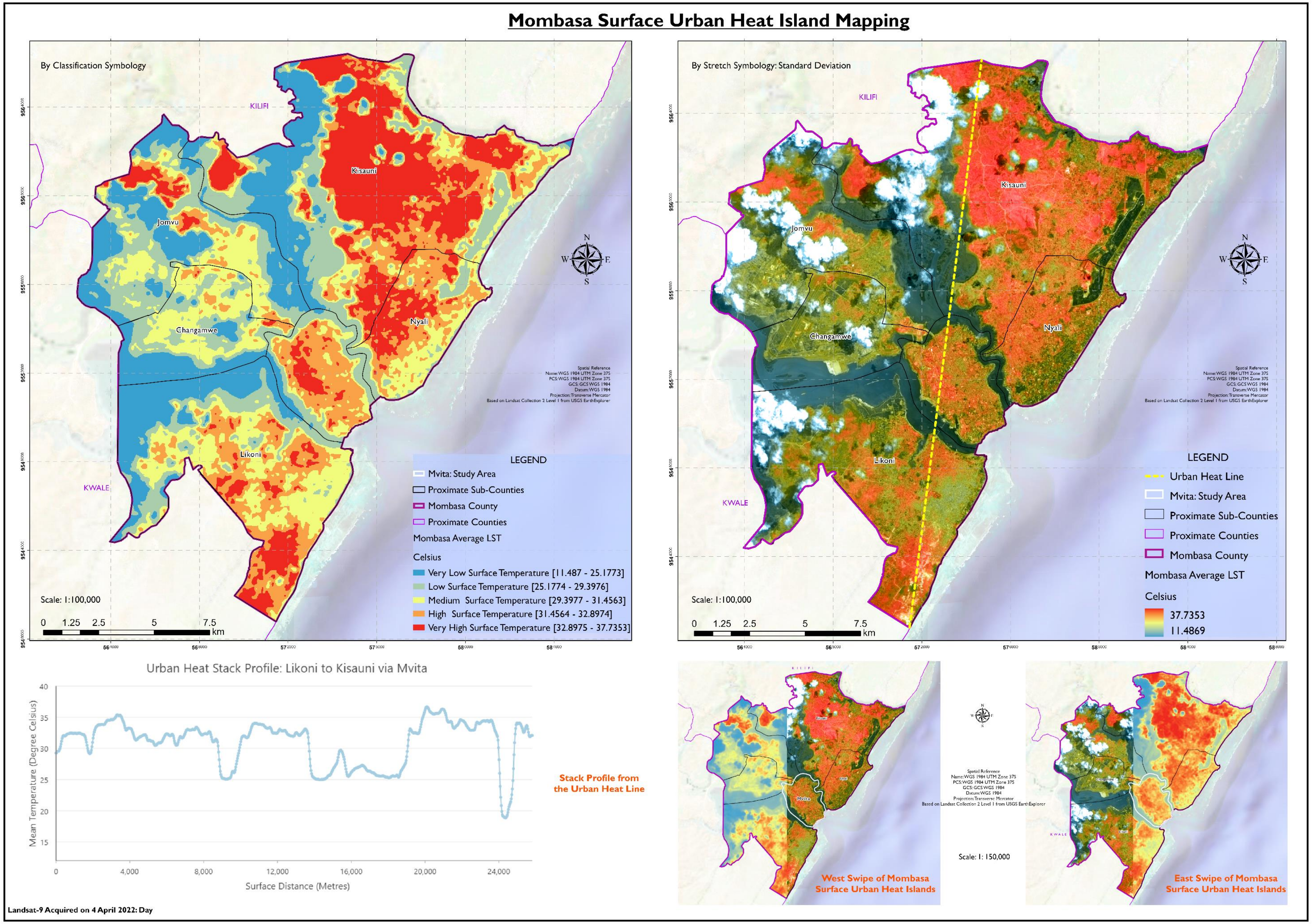
Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

Map 4.6 Surface Urban Heat Island Mapping in Mvita



Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

Map 4.7 Surface Urban Heat Island Mapping in Mombasa County



Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

4.4 Legal, Policy and Institutional Issues on Urban Heat Island Effect

The approach and legitimacy of this research study underlies within the following adopted policy guidelines and laws under the international circles, National Government of Kenya and the County Government of Mombasa.

4.4.1 Issues on Policy Guidelines

Since there is a wide array of ratified policy guidelines on environment, forestry, wildlife, lands, housing and urban development relevant to UHI phenomenon in cities, which exists as complex socio-ecological systems, the Republic of Kenya (2020) place high political commitments to two high level international conferences and meetings. As acknowledged in the 7th *Annual Report on Progress Made in Fulfilling the International Obligations of the Republic of Kenya*, these are the 2030 Agenda for Sustainable Development Goals (SDGs) and the African Union (AU) Agenda, 2063 (Republic of Kenya, 2020). Drawing from the Goal No.3 on good health and well-being; Goal No.11 on making inclusive, safe, resilient and sustainable cities and communities and Goal No. 13 on climate action (UNGA, 2015), the State Department of Planning primarily mandates all implementation and monitoring of the SDGs in the country (Republic of Kenya, 2020). It works in close collaboration with Inter-Agency Technical Committee from the various Ministries, Kenya National Bureau of Statistics (KNBS), National Council for Population and Development, civil society, private sector as well as SDG liaison office by the Secretariat of the Council of Governors (Republic of Kenya, 2020). Despite such strong directives of SDGs, their translations have been poorly correlated with UHIEs demonstrated by the lack of heat mitigation actions in the Big Four Agenda, 2018 and Kenya Vision, 2030 at the national level. Further into this account, through the County Spatial Plans, County Integrated Development Plans and the Local and the Physical and Land Use Development Plans developed at the 47 counties in Kenya.

Although Kenya continues to embrace and progress on the sustainable development (Republic of Kenya, 2020), the high-profile political commitment of the AU Agenda, 2063 also lacks a higher doctrine of urban heat resilience. Nevertheless, it attempts to link systems theory in the execution of its flagship projects as a strategic framework for socio-economic transformations to realize a prosperous, sustainable, integrated, collaborative, peaceful and politically united Africa (African Union Commission, 2015). Key to mitigation of the urban heat island effect is the urgency call to action on urbanization, climate change and environment via implementation of the Programme on

Climate Action Initiative in Africa given by the AU Agenda, 2063. It is currently drafted as an African Climate Change Strategy 2020-2030 (African Union Commission, 2020). Regardless of its advantage in linking African cities as complex socio-ecological adaptive and political systems (African Union Commission, 2020), this draft strategy broaches them widely in the connection to heat stress and vulnerability. UHIE appears as far-fetched in their scope of global warming crisis and potential disasters. Hence, a need for revision of this draft developed by the African Union Commission to underscore heat mitigation that will enable a successful adoption and translation especially of the progress reports of the Big Four Agenda, 2018 and the 5-year Medium Term Plans of the Kenya Vision, 2030 and subsequently to lower order plans and policy guidelines.

Another essential international policy guideline is the 2016 New Urban Agenda (NUA) adopted in Quito, Ecuador which is to be in effect over the next 20 years (Habitat III Secretariat, 2017). It responds significantly to Goal No.11 on making cities and communities that are inclusive, safe, resilient and subsidiarily to Goal No.3 on good health and well-being and Goal No. 13 on climate action. In this fashion, NUA offers a better articulation on heat island effects and heatwaves and their implications on the health, environment, energy and infrastructural services than the 2030 Global SDGs Agenda, AU Agenda, 2063 and its initiatives. In planning for cooler cities, NUA stresses on mainstreaming holistic data-informed disaster mitigations and managements to honor the commitment to an environmentally sustainable and resilient urban development (Habitat III Secretariat, 2017). These strategies are to be integrated, consultative, inclusive in age and gender responsive and implementable policies and plans in line with the ecosystem-based approaches of the Sendai Framework for Disaster Risk Reduction 2015-2030 (Habitat III Secretariat, 2017). Moreover, they are to be adequate, transparent and bear accountable finance mechanisms as well as supportive urban governance structures free from silo mentalities for better coordination at the different scales of Government and society (Habitat III Secretariat, 2017). As such, NUA tries to underpin the application of resilience theory by (Holling, 1973; 2001) in understanding the data needs in the planning for cooler cities.

The framing of the Sendai Framework for Disaster Risk Reduction 2015-2030 was the first main agreement of post-2015 development of the AU Agenda, 2063 that overarches UHI phenomenon as a disaster necessary for mitigation. This Sendai Framework offers Kenya, as an AU Member State (African Union Commission, 2020), with concrete priorities for action to be undertaken by all stakeholders involved in understanding, strengthening, investing and enhancing disaster risk preparedness; recovery and rehabilitation; prevention and mitigation; relief; response; forecasts and warning systems (UNDRR, 2015). By doing so, the Sendai Framework bounds to mitigate adverse effects brought by the urbanization and climate change: reduce global disaster mortality under Target No.1 by 2030 (UNDRR, 2015). The severity of this situation is underpinned by the 2014 fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) which reports land and ocean surface temperatures in Africa could rise faster than the global average to culminate in between $3^{o}C$ and $6^{o}C$ (IPCC, 2014; African Union Commission, 2020). Worsening further are the evolving African institutional systems still unable to adequately coordinate variety of underway mitigation measures (IPCC, 2014; African Union Commission, 2020). Hence, the importance of the Sendai Framework in the national and sub-national levels that might alleviate the shortcomings of poor long-term heat data monitoring during hot seasons as acknowledged by Harrington and Otoo (2020) and understudied connections of the urban heat islands to ecosystem services and greenery in the Sub-Saharan Africa by Toit et al (2018).

Since UHIEs are often human-induced contributing to GHGs that warms the atmosphere (Institut de la statistique du Québec, 2009; TERI, 2017), Kenya has been spearheading the reality of the United Nations Framework Convention on Climate Change, 1992; Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCC), 1997 and the Paris Agreement on Climate Change, 2015 (Republic of Kenya, 2020). Further into emissions of chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs) as part of the GHGs from human activities that trap heat in troposphere and stratosphere are the execution of the Vienna Convention for the Protection of the Ozone Layer, 1985 and the widely successful Montreal Protocol on Substances that Deplete the Ozone Layer, 1987 (Republic of Kenya, 2020). The cross-cutting challenges of these policy guidelines are credited to the slow implementation process of their drafted strategies as well as insufficient funding, awareness and capacity building (Republic of Kenya, 2020).

Specific to the spatial and temporal data monitoring of UHIs is the recently ratified East African Community Protocol on Cooperation in Meteorological Services, 2019, though it is currently not operational as other the Partners States have not yet ratified to the Protocol (Republic of Kenya, 2020). If implemented, both National Government and the 47 County Governments, herein, the County Government of Mombasa, could apply the proposed measures to be a leading force in the tropical Sub-Saharan Africa in combating the heat island effect and heatwaves. This scenario has been strongly showcased in the case of Hanoi, Vietnam (Anticipation Hub, 2021; Taru Leading Edge, 2021). Under the Protocol, Government of the Republic of Kenya is required to cooperate with other ratifying East African Partner States to make plans, develop climate-weather networks and meteorological telecommunications systems (Republic of Kenya, 2020). Such measures will enable computation and analysis of statistics; co-sharing of meteorological data and information and creation of early warning systems (Republic of Kenya, 2020).

Last but not least within the international circle is the Convention on Biological Diversity, 1992 that complements resilience theory. It aims to realize the conservation of the environment and its resources whilst promoting diversity, sustainable usage, equity and beneficial sharing (Secretary of the Convention on Biological Diversity, 1992). Relevant to UHI mitigation is its Aichi Target No.5 on halving the loss of all natural habitats and vegetation; Aichi Target No.8 on lowering pollution levels including thermal pollution in environment and Aichi Target No.14 on restoring and safeguarding urban ecosystems and their essential services (Secretary of the Convention on Biological Diversity, 1992). Measures arising from Convention on Biological Diversity, 1992 are the National Biodiversity Strategy and Action Plan and Publication of Kenya Biodiversity Atlas both yet to be implemented due to limited funding, awareness and capacity building (Republic of Kenya, 2020). NEMA Officer, County Climate Change Expert and County Environment Officer affirms the statement and addresses the spatial climate and diversity atlas or booklet is on-going, however not aware of its specific contents towards heat resilience and sustainability.

The afore-mentioned international policy framing has led to development of the Kenya Vision, 2030 and the Big Four Agenda, 2018 currently as two-high level national political commitments (Republic of Kenya, 2020). The former serves as a long-term development blueprint to transform Kenya into a newly industrializing, middle-income country that delivers a high quality of life in a clean and secure environment to all citizens by the 2030 (Republic of Kenya, 2007). As such, it broaches rather broadly on urban heat island effect and its planning implications on human health, environment, economy and infrastructural services. The latter also suffers from broadness as well as lacks specific measures on addressing mitigation urban heat island effect. This is particularly observed when addressing the component of adequate and affordable housing which is suggested to utilize Goal No.11 of SDGs on making cities and human settlements inclusive, safe, resilient and sustainable (Republic of Kenya, 2018; Republic of Kenya, 2020). Other national policy guidelines include the National Spatial Plan 2015-2045; National Land Policy Sessional Paper No.3 of 2009; National Land Use Policy Sessional Paper No.1 of 2017 and the National Urban Development Policy Sessional Paper No. 6 of 2016 that relate loosely in planning for cooler cities. Nonetheless, they form a spatial framework in managing land carrying capacities, urbanization, housing and urban developments (Republic of Kenya, 2020), critical drivers to the UHIE.

Ultimately is the implementation of the Mombasa Integrated Strategic Uban Development Plan (ISUDP) 2035, also acknowledged as Mombasa Vision 2035 guiding sustainable growth (County Government of Mombasa & Ministry of Land, Housing and Urban Development, 2015). It bears environment and disaster management plan in building climate resilience, but nothing substantial on the urban thermal environment control other than the proposed cumulative 10 per cent share of green areas per plot with the increment of green belts, protection and rehabilitation of mangrove forests and air quality control (County Government of Mombasa & Ministry of Land, Housing and Urban Development, 2015). An air quality monitoring system is yet to be created with potential sites be situated in Mvita Island, north coast, south coast and Changamwe (County Government of Mombasa & Ministry of Land, Housing and Urban Development, 2015). Hence, a study may be undertaken to determine the exact locations as areas of further research. Into this account, Kithia and Lyth (2011) reflect that while plethora of studies within the academic and practical circles across the globe have well been documented, the knowledge gap of urban heat island effect within the urban wildscapes and green spaces are still much overlooked to inform and guide Mombasa as a heat-resilient and sustainable city.

The proposed Mvita land use plan provided under the Mombasa Vision 2035 as well as that of the Draft Mombasa Gate City Master Plan 2040 have not yet been finalized and approved, although referred to as articulated by both County Physical Planner and the County Architect. The County Physical Planner mentioned that the land use plan for Mvita is not yet finalized as there is on-going Mombasa Zoning Policy of which the issue of urban heat island effect has been broached and been incorporated as part of the climate change discussions in the county. Further on binding the urban thermal environment with physical and land use plans, Mombasa County adheres to having 10 per cent of vegetation per plot for developments as mentioned by the County Architect when granting approval for permits. The County Department of Environment, Waste Management and Energy is also set to be guided by the recent adopted Mombasa Climate Change Adaptation Policy 2021 and Mombasa County Solid Waste Management Policy 2021 as mentioned by the County Environment Officer.

4.4.2 Issues on Laws and Regulations

In enhancing the mitigation of heat stress brought by heat islands, the overarching supreme law of the Republic of Kenya — the Constitution of Kenya, 2010 — broadly recognize that every human being has the right to a clean and healthy environment under the Article 42 (Republic of Kenya, 2010). Pursuant to Article 43(a) and (b), the vulnerable population from the UHI phenomenon are respectively entitled to the highest attainable standard of health care services and accessible and adequate housing in a broad sense (Republic of Kenya, 2010). Such economic rights may include provision of cooling centres to communities in the face of extreme heat stress from adverse impacts of urbanization, heat waves and global warming (Taru Leading Edge, 2021). In planning for cooler cities as socio-ecological systems, pursuant to the Fourth Schedule Part I (21) mentions in a broad sense that National Government should assist in the principles of land planning and coordination of planning by counties. On the other hand, the County Governments are to embark on planning and sustainable development on housing, electricity and gas reticulation and energy reticulations within their counties under Four Schedule Part II (8) of the Constitution (Republic of Kenya, 2010). Albeit, aspects of good human health and wellbeing; environment; diversity; sustainable planning and development with regard to the two levels of government have been referred in the Constitution, they are vaguely articulated to the UHI phenomenon. The underlying governance on mitigation is broached widely and without reapproach to heat resilience and sustainable cities.

Relevant to planning for cooler cities, the newfangled Physical and Land Use Planning Act, 2019 has repealed the Physical Planning Act, 1996 to become the umbrella law domain in governing all matters related to the planning, use, regulation and development of land in Kenya (Republic of Kenya, 2019). This 2019 Planning Act provides for the situational analysis, protection and conservation of the environment, public participation, holistic governance, optimal land use and orderly development and execution of proposed strategies and policy interventions at the national and sub-national level of government. In spite of this, there is still a poor correlation between the heat stress mitigation and the provisions of the Act, which have been presented as far-reaching. These mitigation measures at the county, ward and urban scale are to be implemented with the given powers, functions and responsibilities of County Governments following devolution given effect by County Governments Act (CGA) No.17 of 2012 (Republic of Kenya, 2012a). In addition, the 2019 Planning Act under Section 107 provides for the various types of county plans Herein, Mombasa County are obligated to develop, adopt and implement plans like the Mombasa Vision 2035 that serves as an integrated and strategic city plan.

These obligations are required to involve participation, consultative processes as well as funding. Specifically, the public involvement could be stakeholder mapping and engagement on the urban thermal environment as advocated by the Taru Leading Edge (2021) in their *City Heat Resilience Toolkit*. Such inclusion in the management and governance of cities is provided by the Urban Areas and Cities (Amendment) No. 3 of 2019 (Republic of Kenya, 2019). On the other hand, into the financing, upholding of the Public Finance Management Act, 2012 provides for the effective management of public finances inclusive of budgets by the County Governments under Section 27 (Republic of Kenya, 2012b). In this context, lies within the County Government of Mombasa, the National Government and other financial partners in the project costing and resource requirements while upholding citizen participation. The importance of this matter has been underscored by the *7th Annual Report on Progress Made in Fulfilling the International Obligations of the Republic of Kenya*, noting that translations of guiding protocols and directives to national planning strategies experiences limited funding, awareness as well as capacity building (Republic of Kenya, 2020).

Into the urban thermal environment, Environment Management and Coordination (Amendment) Act, 2015 suffers from the similar gaps presented by the Constitution of Kenya, 2010, however gives a more refined understanding to the resilience theory by attaching coastal cities as complex adaptive socio-ecological systems. EMCA describes coastal zone as "*geomorphologic area where the land interacts with the sea comprising terrestrial and marine areas made up of biotic and abiotic components or systems coexisting and interacting with each other and with socio-economic activities"* (Republic of Kenya, 2015). EMCA can be observed to present a stronger case in nested relationships undertaking on the natural landscapes and human-induced activities as conversed by Holling (2001) in the continuous cycles of growth, accumulation, restructuring and urban renewal. Further, pursuant to Section 9 of EMCA, National Environmental Management Agency (NEMA) are to serve as the principal body in all matters of the environment which often is affiliated with climate change and urbanization in Kenya. They are to undertake and coordinate in collaborative research, establish various mitigation measures and enforce the implemented policy interventions as good practices (Republic of Kenya, 2015). Nonetheless, the juxtaposition of EMCA to urban heat island effect is poorly correlated in dealing with heat stress and planning for cooler cities in Kenya, hence evidence that mitigation of urban heat islands has been lacking influence in urban policy domains.

Following the coming into force of the Convention on Biological Diversity, 1992 and the EMCA of 1999, amended 2015; NEMA has been enforcing the launched Environmental Management and Co-ordination, (Biodiversity) Regulations 2006 as well as the Environment Management and Co-ordination, (Water Quality) Regulations 2006. Moreover, the Environment Management and Co-ordination, (Air Quality) Regulations 2014. These regulations strive for quality improvement of ecosystems and beneficial sharing of resources (Republic of Kenya, 2006a), quality water use and control free from pollutants (Republic of Kenya, 2006b) and quality air use and control also free from pollutants (Republic of Kenya, 2014) respectively. Into their execution, the specific measures to thermal pollution by solar radiation are still lacking and the heat dissipation from the air-conditioning or ventilating systems considered as anthropogenic heat contributors (Institut de la statistique du Québec, 2009; Phelan, et al., 2015; TERI, 2017), have been exempted. Thus, the planning for cooler cities has been left generally perceived than actual reality. This is in spite of progressive reported successes on the ratified climate change and environment protocols relating to substitution of CFCs and HFCs substances which normally traps heat and depletes the ozone layer (Republic of Kenya, 2020).

The Physical Planning Handbook, 2007 and Kenyan Building Code, 1968 in providing the urban planning, design and site planning regulatory guidelines and standards are still broached broadly to UHIE mitigation. The Physical Planning Handbook which is now been revised, acts as the principal nation-wide handbook in executing physical and land use developments (Ministry of Lands and Physical Planning, 2007), acknowledged in the Physical and Land Use Planning Act, 2019 and Physical and Land Use Planning (Classification of Strategic and Inter-County Projects) Regulations, 2019. The Handbook provides for the inclusion of 10-30 green belts on the roads as buffer zones (Ministry of Lands and Physical Planning, 2007), very convenient for curbing the pollution between non-compatible land uses and setting up green aeration corridors later seen from the case of Stuggart, Germany (Kapp, 2017). Regardless, the Handbook lacks the provisions in the planning for cooler cities oscillating on urban thermal environment to mitigate heat island effects from urbanization and climate change. As such, Kenya could also learn from the widely acclaimed case review of Stuggart, Germany in creating a spatial Climate Atlas for its towns, municipalities and cities and a Climate Booklet for Urban Development in mitigation of urban heat island effect, heatwaves and global warming (Kapp, 2017; Climate-ADAPT, 2016).

Similarly, the Building Code published by then Ministry of Local Government (1968) is now been revised and has proven convenient to the regulation of urban thermal and design properties of infrastructural surfaces and their erections. Essential to the mitigation of urban heat islands are the installation of ventilation and air-conditioning systems (ACs) in buildings for fresh air-circulation, comfort and humidity control that are to operate at full capacity for 12 consecutive hours without undue rise of temperature within the system (Ministry of Local Government, 1968). Thermal and design properties of metal works, independent linings, floors and walls of erected buildings are to be modified for protection against corrosions and heat exposure (Ministry of Local Government, 1968). Despite that, the Building Code does not provide for measures resultant to the rejected heat from ventilation and air-conditioning systems. Last but not least are the Mombasa County Building By-Laws and UNESCO-based regulations to preserve Swahili Architecture typified the oxidized white coral limestone with mangrove structures as articulated by the County Architect to bind the architectural and urban designing for the mitigation of urban heat island effect. Further, the County Department of Environment, Waste Management and Energy is guided by Environmental Health and Sanitation Act 2017 and Forest Conservation and Management Act 2016 as mentioned by the County Environment Officer.

4.4.3 Issues on Institutions and Governance

On the yet to be operational East African Community Protocol on Cooperation in Meteorological Services, the County Climate Expert is not aware of this protocol, nonetheless acknowledged that it directly binds to the Kenya Meteorological Department which is under the National Government to adequately address and monitor urban heat island effect. The County Physical Planner intuited that Department of Environment, Waste Management and Energy in the County Government of Mombasa should be tasked with enhancing the mitigation of urban heat island effect towards heat resilience and urban sustainable development. This is credited to the Department as it is observed as a cross-sectorial and cross-disciplinary institution to inform on the full picture of implications and regulations of the urban thermal environment in Mombasa. The Department of Environment, Waste Management and Energy is yet to have methods to monitor and address the urban thermal environment as per the County Environmental Officer whereas the County Climate Change Expert is not aware of any measuring methods of the air and surface urban heat islands to monitor and address the urban thermal environment in Mombasa County.

On the other hand, the engaged NEMA Officer addressed that NEMA as a principal institution on the environment is not exclusively in charge of mitigating the impacts of the urban heat island effect per se as the regulation and management of thermal environment is underpinned by different key players who are to collaborate. The NEMA Officer advised on a close collaboration with the County Department of Education and ICT for public awareness while the County Physical Planner and County Architect emphasized a productive collaboration of the County Department of Lands, Housing and Physical Planning with County Department of Environment, Waste Management and Energy. The County Environmental Officer recommended a cross-sectorial and cross-disciplinary collaboration County Department of Environment, Waste Management and Energy with NEMA to adequately address the mitigation of urban heat island effect.

Further into the account, the County Climate Change Expert perceived a close collaboration of the County Department of Environment, Waste Management and Energy which has the Directorate of Climate Change, with the Kenya Metrological Department under the Ministry of Environment and Mineral Resources of the National Government; County Department of Transport, Infrastructure and Public Works as well as the County Department of Water, Sanitation and Natural Resources. Collaboration tends to happen on needed basis oscillating more on urban forestry along the median strips, roundabouts and plot coverages for applied urban developments that needs to have 10 per cent of vegetation cover. There is more need for public awareness and public sensitization not only just County Department of Education and ICT but also with the County Department of Health. On the latter, the engaged Public Health Practitioner is not aware of any collaboration efforts in the mitigation of urban heat island effect in Mvita, Mombasa.

The County Climate Change Expert underpinned that the Kenya Meteorological Department under the National Government and the Directorate of Climate Change under the County Department of Environment, Waste Management and Energy uses media for engagement. Although, such is often on the general awareness of the urban thermal environment to citizens, politicians, urban planners, urban designers, health experts, environmentalists, fellow climate experts and vulnerable groups. The County Environmental Officer also claimed that awareness is broached broadly and that the Community Based Organizations (CBOs) like the Big Ship and Burekenge CBOs mitigate climate change through planting of trees and mangrove.

On the foregoing, the County Climate Change Expert and NEMA Officer acknowledged that there have not been any urban heat island mapping campaigns conducted in Mvita, Mombasa County, other coastal regions and Kenya in its entirety. The reason is widely as a result of having limited institutional capacity development. As articulated by the County Climate Change Expert, currently there is no a Web-Based GIS Climate Resilience Toolkit that is embedded with ancillary data for population, health, spatial distribution of natural and built-up ecosystems in the assessment of heat vulnerability in Mombasa County. Heat vulnerability is a function of risk exposure, sensitivity and adaptive capacity of the urban thermal environment. The County Physical Planner is not aware of the implementation of such tool in the Department of Lands, Housing and Physical Planning that can enhance the mitigation of urban heat island effect.

Figure 4.4 shows the perception of household participants on collaborative efforts especially in mitigation of urban heat island effect in Mvita, Mombasa.

Figure 4.4 Perception of Household Participants on Collaborative Efforts in Heat Mitigation

Value	Frequency	Percentage
Indifferent	52	76.47
Own Resident Efforts	15	22.06
Yes	1	1.47

Source: (Author, 2022) Adapted from Field Work

The results implies that there is need to underscore collaboration theory as approximately 76.47 per cent, 22.06 per cent and 1.47 per cent respectively alluded to not being aware, to supporting themselves as well as to minimal presence of collaboration efforts. Resident own initiatives include the buying and installation of the table fans, ceiling fans and ACs; wearing of light clothes; opening windows and rehydration. These were also stated by the County Physical Planner. The landscaping and gardening are often undertaken by Civil Based Organizations and neighborhood communities and constituted as the minimal collaboration efforts in the mitigation of urban heat island effect in Mvita, Mombasa.

CHAPTER FIVE:

CAUSES AND EFFECTS OF URBAN HEAT ISLANDS IN MOMBASA

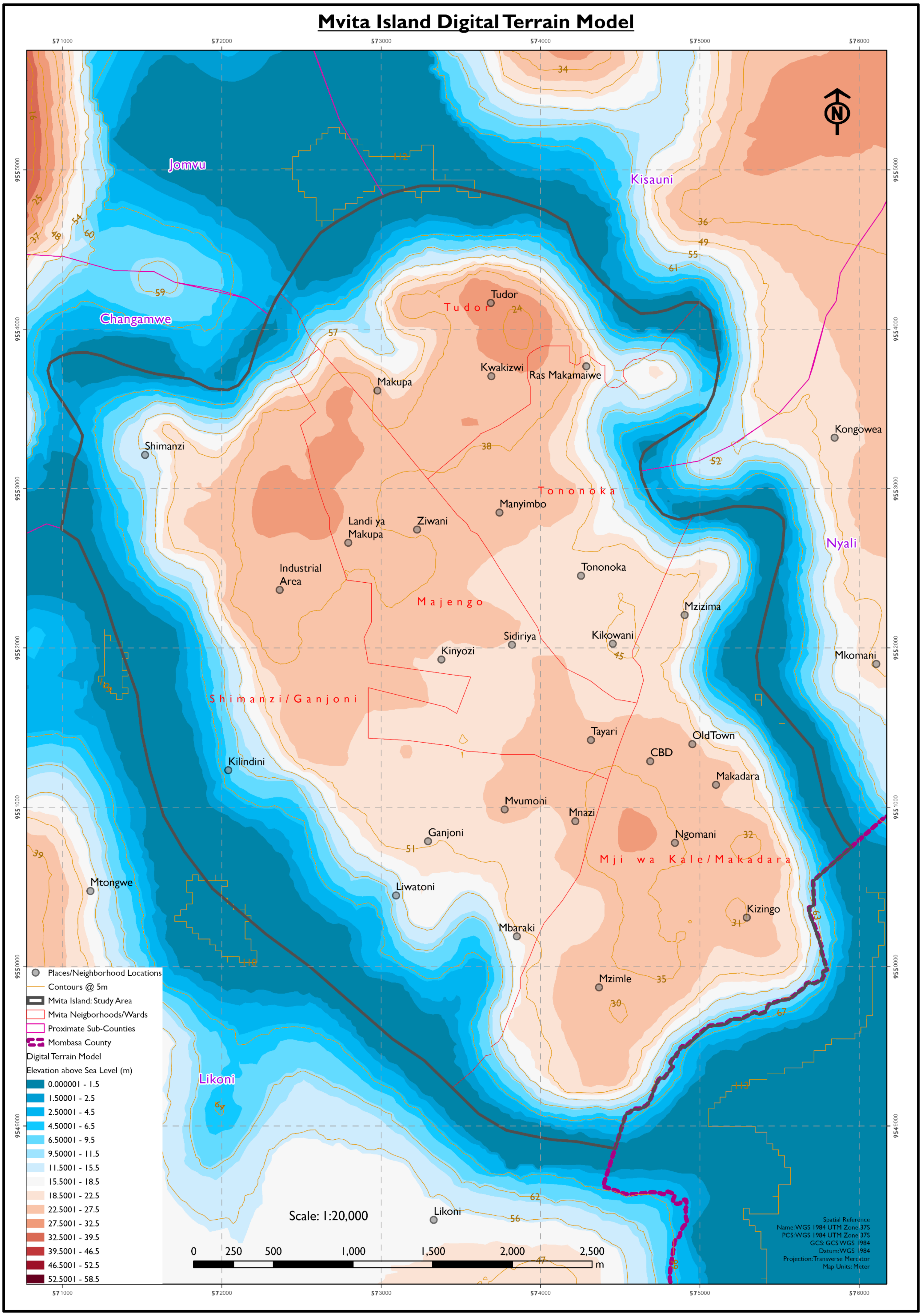
5.1 Causes of Urban Heat Islands in Mombasa

5.1.1 Topography and Elevation

Map 5.1 illustrates the topographic elevation of Mvita Island while Figure 5.1 explores elevation profile of Mvita Island neighborhoods. Mvita sea-island, Mombasa is located at 4°03'11.9"S and 39°39'50.5"E, with an average elevation of 20.17 meters above the sea level. The digital terrain model reflects that most of the land in Mvita is relatively flat. The highest points are located to the north of Majengo and Tudor and south-east of Mji wa Kale ward. The lowest points are located to the west of Shimanzi and east of Tononoka ward.

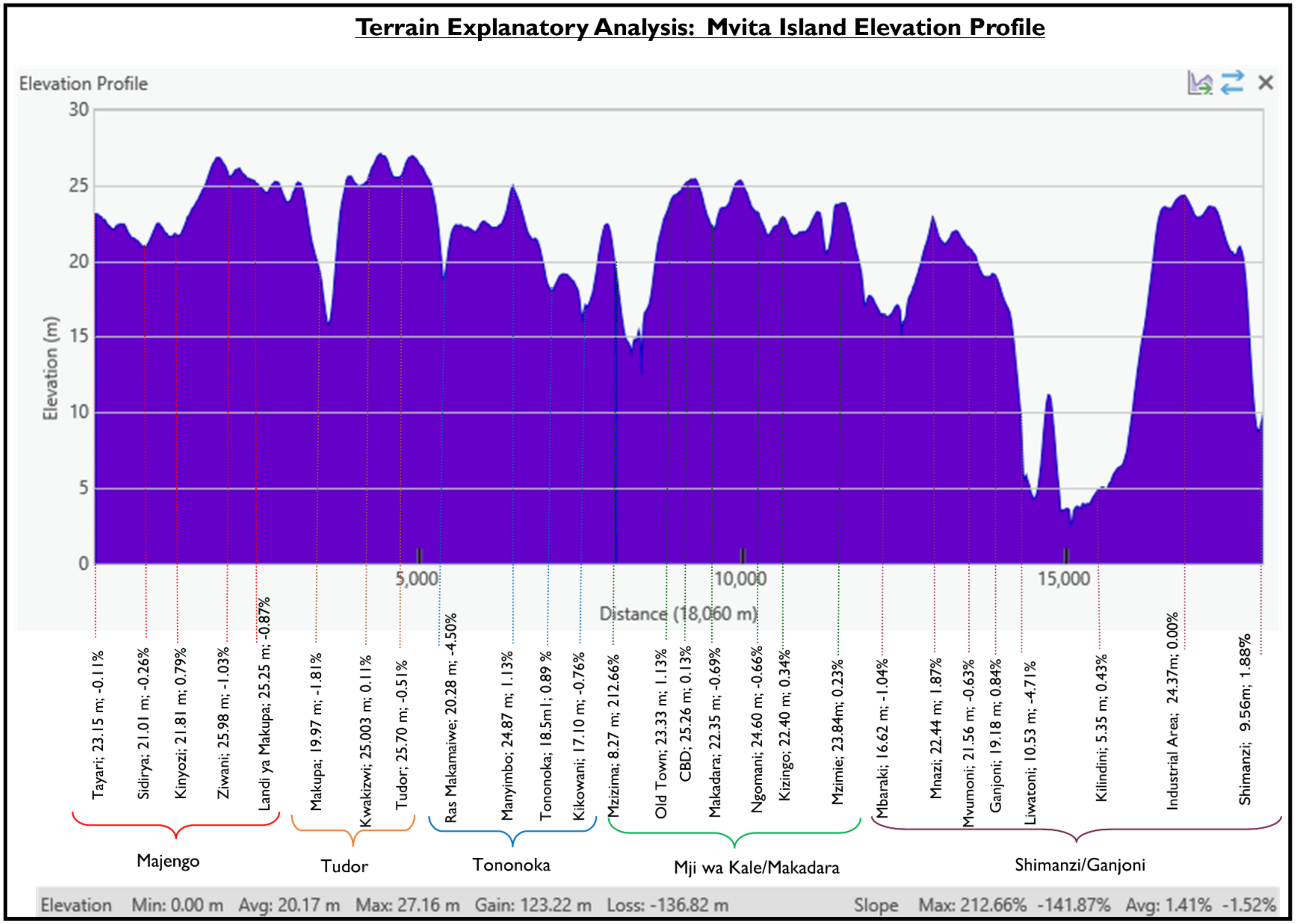
As per the elevation model, Ziwani and Tudor are highest places at 25.98 and 25.70 meters above the sea level respectively whereas Kilindini and Liwatoni are the lowest places at 5.35 and 10.53 meters above the sea level. On the other hand, the average slope of Mvita is between 1.41 per cent and 1.52 per cent. The degree of elevation and slope of the Mvita Island classifies it as suitable for development especially for the proposed planning interventions towards heat resilience. However, the lower altitude is highly susceptible to increased air pressure which contracts and heat up the city, hence contributing to the hot tropical coastal climate of the island.

Map 5.1 Mvita Island Topographic Elevation



Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

Figure 5.1. Mvita Island Neighborhood Elevation Profile

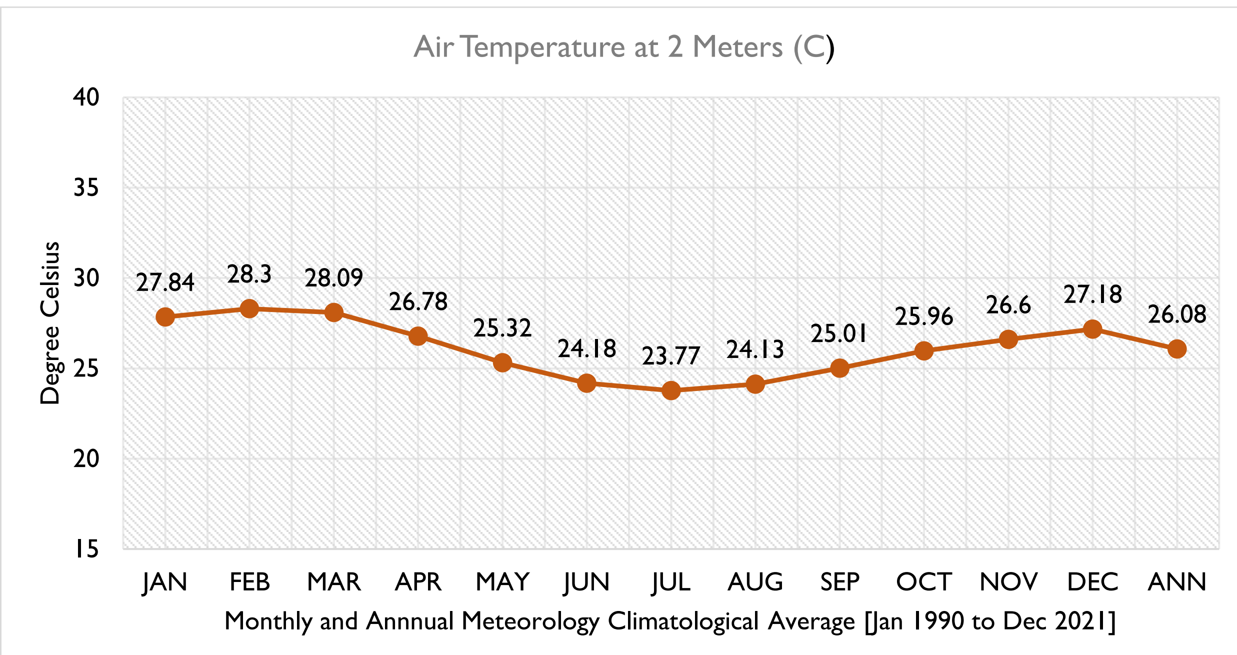


Source: (Author, 2022) Adapted from ArcGIS Pro

5.1.2 Average Variation of Air Temperature at 2 Meters

A time-series analysis of the average air (dry bulb) temperature at 2 meters above the surface of the earth was conducted during the period of January 1990 and December 2021 in Mvita. This air temperature data was sourced from the NASA Power Data Access Viewer (NASA Power Project, 2021). Figure 5.2 demonstrates the average variation of air temperature at 2 meters in Mvita Island. The average trend of the air temperature in Mvita over the 30-year period observed that the higher temperatures in the atmosphere are often between late November to late April. The hottest month of the year in Mvita is March, with an average high of 28.09^{0}C. Such readings portend that during the hot season of the island, the air temperatures could typically vary between a maximum of 38^{0}C and a minimum of 18^{0}C. The greater the air temperatures, the more likely formation of atmospheric urban heat islands in the city, considering that an ideal urban thermal environment ranges between 20°C and 27°C.

Figure 5.2 Average Variation of Air Temperature at 2 Meters in Mvita Island

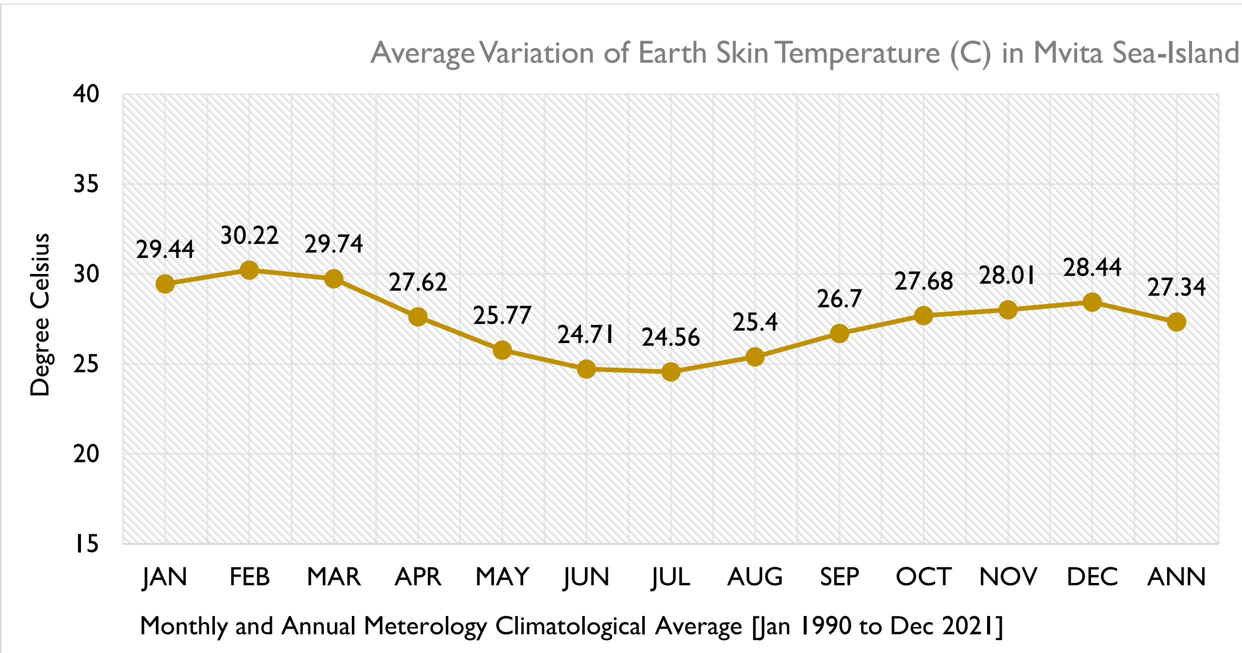


Source: (Author, 2022) Adapted from NASA Power Data Access Viewer

5.1.3 Average Variation of Earth Skin Temperature

A time-series analysis of the average temperature at the earth's surface was undertaken during the period of January 1990 and December 2021 in Mvita. This earth skin temperature data was sourced from the NASA Power Data Access Viewer (NASA Power Project, 2021). Figure 5.3 shows the average variation of earth skin temperature in Mvita Island. Likewise, the average trend of surface temperature of the island over the 30-year period observed that higher temperatures on the earth's ground and building rooftops are often between late November to late April. The hottest month of the year with regards to earth skin temperature is often February with an average high of 30.22^{0}C. Such recordings inference that during the hot season of the island, the surface temperature could typically vary between a maximum of 40^{0}C and a minimum of 20^{0}C. Thus, the greater the surface temperatures, the more likely formation of urban heat islands in the city, considering that an ideal urban thermal environment ranges between 20°C and 27°C.

Figure 5.3 Average Variation of Earth Skin Temperature in Mvita Island



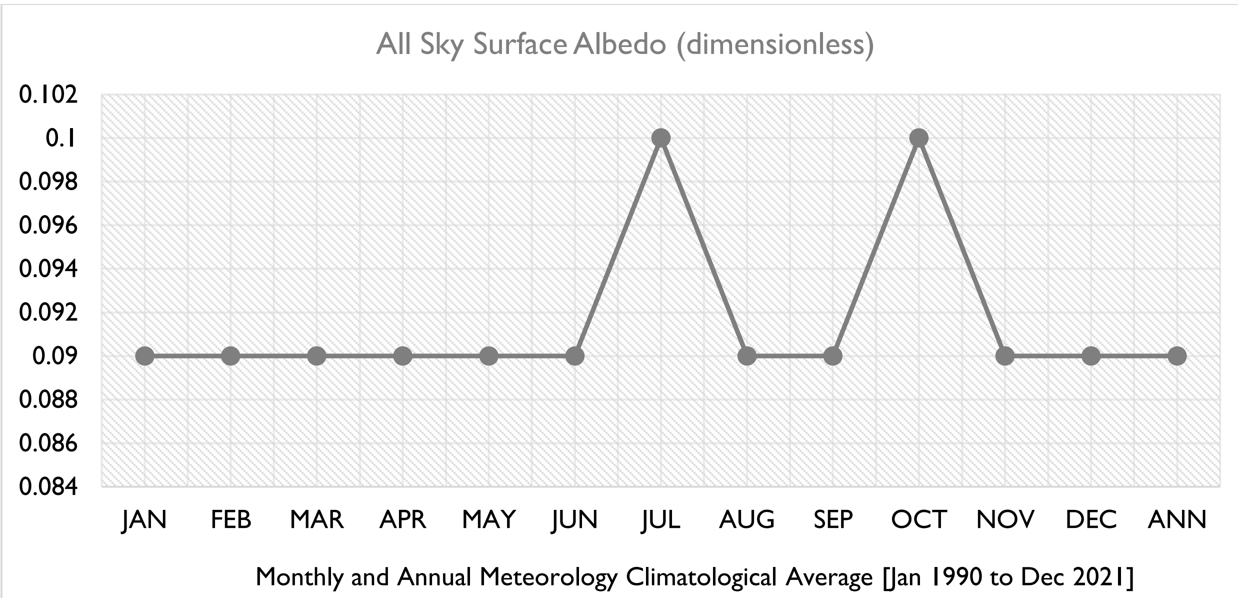
Source: (Author, 2022) Adapted from NASA Power Data Access Viewer

5.1.4 Average Variation of all Sky Surface Albedo

To reiterate, the all-sky surface albedo which is the ratio of the solar energy reflected by the surface of the earth compared to the total solar energy/radiation incident reaching the surface of the earth, represents the rate of reflectivity of the earth's surface. The lower the albedo, the higher the share of the urban heat islands in cities. That said, a time-series analysis of the average variation of all sky surface albedo was carried out during the period of January 1990 and December 2021 in Mvita. This all-sky surface albedo data was sourced from the NASA Power Data Access Viewer (NASA Power Project, 2021). Figure 5.4 displays the average variation of all-sky surface albedo in Mvita

Island. The all-sky surface albedo is generally low in Mvita with greater surface cover modification peaking in the months of July and October during over the 30-year period. The result findings indicate that there is a greater absorption of solar radiation in the island due to multiple reflection and radiation trappings by building walls and vertical surfaces in the city as the impervious urban surfaces are made up of lower albedo materials, as conversed in the urban morphology assessment.

Figure 5.4 Average Variation of all Sky Surface Albedo in Mvita Island

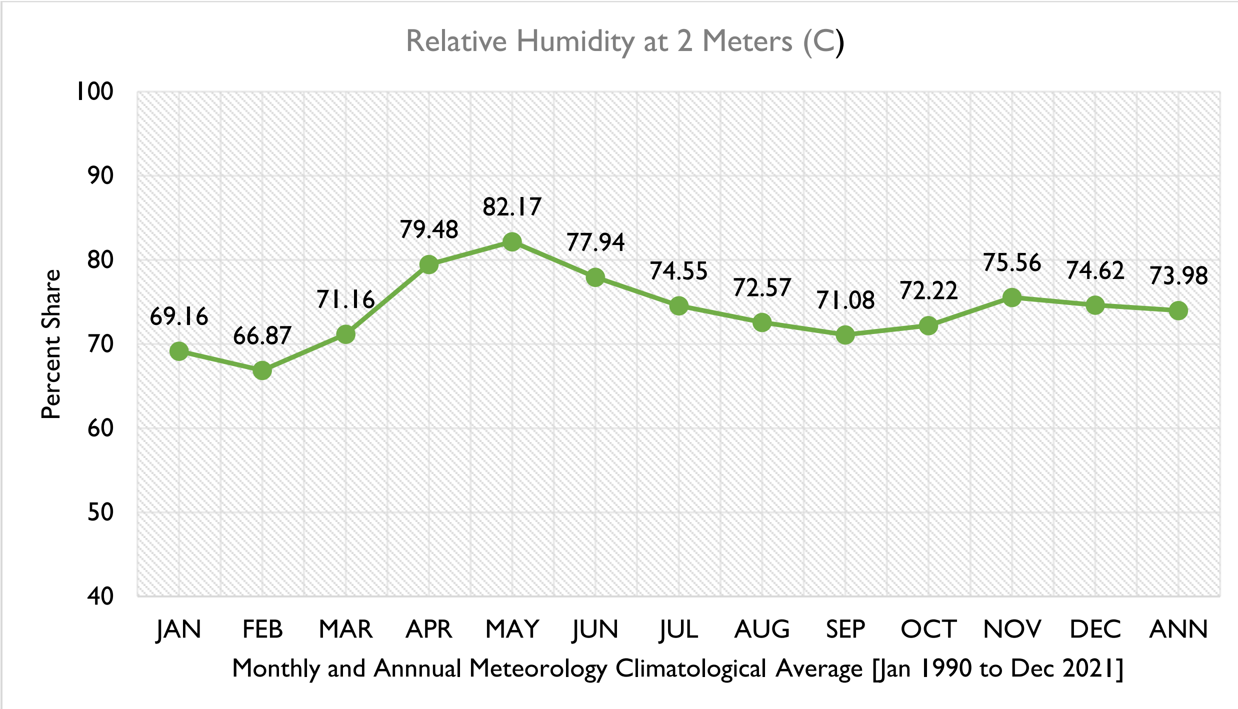


Source: (Author, 2022) Adapted from NASA Power Data Access Viewer

5.1.5 Average Variation of Relative Humidity at 2 Meters

A time-series analysis of the average variation of the ratio of actual partial pressure of water vapor to the partial pressure at saturation — expressed in percent — was undertaken during the period of January 1990 and December 2021 in Mvita. This relative humidity data was sourced from the NASA Power Data Access Viewer (NASA Power Project, 2021). Figure 5.5 indicates the average variation of all-sky surface albedo in Mvita Island. Due to the hot tropical coastal climate of the island, the place is more humid than cool places as a result of increase air pressure as well as faster evaporation of water from heating. The result findings reveals that the average variation of relative humidity is generally high throughout the year, with May recording the highest at 82.17 per cent. The greater the share of relative humidity, the more likely formation of urban heat islands in the city, considering an ideal urban thermal environment has an average optimal humidity rate of 35 to 60 per cent. This could affect the health and well-being of the people of Mvita.

Figure 5.5 Average Variation of Relative Humidity at 2 Meters in Mvita Island

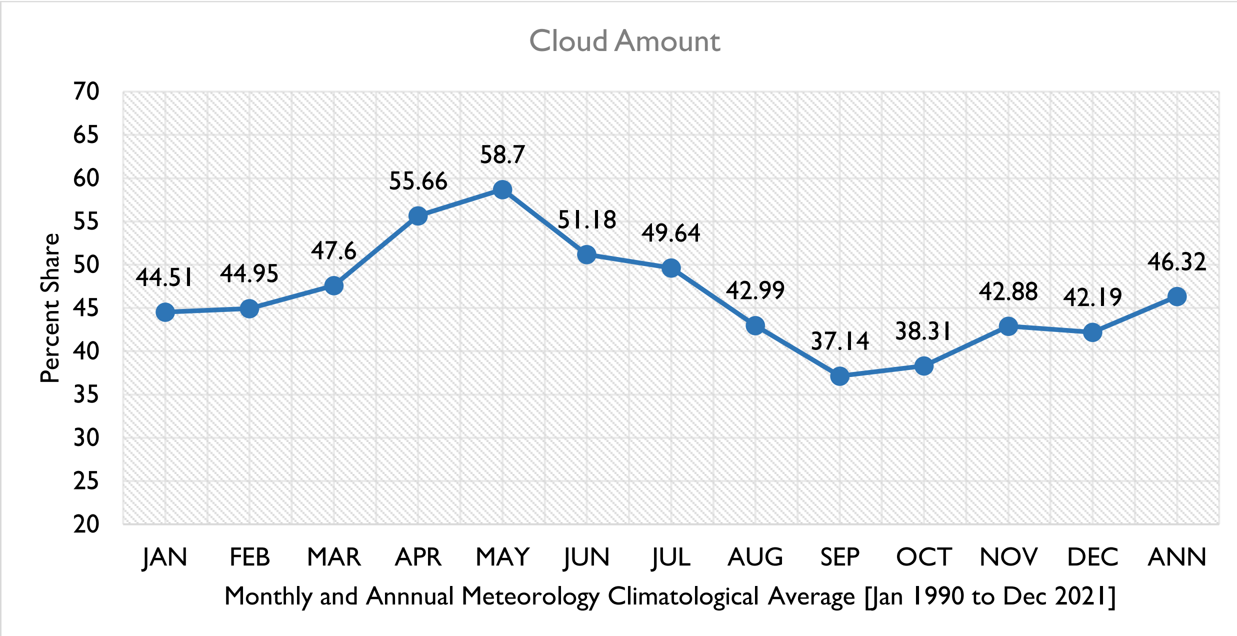


Source: (Author, 2022) Adapted from NASA Power Data Access Viewer

5.1.6 Average Variation of Cloud Cover

A time-series analysis of the average variation of cloud amount— expressed in percent — was performed during the period of January 1990 and December 2021 in Mvita. This cloud cover data was sourced from the NASA Power Data Access Viewer (NASA Power Project, 2021). Figure 5.6 showcases the average variation of cloud cover in Mvita Island. The clearest month of the year in Mvita is September, during which on average the sky is clear, mostly clear, or partly cloudy 37.14 per cent of the time. Alternatively, the cloudiest month of the year in Mvita is May, during which on average the sky is overcast or mostly cloudy 58.7 per cent of the time. In Mvita, the average percentage of the sky covered by clouds experiences significant seasonal variation over the course of the year, with an annual average of 46.32 per cent of the time. Calm and clear weather conditions cause greater absorption of solar energy reaching urban surfaces. Thus, the greater the amount of cloud cover, the more suppression in the formation of urban heat islands in the city.

Figure 5.6 Average Variation of Cloud Cover in Mvita Island



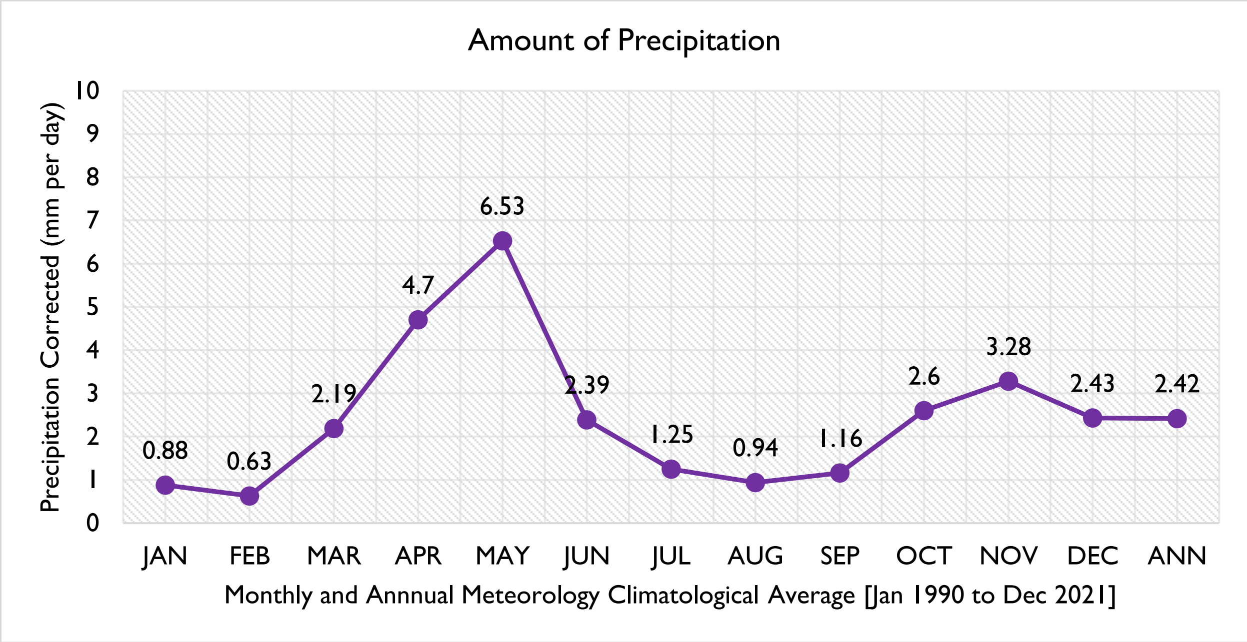
Source: (Author, 2022) Adapted from NASA Power Data Access Viewer

5.1.7 Average Variation of Precipitation

A time-series analysis of the bias corrected average of total precipitation at the surface of the earth in water mass was carried out during the period of January 1990 and December 2021 in Mvita. This precipitation data was sourced from the NASA Power Data Access Viewer (NASA Power Project, 2021). Figure 5.7 depicts the average variation of precipitation in Mvita. The average trend of precipitation in the island over the 30-year period observed that the rainfall amount peaks during the month of May at 6.53 mm/day. This month registers and anticipates major floods throughout the year within the island; following the period of increased air temperature, surface temperature, evapotranspiration and relative humidity that act as contributors to formation of urban heat islands. In this manner, it can be contextualized that the environmental effects of urban heat islands happen to worsen related climate observation parameters such as anticipated flooding due to se-level rise, storm surge and precipitation. These phenomena are often coupled by greater share of impervious surfaces and poor drainage and solid waste management systems which leads to traffic jam delays in Mvita (Mwangi, 2022). Plate 5.1 displays such occurrence along the Moi Avenue and Mwembe Tayari road in Mvita Island, Mombasa County on 5th May 2022 after a heavy downpour, just a week shy from April as one of the hottest months of the island. The gravity of the situation is that

Moi Avenue is a principal arterial street in which Mwembe Tayari — a collector arterial street — joins with, near Guraya-Kiyonzi neighborhoods within central Mvita.

Figure 5.7 Average Variation of Precipitation in Mvita Island



Source: (Author, 2022) Adapted from NASA Power Data Access Viewer

Plate 5.1 Flooding along Major Streets in Mvita Island, Mombasa County

Along Moi Avenue

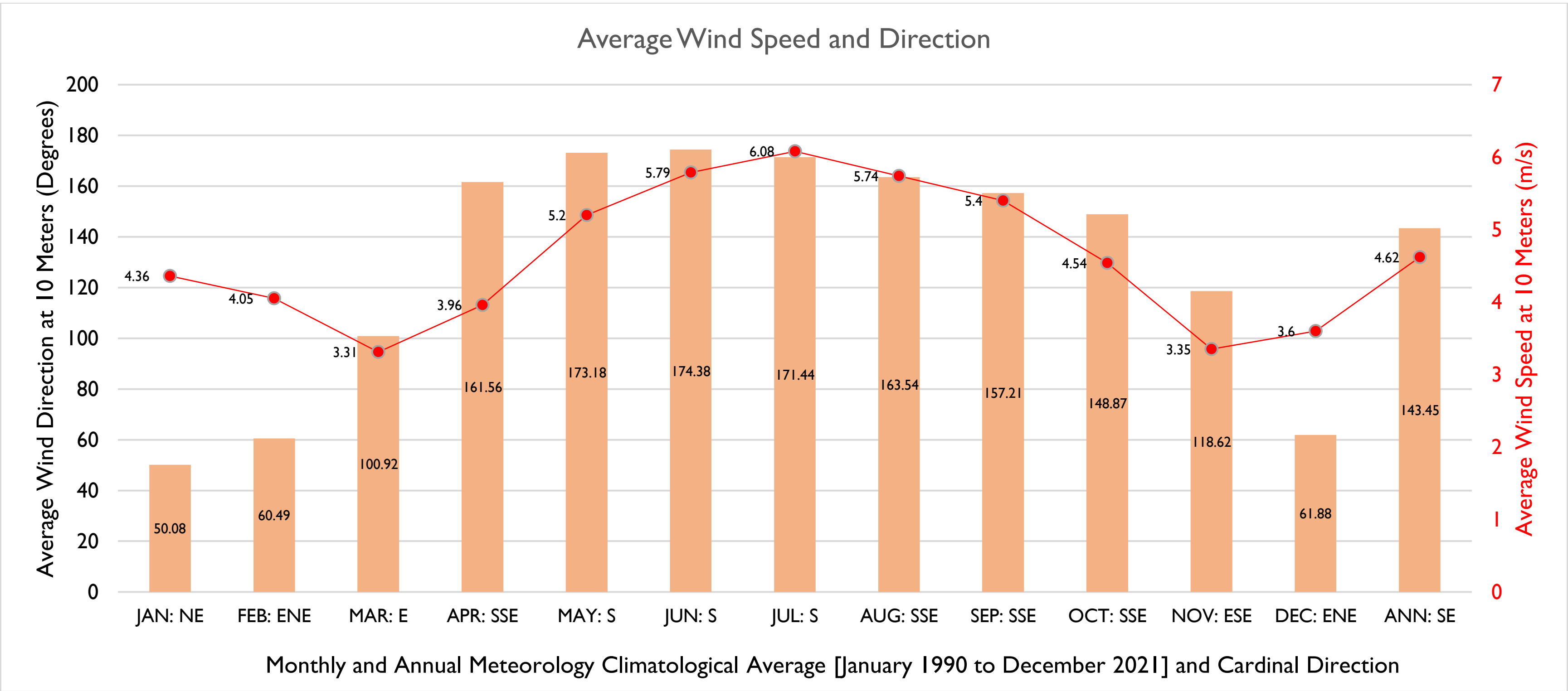
Along Mwembe Tayari

Source: (Mwangi, 2022)

5.1.8 Average Variation Wind Speed and Direction at 10 Meters

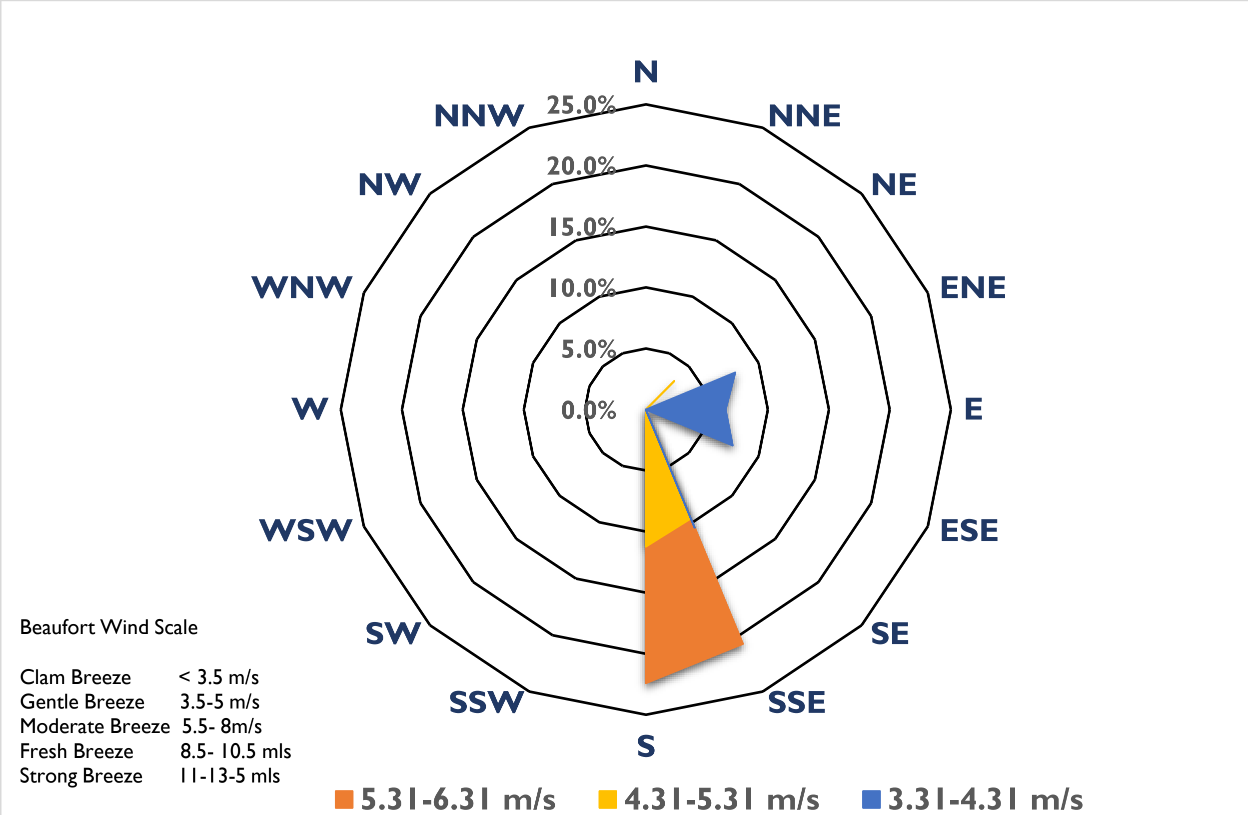
A time-series analysis and windrose development of the average of wind speed and wind direction at 10 meters above the surface of the earth. was performed during the period of January 1990 and December 2021 in Mvita. This wind speed and direction data was sourced from the NASA Power Data Access Viewer (NASA Power Project, 2021). Figure 5.8a depicts the average variation of wind speed and wind direction at 10 meters in Mvita Island while Figure 5.8b displays the windrose diagram of the same.

Figure 5.8a Average Variation Wind Speed and Direction at 10 Meters



Source: (Author, 2022) Adapted from NASA Power Data Access Viewer

Figure 5.8b Windrose Diagram for the Average Variation Wind Speed and Direction in Mvita



Source: (Author, 2022) Adapted from NASA Power Data Access Viewer

The windier part of the year starts from April to October, with average wind direction from south and south-south-east of Mvita with increasing average wind speeds between 4.31 to 5.31 m/s and 5.31 to 6.31 m/s. The windiest month of the year in Mvita is July, oscillating from the south of the island with an average monthly wind speed of 6.08 m/s whereas the calmest month of the year in Mvita is often January over the 30-year period, directing from the north east of the island with an average monthly wind speed of 4.36 m/s. The greater distance from the sea and lesser the velocity as the wind flows from the south and south-south east direction of the island, for the most part of the 30-year period, the more likely formation of urban heat islands especially in central Mvita due to lower cooling effect - *See Map 4.14*. According to the Beaufort wind scale, Mvita experiences a gentle to moderate breeze. The faster and colder the wind is, the more the cooling effect as a result of convention and evaporation of heat. Thus, the axis of urban developments should be erected in a parallel manner to the prevailing wind to avoid obstruction.

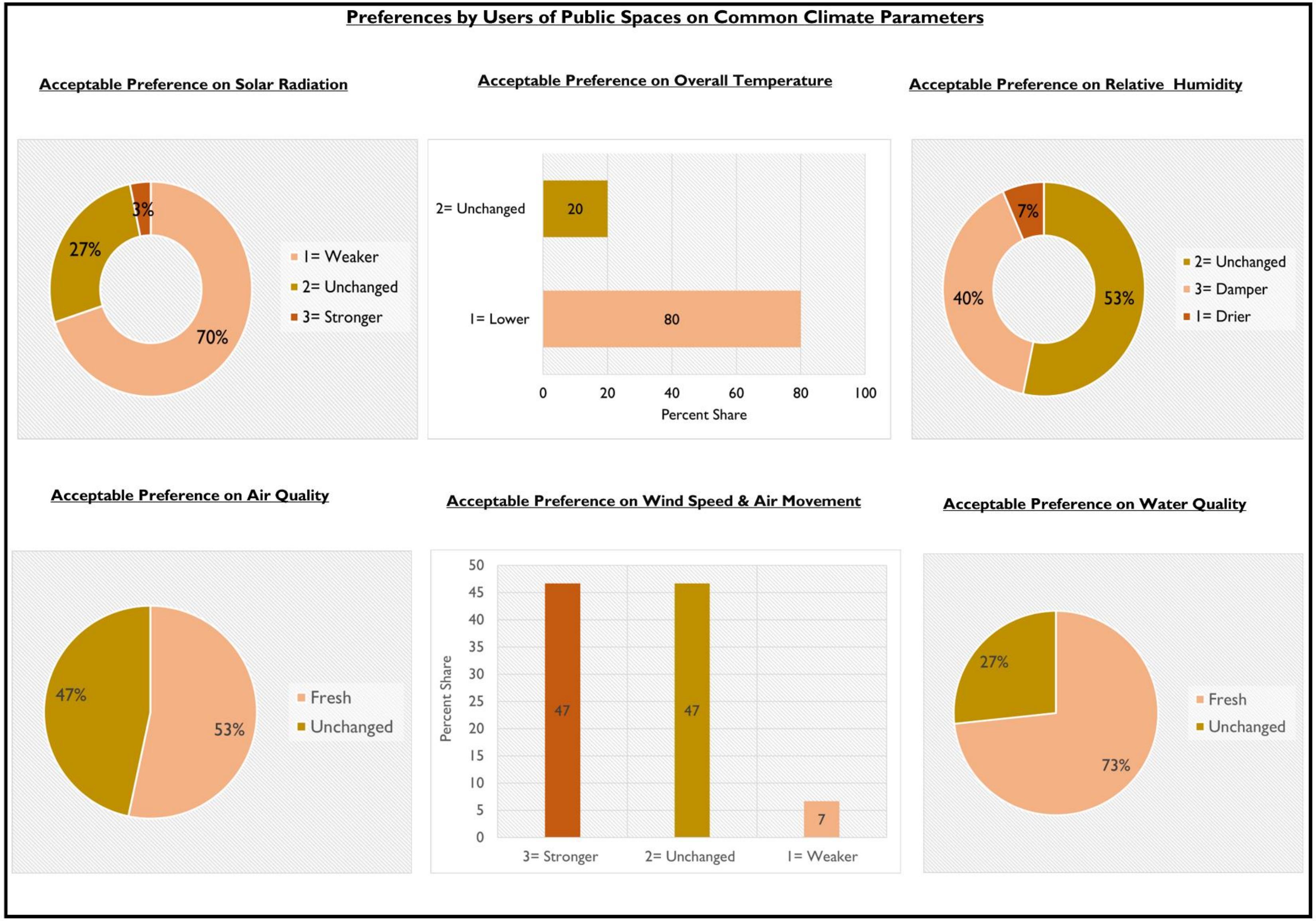
5.1.9 Perception on the Acceptable Outdoor Climatology Parameters

Figure 5.9 illustrates the acceptable preferences desired by the users of public spaces on solar radiation; temperature; relative humidity; wind speed and air movement as well as air and water quality in Mvita Island. The following were the perceptions of the users of public space on their acceptable levels of the some of the outdoor climatological influences in Mvita Island, Mombasa County. These included solar radiation, overall temperature, relative humidity, wind speed and air movement as well as air and water quality. These parameters are critical to the planning of cooler coastal cities as their imbalances within the atmosphere could lead to the formation of the heat islands.

About 53 per cent, 70 per cent and 80 per cent of the responses mentioned by the users of public spaces inclined to having a damper preference of relative humidity, a lower preference of solar radiation and a lower level of the overall temperature in the island, respectively. Based on the weather conditions and climatological assessment of Mvita, such perceptions have an empirical basis that Mvita has been experiencing high temperature which can have adverse impacts on the people of Mvita. Conversely, approximately 47 per cent of the responses articulated by the users of public spaces oscillated to having a stronger or unchanged wind velocity, each while approximately 53 per cent and 73 per cent of the responses suggested by the users of public spaces inclined to having acceptable level of fresh air quality and water quality respectively.

These perceptions allude that there are elevated emissions of air pollutants and GHGs and some level of water degradation that is addressed as occasionally salty with regards to the piped water system. These responses underscore why the urban heat island is a problem in Mvita Island. Thus, going forward attaining adaptive capacity through the social, economic, environmental and institutional resilience strategies is paramount to securing acceptable outdoor climatology parameters not only in Mvita Island, Mombasa County but also in the coastal cities of the Sub-African.

Figure 5.9 Perception of the Acceptable Outdoor Climatology Parameters



Source: (Author, 2022) Adapted from Field Work

5.1.10 Physical and Land Use Planning Efforts

Within the 20th century, three notable physical and land use planning efforts came to light in addressing urbanization and urban development on natural landscapes in Mvita and the entirety of Mombasa County. These were the Mombasa Town Planning Scheme -1926; Comprehensive Long Term Physical Development Plan -1962 and Mombasa Draft Physical Development Plan of 1971-1995. In the midst of 21st century, the recognized land use planning efforts are that of Mombasa Integrated Strategic Urban Development Plan 2015-2035, also known as Mombasa Vision 2035 and the Draft Mombasa Gate City Master Plan 2040. Such understanding the plans assisted in the undertaking of spatio-temporal analyses of the changing pattern of urban built-up density and green cover with urban thermal environment, critical to the testing of the study's research hypothesis.

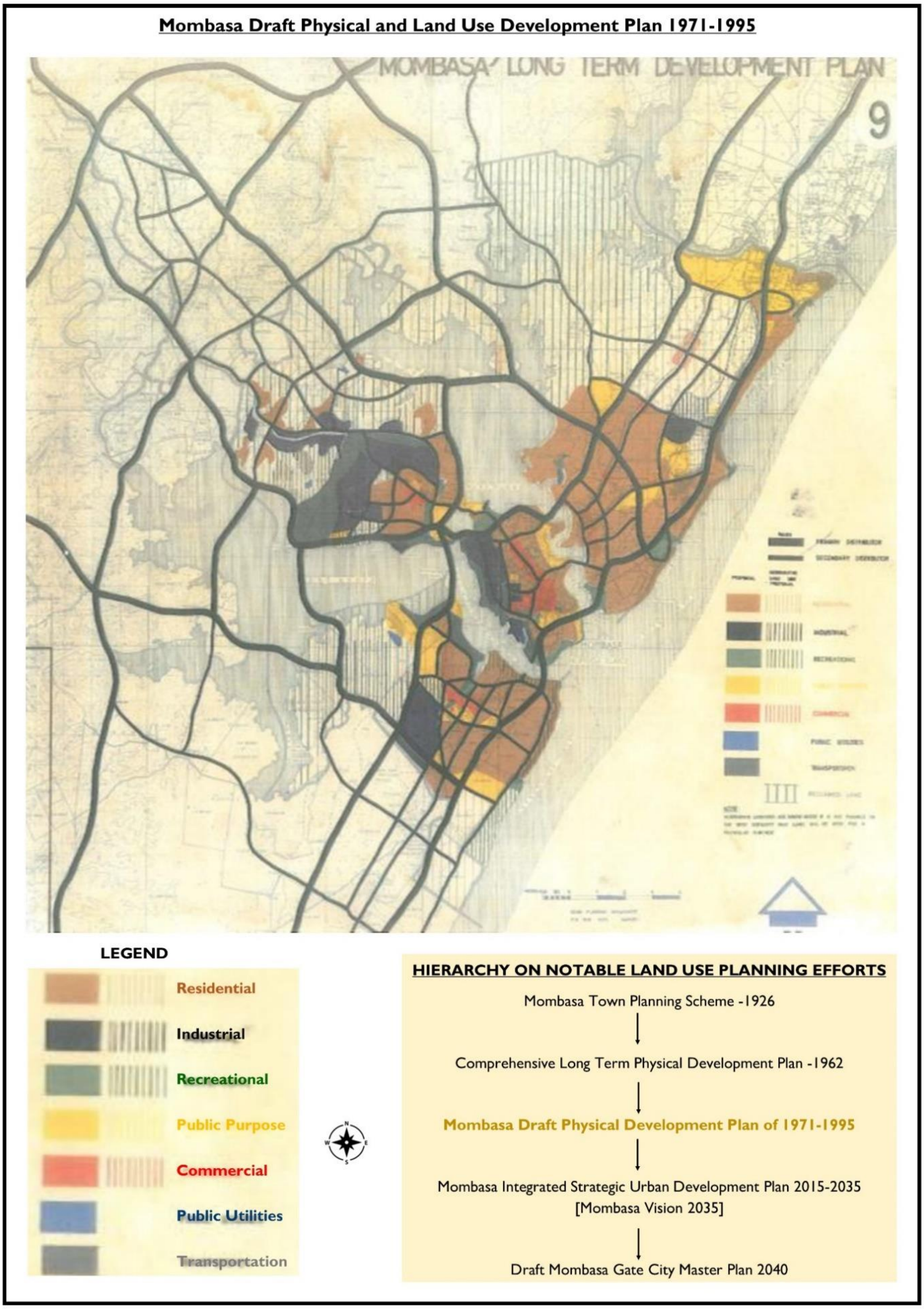
When Mombasa town became the capital of the Coastal British Protectorate in 1920, there was need to prepare a town planning scheme to guide development of the MGR railway and railway station; Kilindini Port in Shimanzi away from the Old Port in Old Town; streets, industrial as well as residential areas. Thus, the Mombasa Town Planning Scheme of 1926 that applied to a larger extent Mvita Island. Others planning efforts during this period were the Mkomani Town Planning Scheme in Nyali Ward and the Changamwe Repooling Scheme in Changamwe Ward. Mombasa town later achieved municipality status in 1928. Further when Mombasa assumed council status in 1959, there was an impetus for the town to have a comprehensive long term physical development plan undertaken in 1962 to guide the needs for the increasing population to the 1980s. Nonetheless, this master plan — by the time it was adopted and published — the population projection assessed to be approximately 250,000 people by 1980 had already been realized 9 years later. Such account of events prompted creation of the Mombasa Draft Physical Development Plan of 1971 to 1995.

This Mombasa Proposed Development Plan of 1971 is still relevant to date as it lays out vast and well-coordinated plans for road, water supply, harbor development, sewage disposal and housing, all of which were to meet county's enormous growth despite its severe topographical circumstances *– See Map 5.2*. To avoid future overcrowding on Mvita Island, this plan advocated settling people in northern and southern mainland districts. It was also suggested that building of a transportation network to stimulate the decentralization of the island's people, industries and services. The plan established a framework under which National Government Ministries, Local Authority — County Government of Mombasa — and other development organizations were to implement government objectives in order to create a good urban environment.

Following the early 21st century, Mombasa was elevated to a city status. Therefore, in order to integrate future development with existing development, Mombasa Integrated Strategic Urban Development Plan (ISUDP) 2015-2035 and Draft Mombasa Gate City Master Plan 2040 have been prepared *– See Maps 5.3 and 5.4*. Mombasa ISUDP 2035 has been approved by the County Assembly of Mombasa to guide urban development. It provides a combined detailed existing and proposed Mombasa County Mvita, Nyali, Kisauni, Likoni and Changamwe-Jomvu Land Use Plans -2035. They are aggregated into Mombasa Proposed Land Use Plan 2015-2035 that proposes to maintain a cumulative 10 per cent of developed land as green as well as achieve at least 4.37 sq.m per capita space as public parks and play grounds. The situation is still wanting in the face of the increasing built-up density and population density that has led to a decreasing share and distribution of urban green cover *– See Maps 5.5 and 5.6.* The urban built-up density in Mvita and Mombasa County has increased by 66.7 per cent and 227.8 per cent respectively from 1992 to 2022 while population density in Mvita Island and Mombasa County has grown by 318.5 per cent and 161.9 per cent from 1992 to 2022. On the other hand, the total share of all green areas (biotope) within the ecosystem in Mvita and Mombasa County have decreased by 68.2 per cent and 73.9 per cent from 1922 to 2022. Such alarming spatio-temporal trends of the changing patterns of built-up area and green cover have been leading to increasing air and land surface temperature *- See Maps 5.7 and 5.8*.

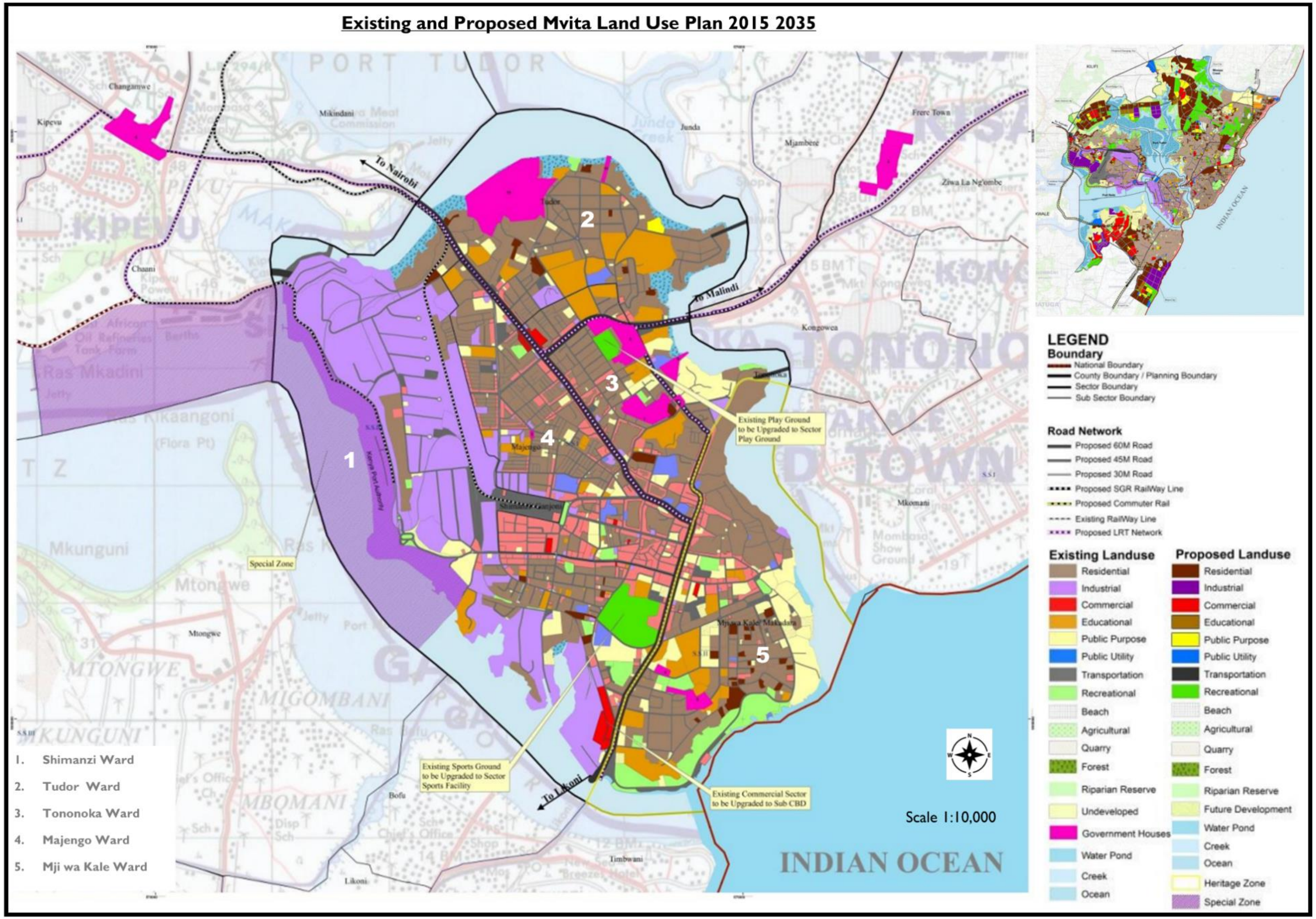
Last but not least, the Draft Mombasa Gate City Master Plan 2040 is a comprehensive plan that aims to promote urban conditions and strengthen logistics conditions to improve the Northern Economic Corridor as a gate city. Relevant to urbanization development on natural landscapes, its Land Use Plan Concept in Mvita Island is mostly oriented to fostering commercial, tourism and industrial logistics at the expense protection of the natural environment *– See Map 5.4*. The land use and development changes in Mvita have seen an increasing urban thermal implication following pearson correlation tests of the built-up area and urban vegetation with land surface temperature *– See Maps 5.5 and 5.7*. It is further evidenced under classification of urban landscapes by local climate zones — advocated by Stewart and Oke (2012) — established through visual survey, aerial imagery and insights from the interviewed County Architect *– See Maps 5.9a and 5.9b.* There is greater absorption of solar radiation and delayed release of heat by walls, roofs and impervious surfaces of the built-up areas. The physical and land use planning of the city of Mombasa has made Mvita a concrete jungle with less vegetation cover contributing to the formation of urban heat islands.

Map 5.2 Mombasa Draft Physical and Land Use Development Plan 1971 -1995



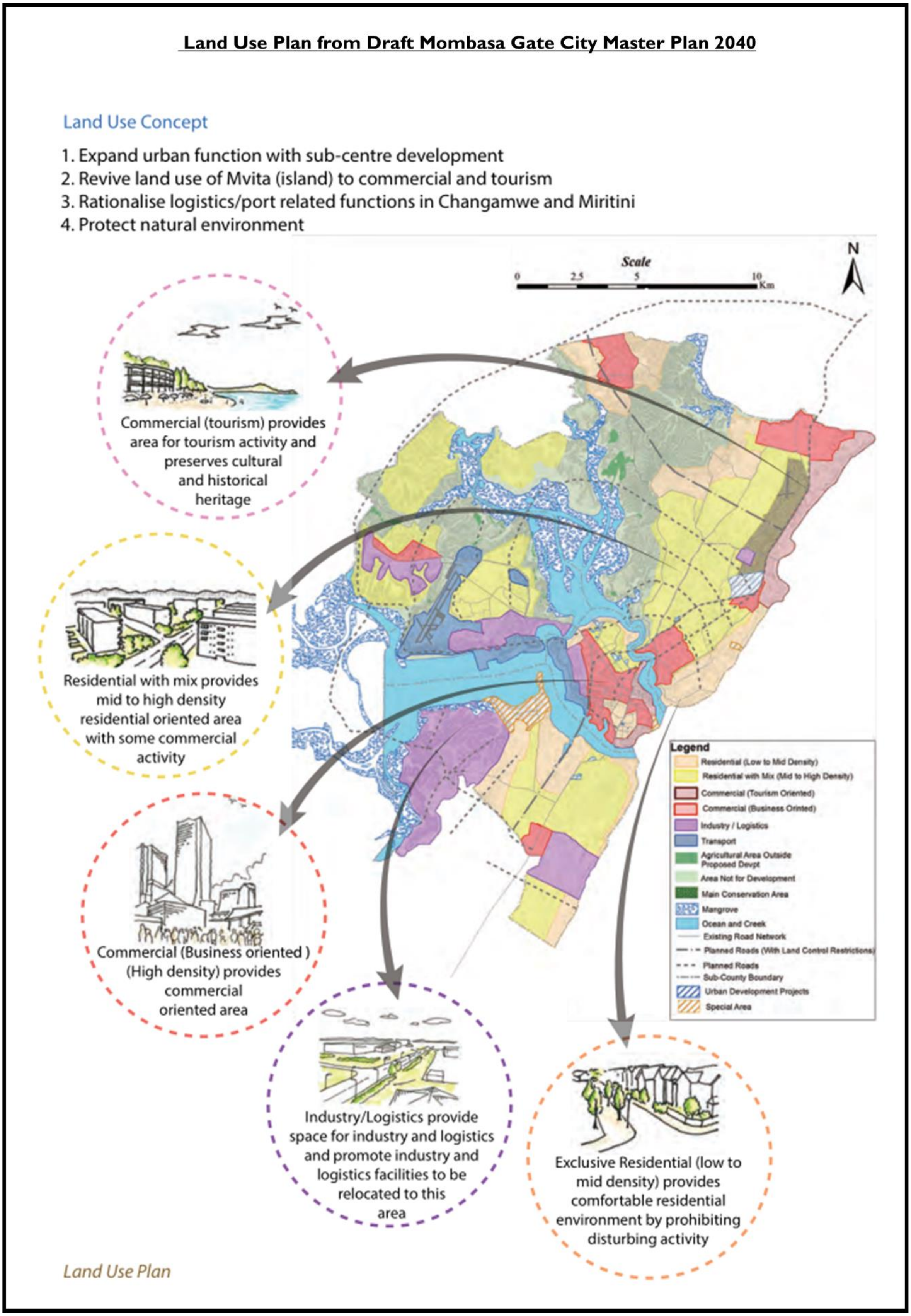
Source: (Author, 2022) Adapted from Mombasa Vision 2035

Map 5.3 Existing and Proposed Mvita and Mombasa Land Use Plan 2015-2035



Source: (Author, 2022) Adapted from Mombasa Vision 2035

Map 5.4 Draft Mombasa Gate City Land Use Plan 2040



Source: (Author, 2022) Adapted from Mombasa Gate City Master Plan 2040

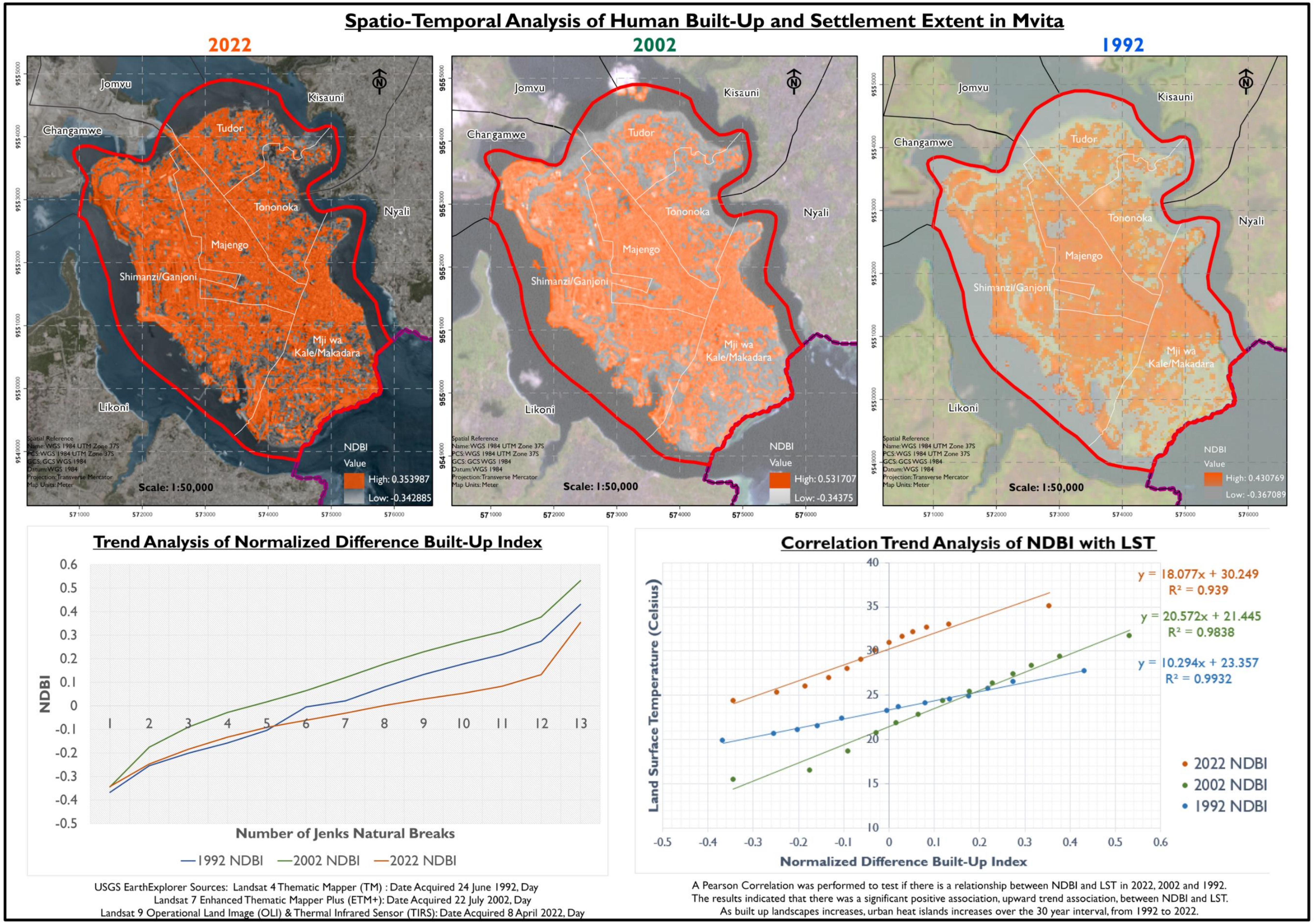
5.1.11 Human Built-Up and Settlement Extent

Understanding the extent of the urban impervious areas in Mvita Island and Mombasa County aids in identifying the root causes of urban heat islands due to the urban surface modification which alters the surface energy and radiation balance in the atmosphere. Map 5.5 illustrates the spatio-temporal trend analysis of human built-up and settlement extent in Mvita while Map 5. 6 explores the share and distribution of built-up area and population density as the urbanization indicators in Mvita.

A spatio-temporal analysis of the Normalized Difference Built-Up Index (NDBI) was done in 1992, 2021 and 2022 respectively from Landsat 4 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM+) and Landsat 9 Operational Land Image (OLI) and Thermal Infrared Sensor (TIRS). NDBI was chosen for this study to represent the human built-up and settlement extent in totality to underpin the built-up ecosystems in Mvita Island. NDBI value lies between -1 to +1. Negative values of NDBI represent water bodies whereas the higher values represent built-up areas *– See Map 5.5.* NDBI value for vegetation is low. The dip inclination between the 11^{th} and 13^{th} jenk natural shows transition of sparse built-up extent to dense built-up extent. In addition, a Pearson Correlation was performed to test if there is a relationship between NDBI and Land Surface Temperature (LST) in 1922, 2021 and 2022. The results indicated that there was a very significant positive association — upward trend association — between NDBI and LST. As the built-up landscapes increase, urban heat islands increase over the 30-year interval, from 1992 to 2022 *– See Map 5.5.*

The changing patterns of urban built-up area/footprint and population density are the two most Essentail Societal Variables (ESV) of urbanization and urban development that most decribe the human system within socio-ecological panancrchy (Ehrlich, Kemper, Pesaresi, & Corbane, 2018), that resilience theory seeks to address. Herein, urban built-up area has been translated further into urban density index — urban foot print exclusive of vegtation cover per total area in the boundary (sq. km) — to juxtapose and quantify the human scoietal system to urbanization patterns and trends as well as climate change hazards, in this context of urban heat islands in Mvita Island and Mombasa. The changing pattern of built-up density and population density reveals an increase in urbanization over the 30 years from 1992 to 2022. The built-up density for Mvita Island and Mombasa County has respectively increased by 66.7 per cent and 227.8 per cent from 1992 to 2022 while population density in Mvita and Mombasa has grown by 318.5 per cent and 161.9 per cent from 1992 to 2022 *- See Map 5.6.* Majengo Ward has a higher urban built-up and population density than rest of the wards in Mvita Island - *See Map 5.6.*

Map 5.5 Spatio-Temporal Trend Analysis of Human Built-Up and Settlement Extent in Mvita

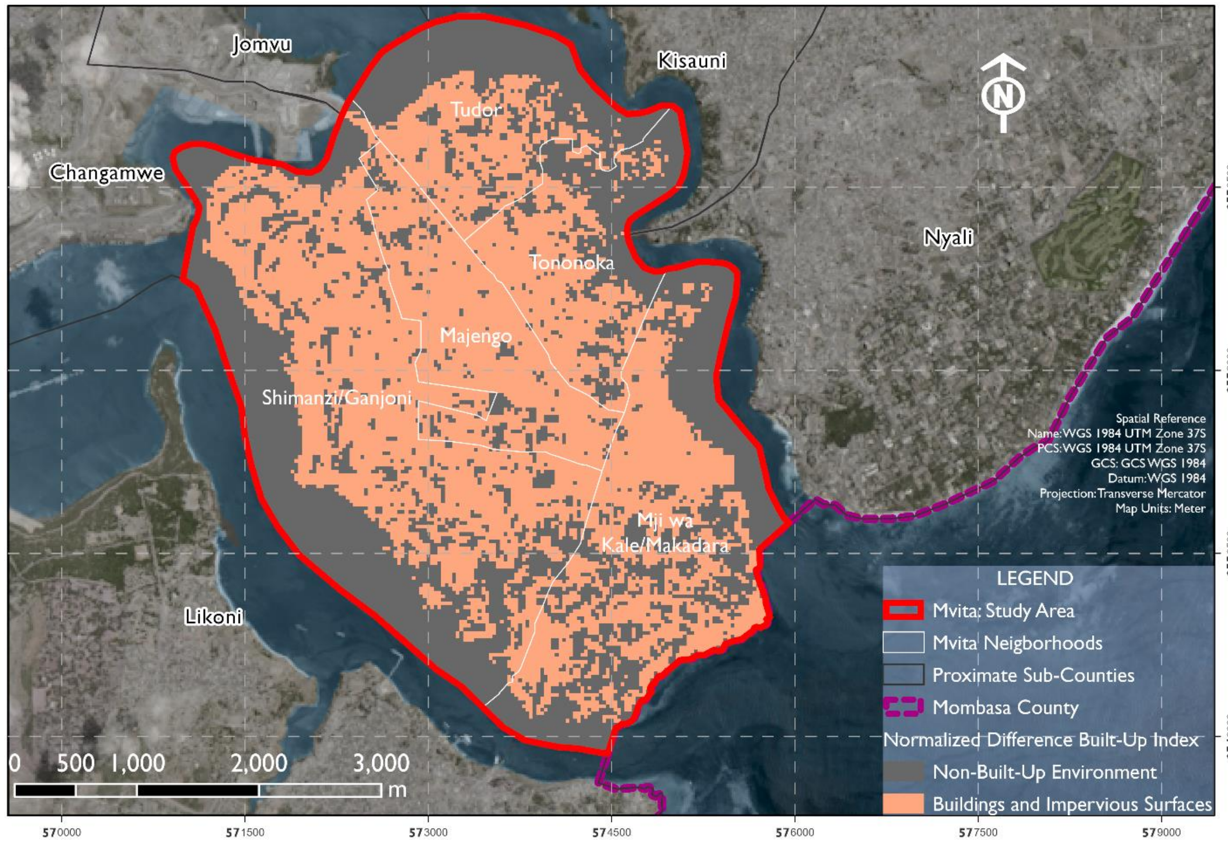


Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

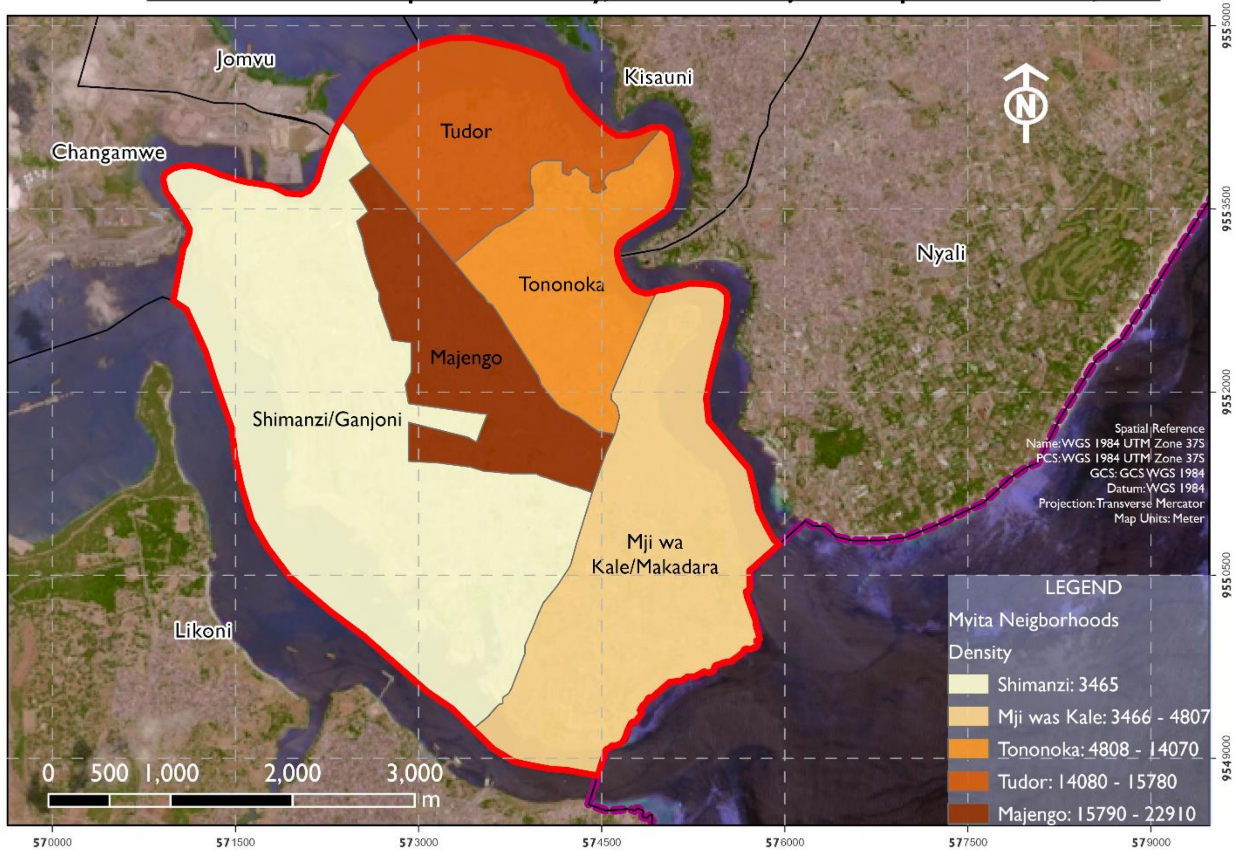
Map 5.6 Share and Distribution of Built-Up Area and Population Density in Mvita

Share and Distribution of Urban Density Index and Population Density in Mvita Island

Distribution of the Built-Up Environment from NDBI by Landsat-9 4 April 2022



Distribution of the Population Density, 2022 from Projected Population Census, 2019



Trend Share of Urban Density Index and Population Density

Urban Density Index: Mvita Island	2022	2002	1992
Total Built-Up Area = Pixel Count*30*30/100000 sq.km in the Boundary	10.6146	7.5249	6.3063
Total Pixel Count Area [Built-Up & Non-Built] in the Boundary	19.1898	19.1898	19.1898
Urban Density Index, built-up area/urban footprint per sq.km	**0.55**	**0.39**	**0.33**

Population Density: Mvita Island	2022	2002	1992
Total Projected Population [Average Growth Rate 3.2 from Baseline Years]	169,450	58,232	40,493
Total Island Area (Landmass+Water Mass) = Digitized Boundary Area	19.19319	19.19319	19.19319
Population Density Index, persons per sq.km	**8828.65**	**3033.99**	**2109.76**

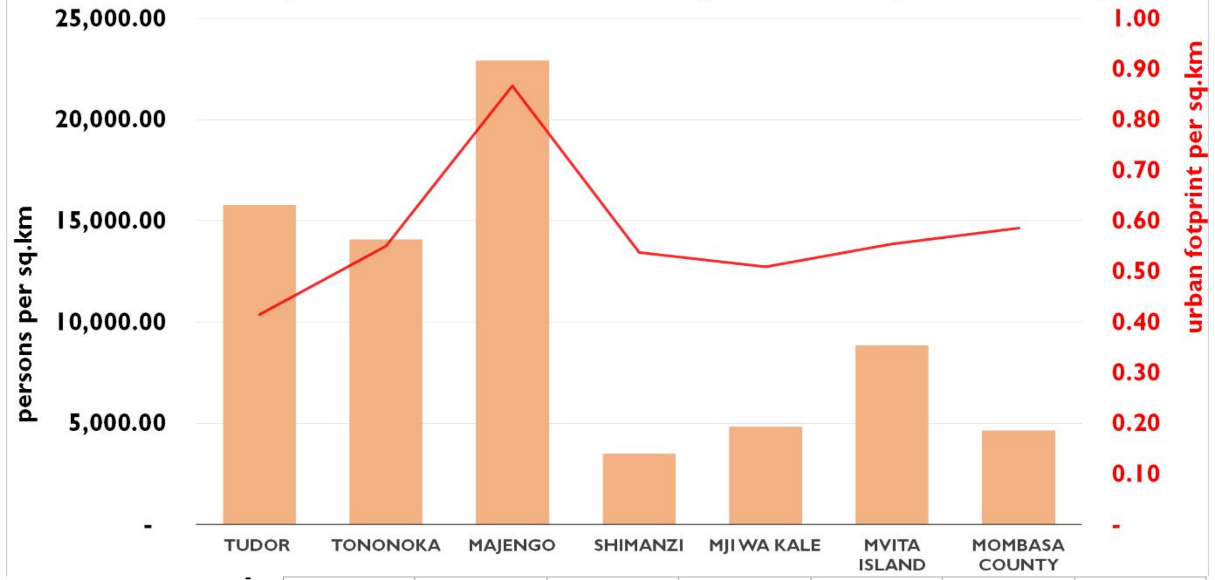
Urban Density Index: Mombasa County	2022	2002	1992
Total Built-Up Area = Pixel Count*30*30/100000 sq.km in the Boundary	168.25777	84.00870	51.8328
Total Pixel Count Area [Built-Up & Non-Built] in the Boundary	287.3844	287.3844	287.3844
Urban Density Index, built-up area/ urban footprint per sq.km	**0.59**	**0.29**	**0.18**

Population Density: Mombasa County	2022	2002	1992
Total Projected Population [Average Growth Rate 3.2 from Baseline Years]	1,328,085	730,924	507,515
Total County Area (Landmass+Water Mass) = Digitized Boundary Area	287.407681	287.407681	287.407681
Population Density Index, pesons per sq.km	**4620.91**	**2543.16**	**1765.84**

Ehrlich, Kemper, Pesaresi & Corbane (2018) highlights that the urban built-up area/footprint and population density are the two most Essential Societal Variables (ESV) of Urbanization that describe the human system within the socio-ecological panarchy that resilience theory seeks to address.

Herein, urban built-up area/footprint has been translated into urban density index which is the urban built-up area/footprint exclusive of vegetation cover per the total area in the boundary (sq.km) to juxtapose and well quantify the human societal system to urbanization patterns and trends as well as climate change hazards, herein, of urban heat islands in cities.

Current Share of Urban Density Index and Population Density



	Tudor	Tononoka	Majengo	Shimanzi	Mji wa Kale	Mvita Island	Mombasa County
Population Density Index	15,776.82	14,072.26	22,905.32	3,464.86	4,806.60	8,829.02	4,620.91
Urban Density Index	0.42	0.55	0.87	0.54	0.51	0.55	0.59

These coupled Essential Societal Variables of Urbanization aids in the quantification of the urban spatial extent and urban human presence on Earth surface. The higher the index, the higher the density of the urban area.
The higher the population density the higher the risk of climate hazards such as heat stress in the area.

Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

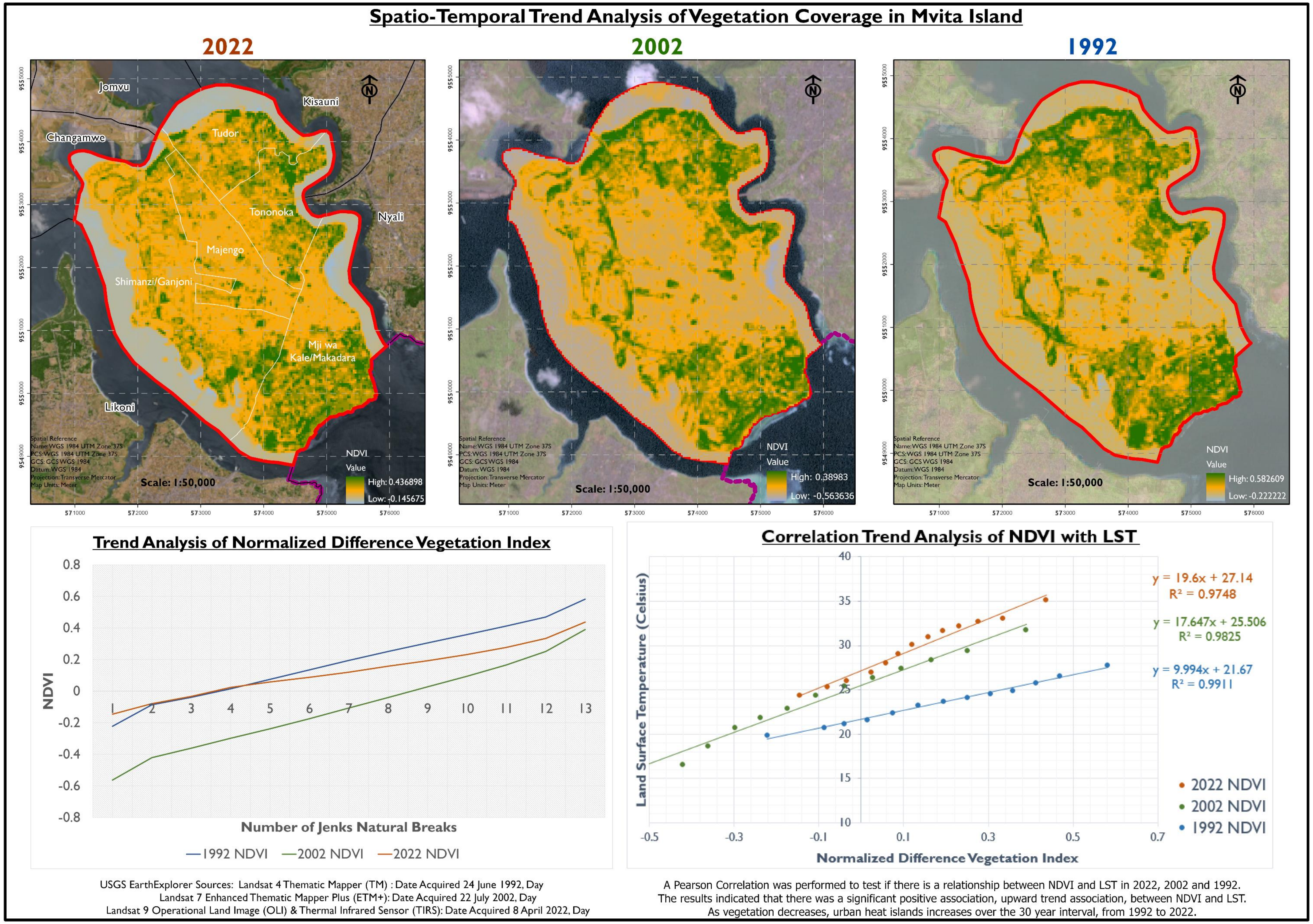
5.1.12 Urban Vegetation Coverage

Understanding the extent of the green space infrastructure (GSI) in Mvita Island and Mombasa County aids in identifying the root causes of urban heat islands as a result of the urban surface modification which alters the surface energy and radiation balance in the atmosphere. Map 5.7 illustrates the spatio-temporal trend analysis of the urban vegetation coverage in Mvita Island while Map 5.8 reveals the share and distribution of all urban green areas seen as the biotope and all public green areas viewed as the sociotope in Mvita Island.

A spatio-temporal analysis of the Normalized Difference Vegetation Index (NDVI) was carried out in 1992, 2021 and 2022 correspondingly from Landsat 4 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM+) as well as the Landsat 9 Operational Land Image (OLI) and Thermal Infrared Sensor (TIRS). NDVI was chosen for this study to represent green areas in entirety to underpin the natural ecosystems in Mvita Island. NDVI value lies between -1 to +1. Negative values of NDVI represent stressed vegetation reflectance while the higher values represent more healthy vegetation reflectance *– See Map 5.7.* The slight dip inclination between the 11th and 13th jenk natural shows transition of dense vegetation coverage to sparse vegetation coverage. Furthermore, a Pearson Correlation was performed to test if there is a relationship between NDVI and Land Surface Temperature (LST) in 1922, 2021 and 2022. The results well indicated that there was a very significant positive association — upward trend association — between NDVI and LST. As vegetation increase, urban heat islands increase over the 30-year interval, from 1992 to 2022 *– See Map 5.7.*

Based on spatial calculations in 2022, the current total share of all green areas in Mvita Island and Mombasa is at 10.03 per cent and 19.26 per cent with a GSI value of 11.36 sq.m per person and 41.67 sq.m per person respectively within the biotope ecosystem -*See Map 5.8*. On the other hand, the current total share of all the public green areas in Mvita Island and Mombasa is at 3.31 per cent and 1.52 per cent with a GSI value of 3.75 per cent and 3.28 per cent respectively within the sociotope ecosystem. Taking into account that WHO (2012) recommends the provision of GSI should be a minimum of 9 sq.m of green space per individual with an ideal urban GSI of 50 sq.m per capita, the situation is left wanting on especially on the share and distribution of public green spaces within the sociotope ecosystem. The total share of all green areas (biotope) within the natural ecosystem in Mvita and Mombasa County have decreased by 68.2 per cent and 73.9 per cent from 1922 to 2022.

Map 5.7 Spatio-Temporal Trend Analysis of Urban Vegetation Coverage

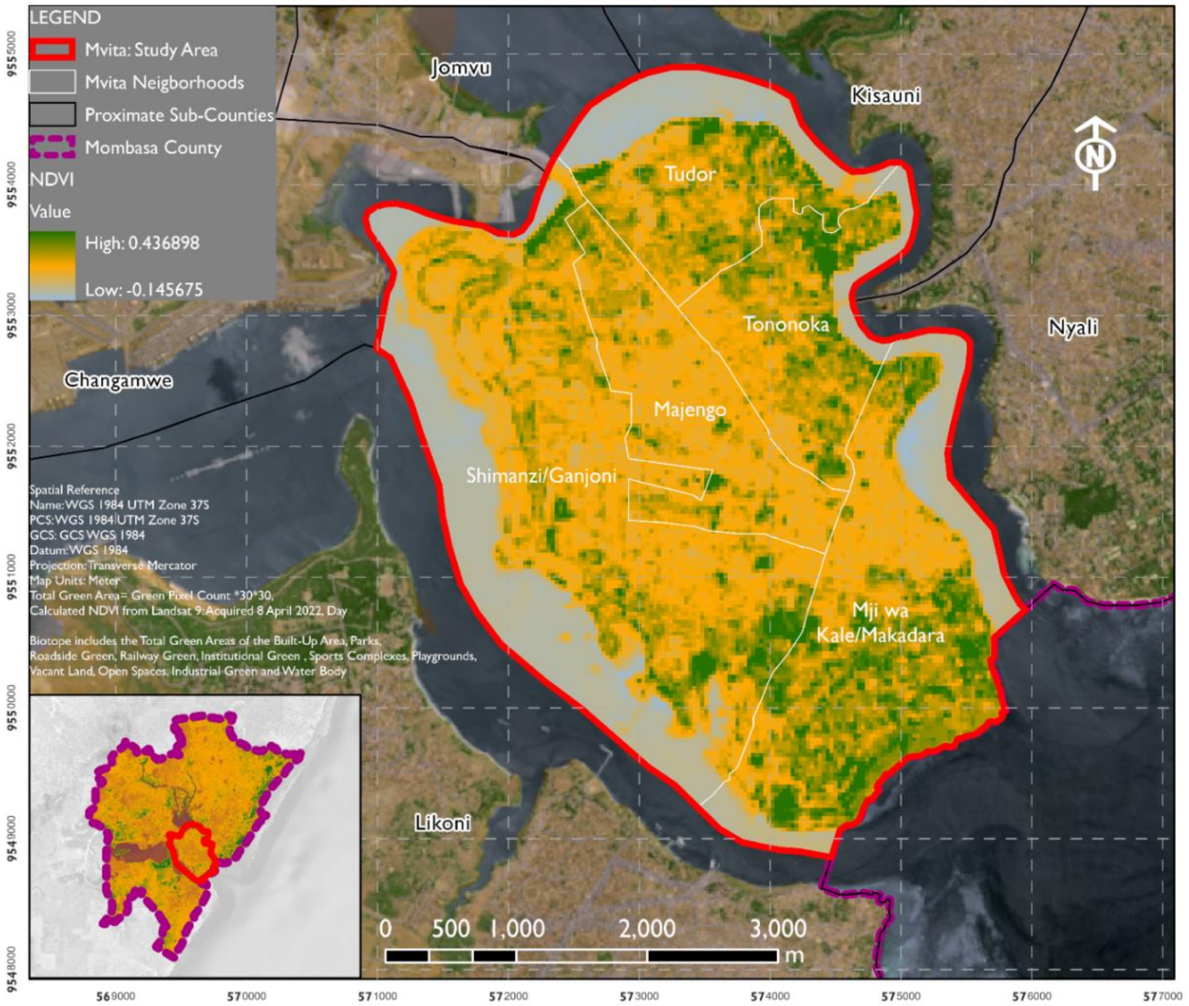


Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

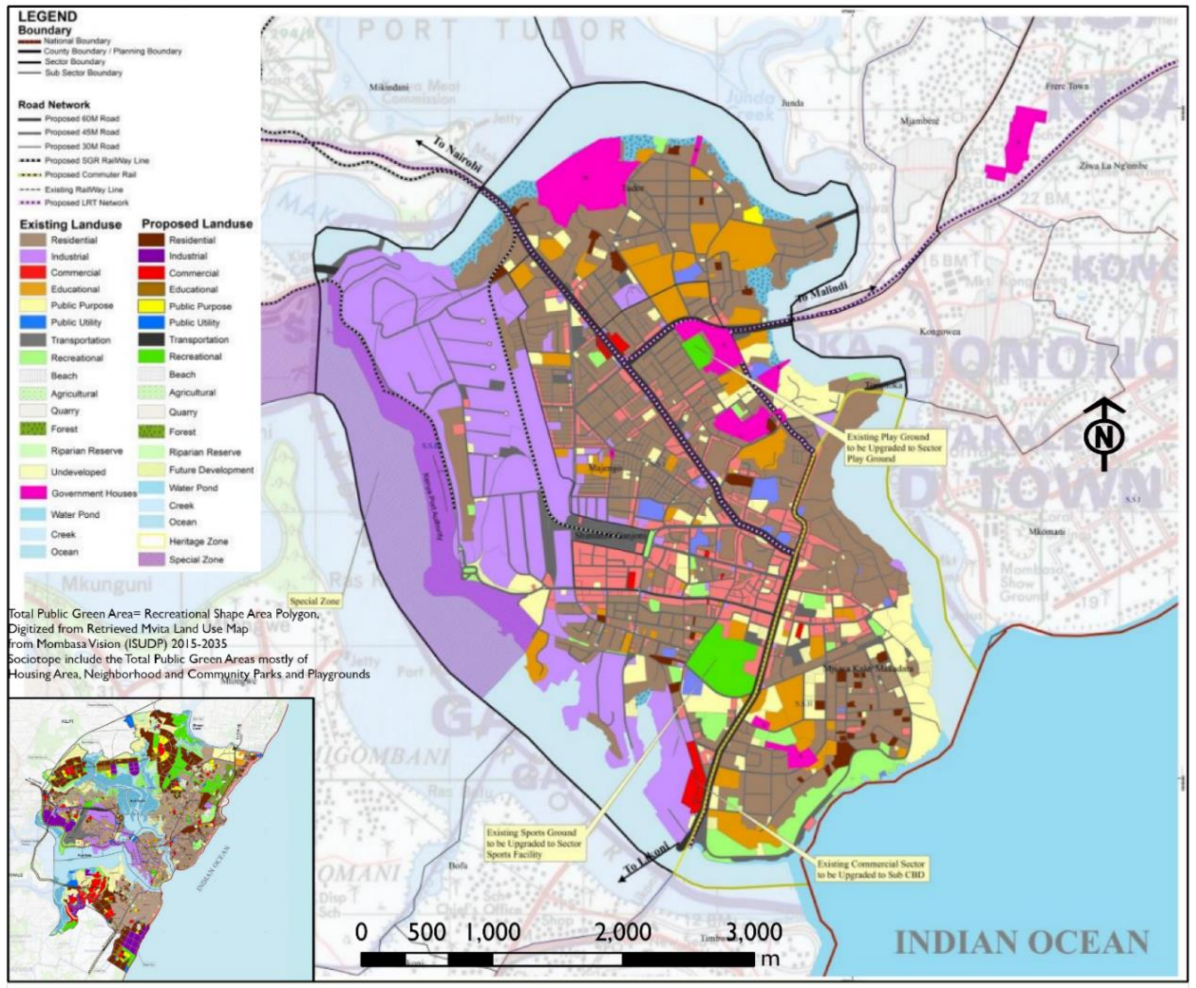
Map 5.8 Share and Distribution of Urban Vegetation Coverage in Mvita

Share and Distribution of all Urban Green Areas and Public Green Spaces in Mvita Island

Distribution of Green Areas from NDVI by Landsat-9, 4 April 2022



Distribution of Public (Recreational) Green Spaces from Mvita Land Use Map 2015-2035



Trend Share of Green Areas (Biotopes) and Public Green Areas (Sociotopes)

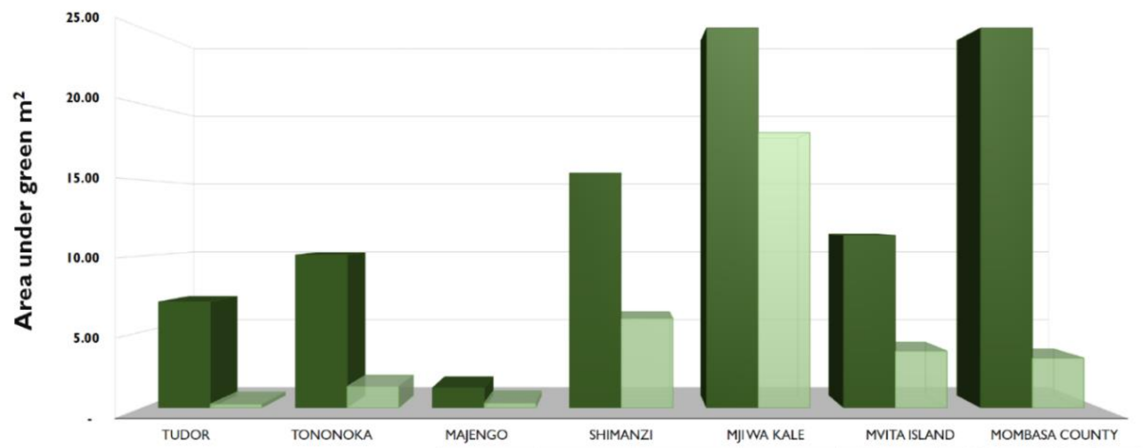
Biotope: Mvita Island	2022	2002	1992
Pixel Green Count Area = Pixel Count*30*30 sq.m in the Boundary	1,924,200	477,000	6,052,500
Total Green Pixel Area = Total Pixel Count*30*30 sq.m in the Boundary	19,189,800	19,189,800	19,189,800
Percentage of Total Green Space Area	**10.03**	**2.49**	**31.54**

Sociotope: Mvita Island	2022	2002	1992
Public (Recreational) Green Area = Digitized Green Area	634,841	no data	no data
Total Island Area (Landmass+Water Mass) = Digitized Boundary Area	19,193,190	19,193,190	19,193,190
Percentage of Total Public Green Space Area	**3.31**	**no data**	**no data**

Biotope: Mombasa County	2022	2002	1992
Pixel Green Count Area= Pixel Count*30*30 sq.m in the Boundary	55,341,900	34,086,600	212,158,800
Total Green Pixel Area=Total Pixel Count*30*30 sq.m in the Boundary	287,384,400	287,384,400	287,384,400
Percentage of Total Green Space Area	**19.26**	**11.86**	**73.82**

Sociotope: Mombasa County	2022	2002	1992
Public (Recreational) Green Area = Digitized Green Area	4,360,000	no data	no data
Total County Area (Landmass+Water Mass) = Digitized Boundary Area	287,407,681	287,407,681	287,407,681
Percentage of Total Public Green Space Area	**1.52**	**no data**	**no data**

Current Share of Green Areas (Biotopes) and Public Green Areas (Sociotopes)



	Tudor	Tononoka	Majengo	Shimanzi	Mji wa Kale	Mvita Island	Mombasa County
Biotope: Total Green Space/Person (sq.m)	6.98	10.07	1.33	15.45	38.28	11.36	41.67
Sociotope: Total Public Green Space/Person (sq.m)	0.26	1.42	0.33	5.90	18.12	3.75	3.28

WHO (2012) recommends the provision and availability of Green Space Infrastructure should be a minimum of 9 sq.m of green space per individual with an ideal urban green space value of 50 sq.m per capita.

Source: (Author, 2022) Adapted from ArcGIS Pro @ A3

5.1.13 Geometry of the Urban Canyons

The geometric parameters of urban canyons with respect to streets and buildings strongly affect the microclimate and level of thermal comfort of the users of public spaces. On the basis of the contextual background of the study area, the origin of the tropical coastal city of Mombasa is in Mvita Island and it had already developed commencing from Old Town and central Majengo and extending to other neighborhoods of Mji wa Kale, Tudor, Tononoka and Shimanzi wards. As posited by the County Architect, given Mvita's historical account, urban renewal to bring about conventional planning and regular standards especially in Old Town and Majengo have been put forward to alter the geometry of the island. Tudor, Tononoka and Shimanzi have more conventional planning and development than Old Town and Majengo neighborhoods.

The streetscape of the island orients towards the Ocean especially in Old Town *– See Plate 4.2*. Old Town and Majengo have narrow streets and closely packed houses, casting shade on each other *– See Plates 4.1and 5.3.* Their Swahili architecture predominantly with shingled and concrete roofs and compact buildings trap incoming and outgoing radiant energy more than those of open as well as lightweight density urban developments within the rest of Mvita Island, thus, contributing to more urban island effect *- See Map 5.9a.* Thus, the sky view factor — the fraction of the sky hemisphere visible from the ground level that is between 0 to 1 and varies with height and the spacing of buildings and trees (Stewart & Oke, 2012) — is generally lower in the Old Town and Majengo neighborhoods as a result *- See Plate 4.1*.

The sky view does become increasingly restricted with taller and more compact buildings. Plates 5.2a and 5.2b illustrates a high-angle panoramic view of the Mombasa CBD towards north west and south east of Mvita Island respectively that underscores the veracity of the aforementioned statement. The high angle-panoramic photographic views were taken from Bima Towers in the Mombasa CBD. It is the tallest building, approximately 67 meters above the sea level, in Mvita Island and Mombasa County in its entirety. Restricted sky view of cities contributes to greater retention of infrared radiation in street canyons. In addition, as the geometry of urban canyons affects the microclimate of the city; classification of the local climate zones on urban landscape (Stewart & Oke, 2012) as well as understanding of surface structure and urban ventilation, have been subsequently conversed to bring forth the full picture of urban heat islands in Mvita Island - *See Plate 5.3 and Maps 5.9a and 5.9b*

Plate 5.2a North West Panoramic View of Mombasa CBD, Mvita Island

Source: (Author, 2022) Adapted from Field Work

Plate 5.2b South East Panoramic View of Mombasa CBD, Mvita Island

Source: (Author, 2022) Adapted from Field Work

5.1.14 Classification of the Local Climate Zones

Local climate zones (LCZ) are logical divisions of the urban landscape combining human built-up and settlement extent as well as vegetation coverage in terms of classes that have a zonal as well as climatic representation. Following the visual survey undertaken and historical account on the urban density insighted by the County Architect; Mvita Island presented varying surface structure, surface cover, surface fabric and human activity on its wards based on a standardized classification of the local climate zones by Stewart and Oke (2012) for the urban temperature studies and observations *– See Plate 5.3 and Maps 5.9a and 5.9b*.

The surface structure does modify the shortwave and longwave radiation balances, airflow and atmospheric heat transport and bears zonal properties relating to the sky-view, aspect ratio and roughness element height (Stewart & Oke, 2012). On the other hand, the surface cover does affect the plan fraction occupied by the buildings, vegetation and impervious ground while the surface fabric relates to the material type, both of which have the climate properties relating to the albedo level, moisture availability and heating and cooling potential of the ground (Stewart & Oke, 2012). The human activity within the local climate zones induces varying emissions which are quantified as anthropogenic heat output (MDDEP, 2006; Institut de la statistique du Québec, 2009; Stewart & Oke, 2012; Phelan, et al., 2015; TERI, 2017). The assessment of the neighborhood density, the acquisition of the bird's eye view aerial world imagery as well as the taking of the low-level photographs contextualized the urban landscape of Mvita for urban temperature studies and observations *– See Plate 5.3 and Maps 5.9a and 5.9b*.

In relation to the urban thermal environment, the higher the aspect ratio — of deep canyons — the greater the intensity of urban heat islands in the city, particularly at night in areas of compact urban developments. This is because as the sky view becomes increasingly restricted with taller and more compact buildings that cast shade on surfaces — lower sky view — there is a lower penetration rate of incoming solar radiation during the day and a larger share of the outgoing longwave radiation during the night. The taller and narrow streets act as obstacles of wind flow and ventilation increasing air temperatures due to the outgoing radiation trappings and reduced cooling effects. As such, deep canyons of the island are often cooler than the shallow ones — of lower aspect ratio — during the daytime and warmer during the nighttime.

This research study focuses on the day urban heat islands processed from Landsat satellites acquired at USGS Earth Explorer during the day and not nocturnal urban heat islands. Shallow canyons have more widely spaced with regard to the buildings and trees and does allow more penetration of direct solar radiation contacting the pervious surfaces for absorption. Thus, they are more warmer during daytime than at nighttime as their higher sky view factor does allow more exposure of incoming solar radiation.

The shallow canyons on the island are more presently within Shimanzi ward, east of Tononoka, south of Mji wa Kale and west of Tudor Ward that bears low to medium density developments with wider streets linked with varied classes of the local climate zones *- See Plate 5.3 and Maps*

5.9a and 5.9b. Indeed, these places have a greater intensity of surface and ambient air temperature that in turn causes peaked intensities of urban heat islands. The former has been mapped under urban thermal environment assessment on mapping the land surface temperature whereas the latter has been conversed under weather conditions and climatology assessment.

The aspect ratios of the deep and shallow canyons are dependent of both the sky-view factor and height of roughness elements which presents the average geometric of building heights and trees heights. In Mvita, the buildings heights are varied — 3 to 25 meters — especially towards the direction where the prevailing wind comes from. The wind blows from the south and south-south east of the island, which is Mji wa Kale Ward, that possess low, medium and density developments. The tallest building there is the Bima Towers, at 67 meters above the sea level, situated in the CBD in south east of the island and less than 1 kilometers from the sea. Although varied, going forward new urban developments should possess decreasing heights towards the direction where the prevailing wind comes from to allow the cool air reach the central Mvita.

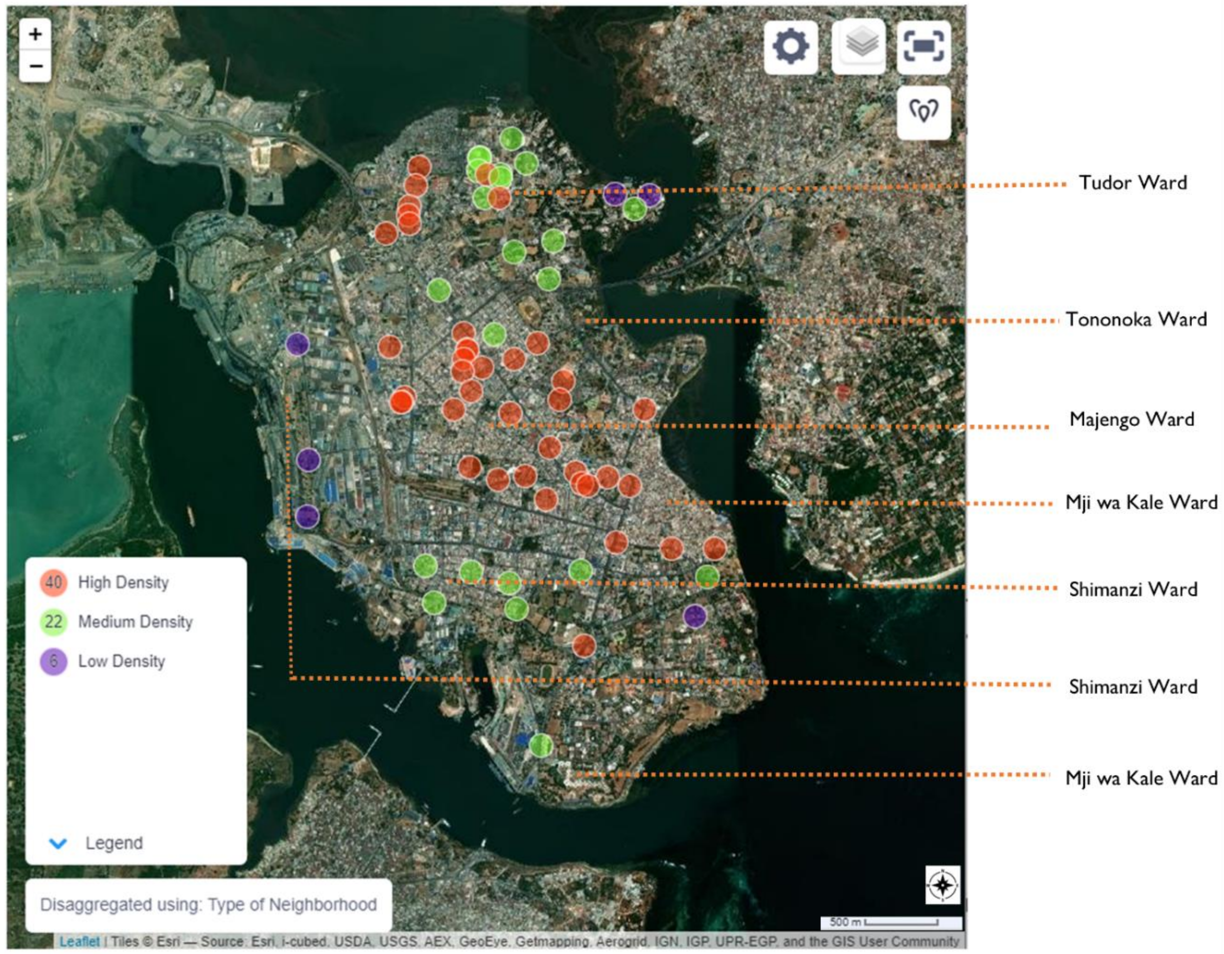
As demonstrated from the NDBI influence with LST in the spatio-temporal analysis of human built-up and settlement extent and share of urban density index and population density of Mvita coupled by Stewart and Oke's (2012) classification of the local climate zones, the larger the building surface fraction and pervious surface fraction of the island, the greater the formation of urban heat islands. The building surface fraction and pervious surface fraction are associated with low levels of albedo. In addition, the larger and denser the type of neighborhood of the island is by the classification of the local climate zones, the greater the levels of anthropogenic heat output, especially heavy industry areas of Shimanzi and the compact urban developments distributed across the five wards. In addition, the greater pervious surfaces of green vegetation cover, the more suppression in formation of urban heat islands

Map 5.9a Classification of the Local Climate Zones by Neighborhood Density Type

Classification of the Local Climate Zones in Mvita Island, Mombasa County

Local climate zone (LCZ)	Sky view factor	Aspect ratio	Building surface fraction	Impervious surface fraction	Pervious surface fraction	Height of roughness elements	Surface albedo	Anthropogenic heat output
LCZ 1 *Compact high-rise*	0.2–0.4	> 2	40–60	40–60	< 10	> 25	0.10–0.20	50–300
LCZ 2 *Compact midrise*	0.3–0.6	0.75–2	40–70	30–50	< 20	10–25	0.10–0.20	<75
LCZ 3 *Compact low-rise*	0.2–0.6	0.75–1.5	40–70	20–50	< 30	3–10	0.10–0.20	<75
LCZ 4 *Open high-rise*	0.5–0.7	0.75–1.25	20–40	30–40	30–40	>25	0.12–0.25	<50
LCZ 5 *Open midrise*	0.5–0.8	0.3–0.75	20–40	30–50	20–40	10–25	0.12–0.25	<25
LCZ 6 *Open low-rise*	0.6–0.9	0.3–0.75	20–40	20–50	30–60	3–10	0.12–0.25	<25
LCZ 7 *Lightweight low-rise*	0.2–0.5	1–2	60–90	< 20	<30	2–4	0.15–0.35	<35
LCZ 8 *Large low-rise*	>0.7	0.1–0.3	30–50	40–50	<20	3–10	0.15–0.25	<50
LCZ 9 *Sparsely built*	> 0.8	0.1–0.25	10–20	< 20	60–80	3–10	0.12–0.25	<10
LCZ 10 *Heavy industry*	0.6–0.9	0.2–0.5	20–30	20–40	40–50	5–15	0.12–0.20	>300
LCZ A *Dense trees*	<0.4	>1	<10	<10	>90	3–30	0.10–0.20	0
LCZ B *Scattered trees*	0.5–0.8	0.25–0.75	<10	<10	>90	3–15	0.15–0.25	0
LCZ C *Bush, scrub*	0.7–0.9	0.25–1.0	<10	<10	>90	<2	0.15–0.30	0
LCZ D *Low plants*	>0.9	<0.1	<10	<10	>90	<1	0.15–0.25	0
LCZ E *Bare rock or paved*	>0.9	<0.1	<10	>90	<10	<0.25	0.15–0.30	0
LCZ F *Bare soil or sand*	>0.9	<0.1	<10	<10	>90	< 0.25	0.20–0.35	0
LCZ G *Water*	>0.9	<0.1	<10	<10	>90	–	0.02–0.10	0

Type of Neighborhood by Density (Field Work, 2022)



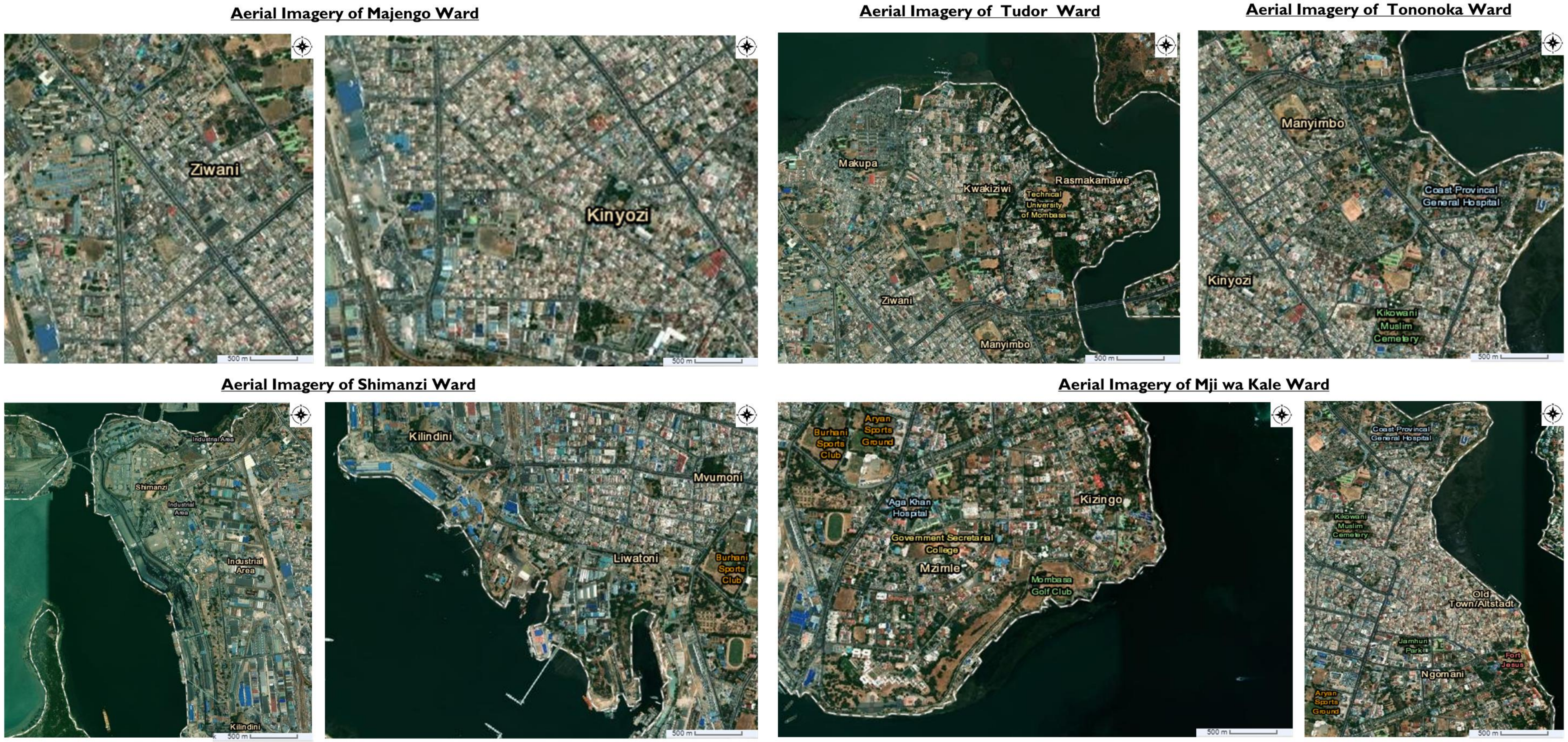
- **Sky view factor** is the ratio of the amount of sky hemisphere visible from ground level to that of an unobstructed hemisphere. It is dimensionless.
- **Aspect ratio** is the mean height-to-width ratio of urban street canyons (LCZs 1–7), building spacing (LCZs 8–10) and tree spacing (LCZs A–G). It is dimensionless.
- **Building surface fraction** is the ratio of building plan area to total plan area (%)
- **Impervious surface ratio** is the ratio of impervious plan area (paved, rock) to total plan area (%)
- **Pervious surface ratio** is the ratio of pervious plan area (bare soil, vegetation, water) to total plan area (%)
- **Height of roughness** elements is the geometric average of building heights (LCZs 1–10) and tree/plant heights (LCZs A–F) (m)
- **Surface albedo** is the ratio of the amount of solar radiation reflected by a surface to the amount received by it. It varies with surface color, wetness, and roughness.
- **Anthropogenic heat output** is the mean annual heat flux density (W m–2) from fuel combustion and human activity (transportation, space cooling/heating, industrial processing, human metabolism). It varies significantly with latitude, season, and population density.

Type of Neighborhood/Ward By Density		Classification of the Local Climate Zones (Stewart & Oke, 2012)						
Majengo:	**High** [Landi ya Makupa, Ziwani and Kinyozi] **Density Developments**	Compact Midrise	Low Plants	Paved				
Tudor:	**Medium** [Tudor, Kwakizwi] **to High** [Makupa] **Density Developments**	Open High-rise	Lightweight low-rise	Large Low-rise	Dense Trees	Bush/scrub	Paved	Water
Tononoka:	**Low** [Mzizima, Ras Makamaiwe] **to** **Medium** [Manyimbo, Kikowani] **Density Developments**	Open-Midrise	Dense Trees	Bush/scrub	Water	Paved		
Shimanzi:	**Low** [Shimanzi, Industrial Area, Kilindini, Liwatoni] **to** **Medium** [Ganjoni, Mvumoni, Mnazi. Mbaraki] **Density Developments**	Heavy Industry	Compact low-rise	Open low-rise	Sparsely built	Scattered trees	Bare rock	Water
Mji wa Kale:	**Low** [Kizingo, Mzimle] to **Medium** [Ngomani] **to** **High** [Old Town, CBD, Makadara] **Density Developments**	Compact High-rise	Scattered Trees	Bare Soil	Water	Paved		

Source: (Author, 2022) Adapted from Fieldwork, KoboToolbox and Literature View @ A3

Map 5.9b Bird's Eye View Illustration of Mvita Urban Landscape by Local Climate Zones

Aerial Urban Landscape of Mvita Island, Mombasa County

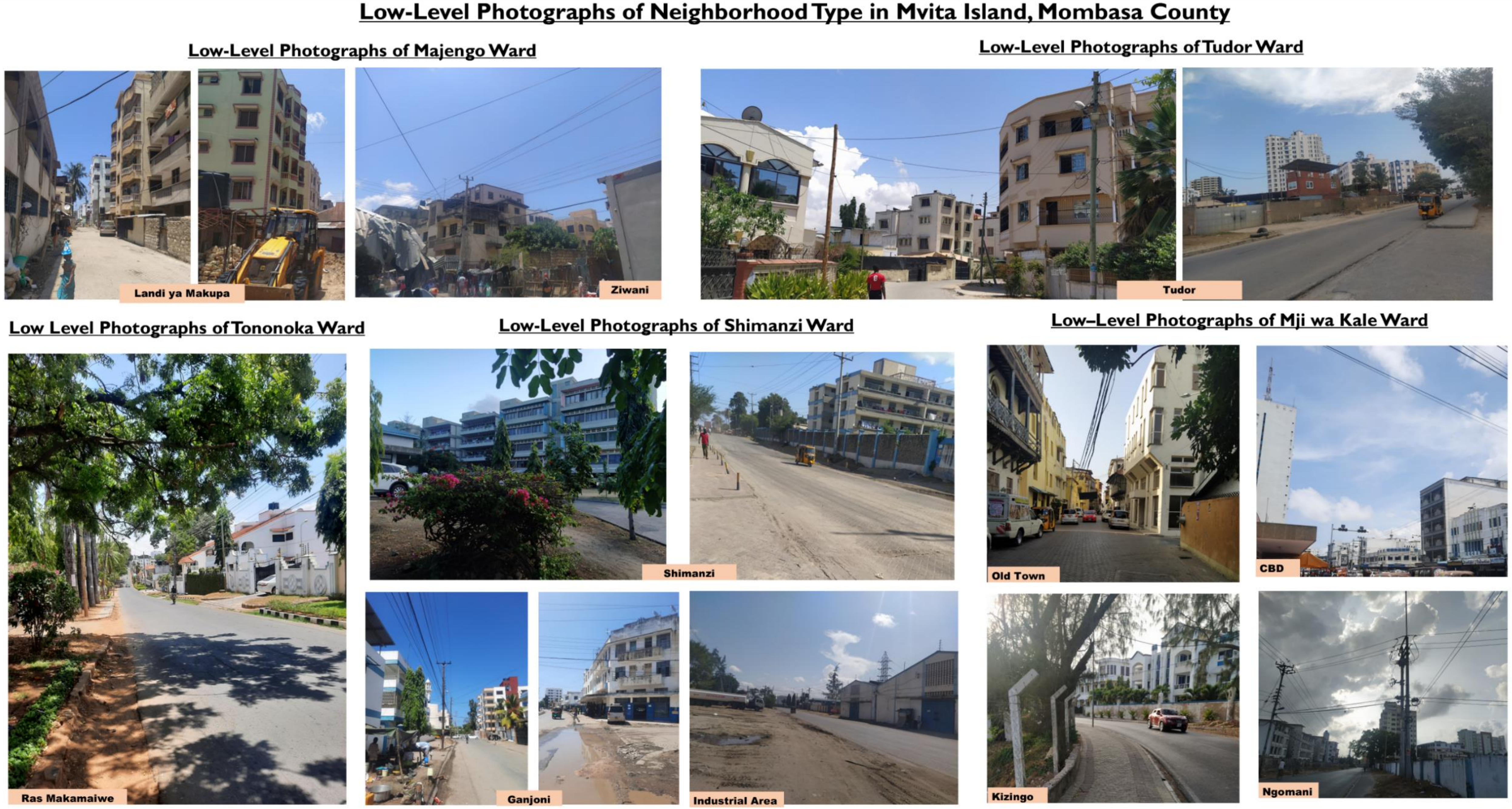


Type of Neighborhood/Ward By Density		Classification of the Local Climate Zones (Stewart & Oke, 2012)						
Majengo:	**High** [Landi ya Makupa, Ziwani and Kinyozi] **Density Developments**	Compact Midrise	Low Plants	Paved				
Tudor:	**Medium** [Tudor, Kwakizwi] **to High** [Makupa] **Density Developments**	Open High-rise	Lightweight low-rise	Large Low-rise	Dense Trees	Bush/scrub	Paved	Water
Tononoka:	**Low** [Mzizima, Ras Makamaiwe] **to** **Medium** [Manyimbo, Kikowani] **Density Developments**	Open-Midrise	Dense Trees	Bush/scrub	Water	Paved		
Shimanzi:	**Low** [Shimanzi, Industrial Area, Kilindini, Liwatoni] **to** **Medium** [Ganjoni, Mvumoni, Mnazi. Mbaraki] **Density Developments**	Heavy Industry	Compact low-rise	Open low-rise	Sparsely built	Scattered trees	Bare rock	Water
Mji wa Kale:	**Low** [Kizingo, Mzimle] to **Medium** [Ngomani] **to** **High** [Old Town, CBD, Makadara] **Density Developments**	Compact High-rise	Scattered Trees	Bare Soil	Water	Paved		

ESRI World Imagery courtesy of USGS Earth Explorer, 2022

Source: (Author, 2022) Adapted from USGS Earth Explorer, Field Work and Literature View @ A3

Plate 5.3 Low-Level Photographs of Mvita Urban Landscape by Neighborhood Density Type



Type of Neighborhood/Ward By Density		Classification of the Local Climate Zones (Stewart & Oke, 2012)						
Majengo:	**High** [Landi ya Makupa, Ziwani and Kinyozi] **Density Developments**	Compact Midrise	Low Plants	Paved				
Tudor:	**Medium** [Tudor, Kwakizwi] **to High** [Makupa] **Density Developments**	Open High-rise	Lightweight low-rise	Large Low-rise	Dense Trees	Bush/scrub	Paved	Water
Tononoka:	**Low** [Mzizima, Ras Makamaiwe] **to** **Medium** [Manyimbo, Kikowani] **Density Developments**	Open-Midrise	Dense Trees	Bush/scrub	Water	Paved		
Shimanzi:	**Low** [Shimanzi, Industrial Area, Kilindini, Liwatoni] **to** **Medium** [Ganjoni, Mvumoni, Mnazi. Mbaraki] **Density Developments**	Heavy Industry	Compact low-rise	Open low-rise	Sparsely built	Scattered trees	Bare rock	Water
Mji wa Kale:	**Low** [Kizingo, Mzimle] to **Medium** [Ngomani] **to** **High** [Old Town, CBD, Makadara] **Density Developments**	Compact High-rise	Scattered Trees	Bare Soil	Water	Paved		

Source: (Author, 2022) Adapted from Field Work and Literature View @ A3

5.1.15 Pervious and Impervious Materials and Surfaces

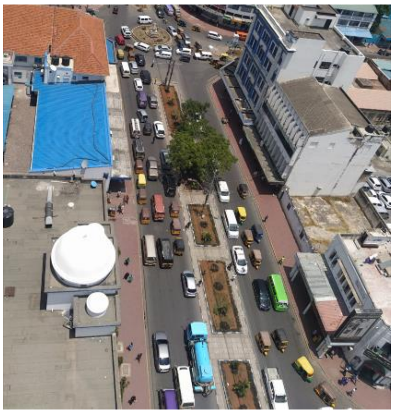
To reiterate, the tropical coastal city of Mombasa that started in Mvita saw transformation of the construction materials from clay with mangrove structures as well as coral limestone walls with mangrove structures to industrialized materials such as glass, steel and concrete during its changing shift in socio-cultural, economic and political controlling interests over the centuries. Currently, the urban ecosystem of Mvita is characterized with more impervious materials as well as surfaces than pervious materials and surfaces *– See Map 5.5 and 5.7.* Majengo has more pervious materials and surfaces, followed by the wards of Tononoka, Shimanzi, Mji wa kale and Tudor. On the other hand, Mji wa Kale has more pervious materials and surfaces, followed by the wards of Shimanzi, Tononoka, Tudor and Majengo. Further classification of the land cover types has been provided by the classification of the local climate zones *– See Plate 5.3 and Maps 5.9a and 5.9b.*

Plates 5.4 and Plates 5.5 attempts to give the prevailing picture of the pervious and impervious materials and surfaces in Mvita within its built-up and natural ecosystems respectively. Grass landscaping along median strips and roundabouts and green tree corridors along streetscapes does not occur throughout the island. They are quite sporadic based on varied geographical locations as well as topography of the island. Urban community parks and spaces of the island possess scattered to dense vegetation. The County Environment Officer underpinned that housing developments have been reducing the share and distribution of vegetation cover in Mvita. Currently, green areas [biotope] in Mvita are approximately 10.03 per cent while public green areas [sociotope] are approximately 3.31 per cent.

The asphalt and cabro along streetscapes are very predominant. Tarmacked roads have higher thermal absorption due to the colour and asphalt material than the paved cabro road surfaces. Cabro surfaces are more as articulated by the County Architect. There are a few buildings with glass facades and structural glazing in the Mombasa CBD such as the TSS Tower, Bima Tower and Naivas Mwembe Tayari and more buildings with concrete and shingled roofs as well as concrete and brick walls. The glass surfaces and materials reflect more radiation energy while concrete surfaces and shingled roofs retain more heat. Swahili Architecture within the island is typified by mangrove structures and white color from local coral limestone especially in Old Town. The white and Egyptian blue color is predominant for residential and commercial land use developments in the Mombasa CBD, for city beautification and thermal regulation. Urban planners should therefore mainstream the cool and green surfaces as well as choice of materials and colors on roofs, pavements and walls for cool communities.

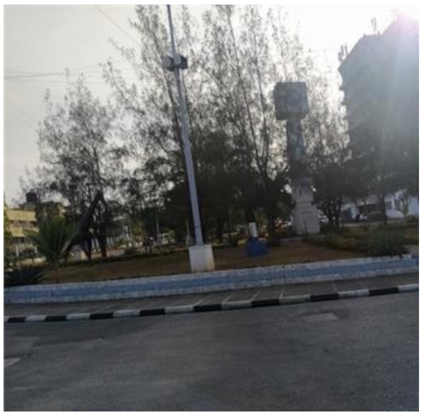
Plate 5.4a Green Landscaping along Median Strips and Roundabouts

Makadara Road



Mombasa-Faza Roundabout

Hatimy Talyani Roundabout

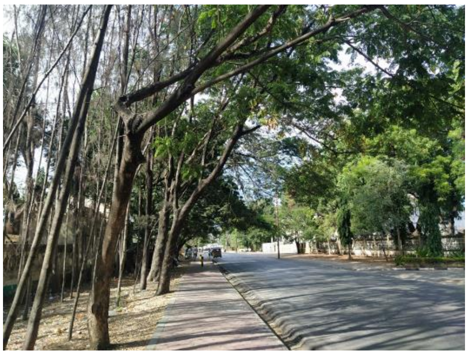


Source: (Author, 2022) Adapted from Field Work

Plate 5.4b Green Tree Corridors along the Streetscape

Haile Selassie Street

Tom Mboya Street



Mama Ngina Drive

Source: (Author, 2022) Adapted from Field Work

Plate 5.4c Scattered to Dense Vegetation on Urban Community Parks and Spaces

Uhuru Gardens

Fort Jesus Park

Source: (Author, 2022) Adapted from Field Work

Plate 5.5a Asphalt and Cabro along the Streetscape

Makadara Road

Moi Avenue

Source: (Author, 2022) Adapted from Field Work

Plate 5.5b Predominant Concrete and Shingled Roofs on Buildings and Settlements

Concrete Roofs

Shingled Roofs near Fort Jesus Park

Source: (Author, 2022) Adapted from Field Work

Plate 5.5c Predominant Concrete and Brick Walls on Buildings and Settlements

Mombasa CBD

Shimanzi

Source: (Author, 2022) Adapted from Field Work

Plate 5.5d Glass Facades and Structural Glazing on Buildings

TSS Tower Building, CBD

Naivas Building, MwembeTayari

Source: (Author, 2022) Adapted from Field Work and Desktop Review

Plate 5.5e Predominant White and Egyptian Blue Colour in Mombasa CBD

Source: (Author, 2022) Adapted from Field Work

Plate 5.5f Predominant Oxidized White Coral Limestone and Mangrove Swahili Architecture

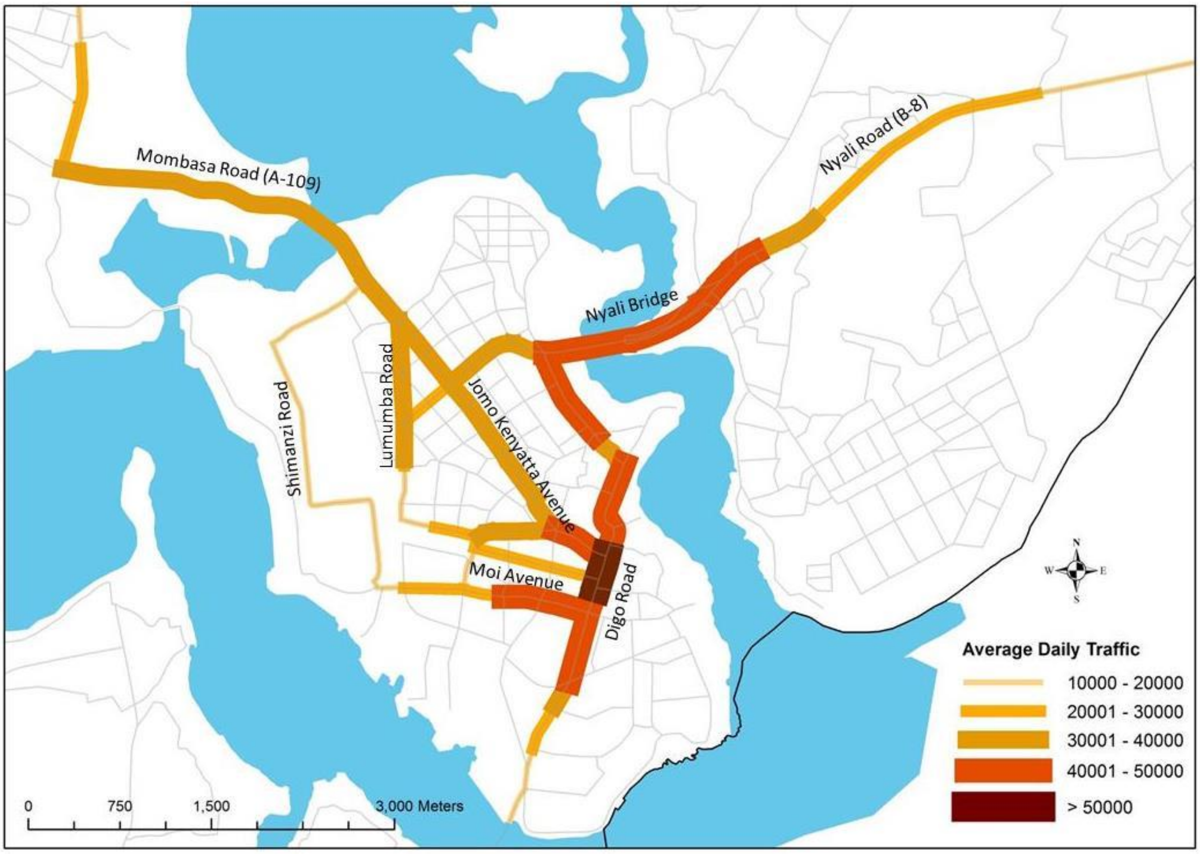
Source: (Author, 2022) Adapted from Field Work

5.1.16 Urban Transport and Ventilation of the Island

Aside of compact land uses within the island, there are more traffic along the roads especially in central Mvita that impact the scale of temperature through carbon emissions that in turn adds to the anthropogenic heat output. The large volume of tuk tuks in the island could be a primary contributor to the addition of anthropogenic heat as they the main means of public transport in Mvita. On this account, urban planners have to therefore ensure that the public transport system can handle additional number of passengers to lessen the traffic volume within the island. In addition, advocating for electric vehicles and electric public transport to mitigate the perceived higher carbon emissions in the Island.

Map 5.10 illustrates the average daily traffic in Mvita while Plate 5.11 reveals the situation of the large volumes of tuk tuks as the main means of public transport for the island.

Map 5.10 Average Daily Traffic in Mvita Island



Source (County Government of Mombasa & Ministry of Land, Housing and Urban Development, 2015), Mombasa Vision 2035

Plate 5.11 Tuk Tuks as the Main Means of Transport

Makadara Road, Mji wa Kale

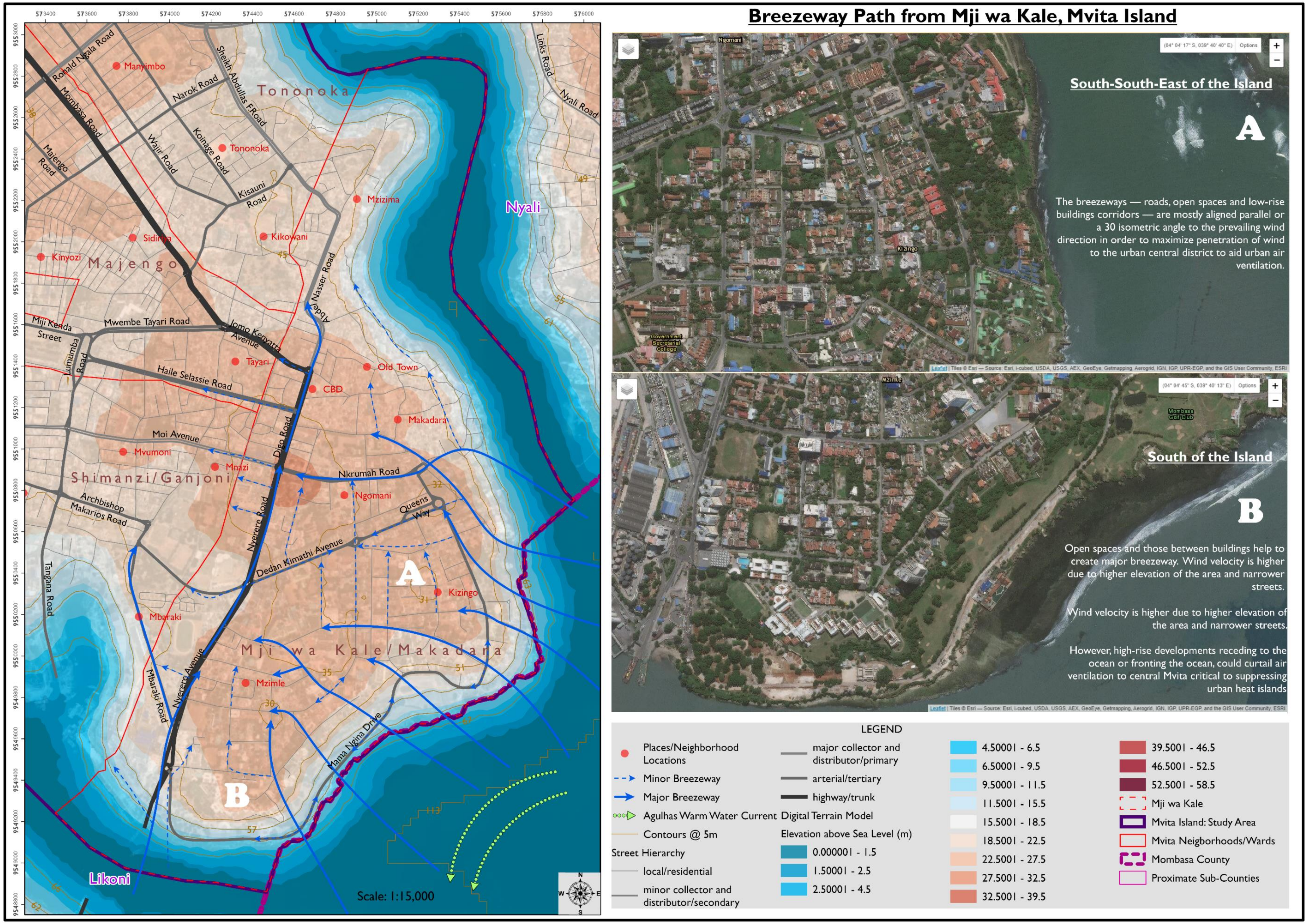
Tom Mboya Road, Tudor

Source: (Author, 2022) Adapted from Field Work

Urban ventilation of the cities varies with different land uses and activities and geometry of the city. As conversed earlier on weather conditions and climatology assessment as well as urban morphology of Mvita Island, the air movement often prevails from the south-south-east in Mji wa Kale. The breezeways — roads, open spaces and low-rise buildings corridors — are mostly aligned parallel or a 30 isometric angle to the prevailing wind direction in order to maximize penetration of wind to the urban central district.

The buildings have irregular heights which is a good design for urban ventilation, however the fact that the developments are rising towards the ocean in the south-south east of the island, act as obstacles for the wind direction and wind velocity. Going forward, the planning of high-rise developments should be receding towards the ocean, especially in the south-south east of the island.

Map 5.11 Breezeway Path from South and South-South-East of Mvita Island



Source: (Author, 2022) Adapted from ArcGIS and USGS EarthExplorer @A3

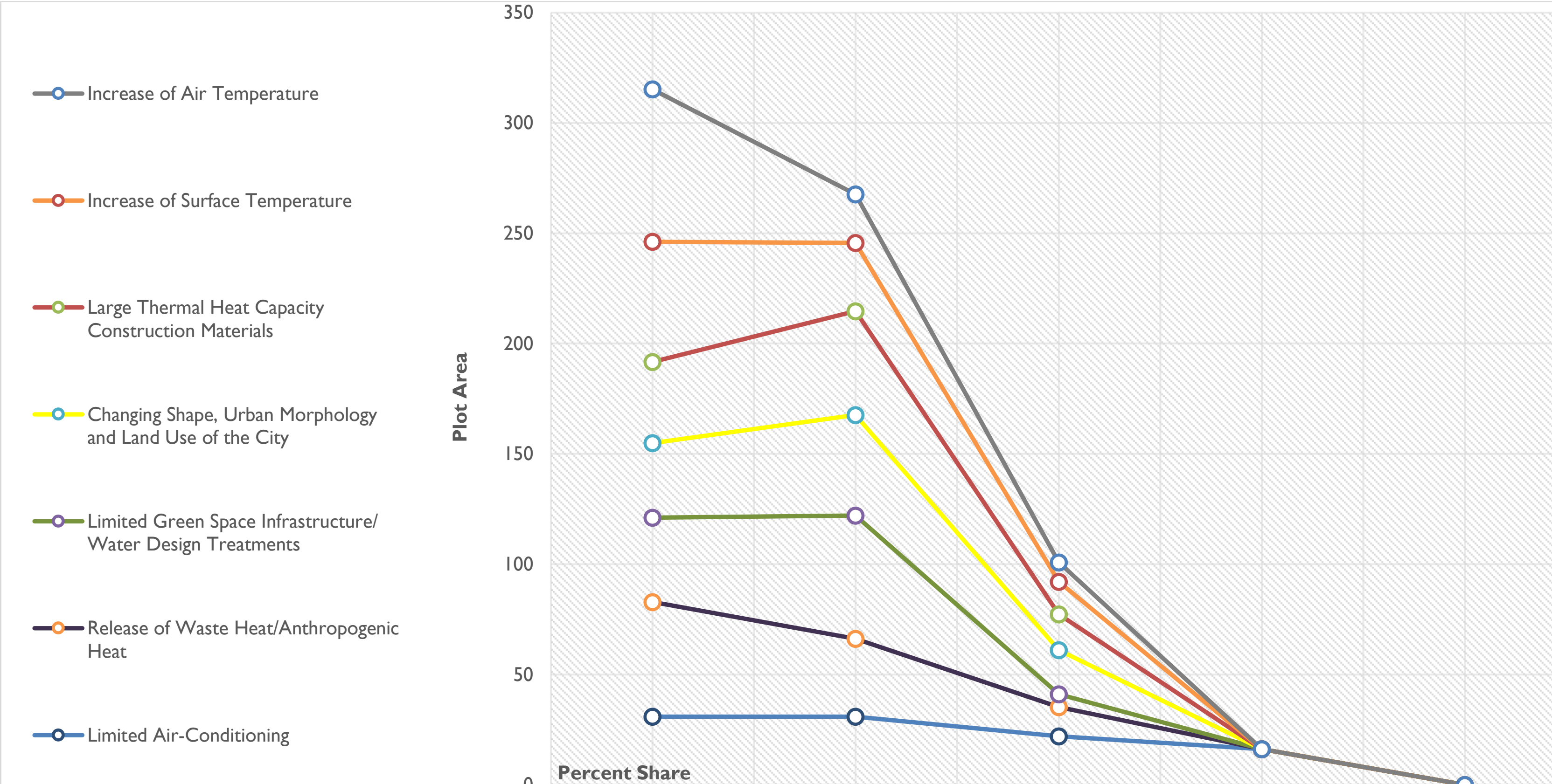
5.1.17 Perception on the Causes of Urban Heat Islands

Earlier, profiling of the surface urban heat islands in Mvita established that it experiences higher temperatures to the outlying areas of Likoni to the west and Jomvu and Changamwe to the north, excluding the adjacent areas of Kisauni and Nyali sub-counties. Understanding the perceptions of the people of Mvita is critical in attaining veracity of higher temperatures as well as root causes of the urban heat islands in its entirety to complement weather conditions and climatology assessment and urbanization development assessment earlier performed for the island. Figure 5.10 presents the household perception on risk exposure rating on the intensity of urban heat islands in Mvita.

A greater proportion of household participants at 69 per cent perceived that the risk exposure rating on the intensity of urban heat islands in Mvita due to increase of air temperature following more periodic heat waves during the hot days and seasons as very high. Only, 22 per cent and 9 per cent respectively weighed it as high and moderate. On the key informants; County Physical Planner, County Architect, County Environmental Officer and NEMA Officer considered the events as high while the County Climate Change Expert perceived the phenomenon as moderate in causing of urban heat islands. Based on air temperature assessment, the higher temperatures in the atmosphere since 1922 to 2021 are often between late November at 26.6^0C, December at 27.18^0C, January at 27.8^0C, February at 28.3^0C, March at 28.09^0C and to late April at 26.78^0C, given an acceptable thermal environment is usually between 20°C and 27°C. Therefore, the increase of air temperature due to more periodic heat waves in Mvita Island can be thus deduced at moderate in causing urban heat islands in Mvita.

On the second potential root cause, a larger share of household participants at 54 per cent intuited that the risk exposure on the intensity of urban heat islands in Mvita as a result of the increase of surface temperature following dominance of impervious infrastructural surfaces and buildings as very high. Around 31 per cent and 15 per cent rated the occurrence as high and moderate in that order. On the key informants; NEMA Officer rated the situation as very high while the County Physical Planner and County Environmental Officer considered it as high. The County Climate Change Expert perceived the event as moderate while the County Architect gauged that it would depend on thermal properties of the existing developments in Mvita in causing urban heat islands. Based on earth skin temperature, the higher temperatures on the surfaces experienced since 1922 to 2021 are usually between late November at 28.1^0C, December at 28.44^0C, January at 29.44^0C,

Figure 5.10 Household Perception on Risk Exposure Rating on the Intensity of Urban Heat Islands



Percent Share	Very High = 5	High = 4	Moderate = 3	Low = 2	Very Low = 1
Increase of Air Temperature	69	22	9		
Increase of Surface Temperature	54	31	15		
Large Thermal Heat Capacity Construction Materials	37	47	16		
Changing Shape, Urban Morphology and Land Use of the City	34	46	20		
Limited Green Space Infrastructure/ Water Design Treatments	38	56	6		
Release of Waste Heat/Anthropogenic Heat	52	35	13		
Limited Air-Conditioning	31	31	22	16	

Source: (Author, 2022) Adapted from Field Work

February at 30.22^{0}C, March at 29.74^{0}C and to late April at 27.62^{0}C, given the ideal urban thermal environment is usually between 20°C and 27°C. Further the Pearson correlation test between the LST and NDBI, pointed out that as the built-up areas increase, urban heat islands increase over the 30-year interval, from 1992 to 2022 in Mvita. Empirically speaking, the surface urban heat island mapping in Mvita for 2022 does quantify the medium land surface temperature range as 31.03^{0}C to 32.02^{0}C while the very high land surface temperature monitored as 32.56 to 35.09^{0}C, which are quite alarming considering that an acceptable urban thermal environment is between 20°C and 27°C. The increase of surface temperature as a result of impervious infrastructural surfaces and buildings dominance can be therefore deduced as very high in causing urban heat islands in Mvita. There is greater absorption of solar radiation credited to the multiple reflection as well as outgoing radiation trapping by the building walls and vertical surfaces of the island.

With regards to the third potential root cause, a decent proportion of household participants at 47 per cent appraised that the risk exposure on the intensity of urban heat islands in Mvita as a result of large thermal heat capacity construction materials that absorb and store more solar energy as high. Only 37 per cent and 16 per cent rated it respectively as very high and moderate. Likewise on the key informants; NEMA Officer rated the occurrence as very high while the County Physical Planner as well as County Environmental Officer weighed it as high. The County Climate Change Expert perceived the event as moderate while the County Architect intellectualized it would also depend on thermal properties of the existing developments in Mvita in causing urban heat islands.

Based on urban morphology assessment of the island, the impervious surfaces and materials have low albedo levels which absorbs more solar during the day and release more during the night. The tarmacked asphalt, cabro, concrete and steel materials in Mvita have a larger thermal heat capacity than grass, plants, glass, clay and mangrove structures. The presence of large thermal heat capacity construction materials depends on development historical account of Mvita Island, now with more newly industrialized materials. Nonetheless, the present mangrove structures and oxidized white coral limestone typifying Swahili Architecture and white and Egyptian blue colour characterizing Mombasa CBD does offer high emissivity to induce a cool thermal environment in Mvita. As such, the large thermal heat capacity construction materials that absorb and store more solar energy can therefore be deduced as high for this study, following the greater uptake and delayed release of heat by buildings and paved surfaces in the city.

With respect to the fourth potential root cause, a modest share of household participants accounting at 46 per cent perceived that the risk exposure on the intensity of urban heat islands in Mvita due to changing shape, urban morphology and land use of the city as high. Only 34 per cent and 20 per cent rated the occurrence as very high and moderate in that order. Based on the key informants; County Environmental Officer considered it as high while the County Physical Planner and NEMA Officer termed the situation as moderate. Moreover, the County Climate Change Expert perceived it as low whereas the County Architect intellectualized that such occurrence would depend on the development history of Mvita that was already developed. This is based during its earlier centuries that saw changing shift in socio-cultural, economic and political controlling interests vested by the Arabs, Persians, Portuguese, Turks, Sultanate of Zanzibar, British administration and Government of the Republic of Kenya. The city grew from the south east of the island. Currently, urban renewal is taking place in Mvita to bring about more regular and conventional planning standards in earlier settled areas of Mji wa Kale and Majengo.

The topography and elevation, the classification of the climate zones inclusive of urban canyons and the previous land use planning efforts and the spatio-temporal analysis of LST assessed earlier over the 30 years weighs heavily on this potential root cause, although varies across the five wards. Further comprising, the County Architect commented that despite approval of the Mombasa Vision 2035 dossier by the County Assembly, a finalized Mvita land use plan — zoning plan and zoning ordinances — was yet to be approved to inform and guide activity in spaces and align itself with the other proposed Mvita land use plan underpinned by the Draft Mombasa Gate City Master Plan 2040. Nevertheless, the application of these two land use plans have been accepted by the County Executive and now used by the County Public Service Board. Following the aforementioned, the changing shape, urban morphology and land use of Mvita, Mombasa can thus be deduced currently as moderate in causing urban heat islands.

On the fifth potential root cause, a greater share of the household participants at 56 per cent intuited limited share of distribution of urban green space infrastructure and water urban design treatments as high in causing urban heat islands in Mvita. Only 38 per cent and 6 per cent rated it as very high and moderate. On the key informants interviewed; County Environmental Officer considered it as very high while the NEMA Officer and County Physical Planner rated the phenomenon as high. Further, the County Climate Change Expert perceived it as a low-risk exposure on the intensity of urban heat islands in Mvita, Mombasa. Both the NEMA Officer and County Environmental Officer articulated that the share and distribution of urban green areas are less than 2 per cent for the public recreation. The notable urban green areas for the public include Mombasa Municipal Stadium and Kikowani Muslim Cemetery Park in Tononoka and Jamhuri Park, Fort Jesus Park, Mombasa Golf Club with membership, Mama Ngina Waterfront Park and Burhani Gardens in Mji wa Kale. Others include Uhuru Gardens, Mombasa Railway Station Recreation Park, Mombasa Mbaraki Cemetery Park, Aryan Sports Ground and memberships sports club in Shimanzi. The latter include Burhani Sports Club, Mombasa Railway Sports Club, Mombasa Sports Club and KPA Sports Club in close proximity to each other. Tudor has dense vegetation in Ras Makamaiwe while Majengo ward has low plants and green parks with the notable one being of Khoja Sha Ithina-Ashani Cemetry. There is green landscaping along median strips and roundabouts. However, there are no water fountains and designs cooling treatments around the roundabouts and the present one in Mombasa Railway Station Recreation Park isn't operational. This is due to the large amount of potable water required as well as investment in water reticulation systems of the city.

That said, based on urban vegetation coverage assessment, the current total share of all green areas in Mvita is at 10.03 per cent with a green space infrastructure (GSI) value of 11.36 sq.m per person within the biotope ecosystem. On the other hand, the current total share of all the public green areas in Mvita is at 3.31 per cent with a GSI value of 3.75 per cent within the sociotope ecosystem. On both accounts, the situation is alarming as the recommended the provision of GSI should be a minimum of 9 sq.m of green space per individual with an ideal urban GSI of 50 sq.m per capita. Empirically, with the rate the urban built-up density index and population density for Mvita Island increasing by 66.7 per cent and 318.5 per cent between 1992 to 2022 on the natural landscapes, such occurrence brings forth minimized natural cooling effects of shading and evapotranspiration from soil and vegetation. The Pearson correlation test between the urban vegetation coverage as well as temperature showed that there is a very significant positive association. As the vegetation increase, urban heat islands increase over the 30-year interval, from 1992 to 2022. Altogether, the limited share of distribution of urban GSI and water design cooling treatments accounts can therefore be deduced as a high-risk exposure on intensity of urban heat islands in Mvita, Mombasa.

On the sixth potential root cause, a greater share of household participants accounting at 52 percent perceived the release of waste heat or anthropogenic heat to the atmosphere as a high-risk exposure on the intensity of urban heat islands in Mvita, Mombasa. Around 35 per cent and 13 per cent rated the phenomenon respectively as high and moderate in Mvita. Based on the key informants; NEMA Officer, County Environmental Officer and County Physical Planer perceived it as high whereas the Climate Change Expert rated the situation as low in Mvita. As broached under the previous land use planning efforts as well as urban transport and ventilation with respect to the mapping of the surface urban heat island, the industrial and vehicular emissions add heat into the atmosphere. The extensive industrial areas of Shimanzi and the rise on traffic volume especially of tuk tuks in the island attempts to elucidate the higher temperatures in Mvita. In addition, as seen earlier under the classification of the local climate zones, compact areas of development of the island cutting across the wards of Majengo, Tudor, Tononoka and Mji wa Kale exhibit more anthropogenic heat output. Taking all insights into account, the release of the anthropogenic heat to the atmosphere can thus be deduced as a high-risk exposure on intensity of urban heat islands in Mvita, Mombasa.

Last but not least, a fair share of household participants tallying at 31 per cent, 31 per cent, 22 per cent and 16 per percent perceived the presence of limited air-conditioning as a non-climate stressor and a cooling opportunity respectively to be very high, high, moderate and low-risk exposure on the intensity of urban heat islands in Mvita, Mombasa. With respect to the key informants; only NEMA Officer rated the situation as high in Mvita while the County Climate Change Expert, County Environmental Officer and County Physical Planner rated it as low in causing urban heat islands. Based on literature review, increase of the use of artificial cooling — fans and ACs — leads to increase in electricity usage, which in turn increases in waste and external energy inputs, albeit seen as smaller emissions compared with other causes of urban heat islands. The situation in Mvita is that not every household can afford an air-conditioning system (ACs), however most possess artificial fans for cooling with about 63 per cent experiencing very high share of energy (electricity) demand or consumption. That said, the presence of limited air-conditioning as a non-climate stressor and a cooling opportunity can be therefore deduced as a low-risk exposure on the intensity of urban heat islands in Mvita, Mombasa.

5.2 Effects of Urban Heat Islands in Mombasa

5.2.1 Perception on the Impacts of Urban Heat Islands

Table 5.1a shows the common heat-related illness and symptoms experienced in Mvita while Table 5.1b reveals the overall sensitivity rating on the effects of urban heat islands in Mvita as put across by household participants and key informants. Mode as a measure of central tendency constituted as the articulation made by households and deduction levels across all the participants. On social impacts of urban heat islands, perception concerns are varied for both household participants and key informants credited to the direct and indirect implications on people, health and well-being. Based on mode, levels of heat stress intolerance are seemingly moderate, though likely to increase the occurrence of heat illnesses and health services *– See Table 5.1b*.

Table 5.1b Household Common Heat-Related Illness and Symptoms

Types of Heat-Related Illnesses and Symptoms	Rank	% Mentioned Within the Rank
Heavy Sweating	1	44
Dehydration/Thirst/Dry Mouth	2	41
Body Weakness/ Fatigue	3	31
General Human Thermal Discomfort/Aches	4	32
Unconsciousness/Fainting	5	25
Muscles Cramps and Convulsions	6	32
Heat Rash	7	25
Heat Stroke	8	28
Air and Water Borne Diseases	9	32
Respiratory Diseases	10	57
Cardiovascular Illnesses/Symptoms	11	62
Renal Diseases	12	90

Source: (Author, 2022) Adapted from Field Work

The presence of limited empirical evidences and lack of standardised health data affiliated directly with the urban thermal environment, herein, of urban heat islands to monitor heat vulnerability on people, health and well-being forms the basis of the varied social responses. As put by the Public Health Practitioner, there is an urgent need to come up with indicators for assessing and capturing health information systems on heat resilience. The County Architect also attached it to the socio-cultural preference typifying Mvita as more reliant on traditional methods in dealing with heat.

Based on mode, the economic impacts of urban heat islands across for both household participants and key informants are apparently highly perceived attributed to indirect influences of heat stress intolerance on energy and expenditures. The responses fluctuate given on the level of households' incomes and socio-cultural lifestyles practiced in Mvita as intuited by the County Architect. There is a stronger need to build awareness of energy conservation and to foster social acceptance and adoption of the use of renewable energy to cut economic costs in regulating both the indoor and outdoor urban thermal environment.

The environmental impacts of urban heat islands are also highly perceived based on mode by both household participants and key informants as a result of direct and indirect influences of heat stress intolerance on urban built-up and natural ecosystems. The responses differ following the historical background of Mvita when the Sultanate of Zanzibar reigned and partially due to a socio-cultural preference. Mvita was already then developed as a town linked with poor infrastructure, flooding and blockage. Now, developable land in Mvita is rather depleted as it is a concrete jungle bearing limited vegetation and poor soils explaining a higher heat sensitivity rating on the degradation of environment and the deterioration of infrastructural services. Dates are preferred more than water melons on the influence of the level of food production and supply.

On institutional impacts of urban heat islands, perceptions on the level of sensitivity varies across for both household participants and key informants credited to the direct and indirect implications on vulnerable groups, frameworks, awareness and funding exercises. On mode basis, levels of heat stress intolerance are seemingly moderate. Nonetheless, infants, school children, homeless people, outdoor laborers, elderly as well as disable people are very susceptible to high levels of heat stress intolerance as purported by the engaged Public Health Practitioner. Present frameworks face laxity in implementation as conversed under the legal, policy and institutional issues on urban heat island effect. There is more need for awareness, funding and efforts to curb corruption. The attempts on the execution of institutional roles and responsibilities are still wanting in dealing with the urban thermal environment in Mvita as addressed by the County Architect.

Table 5.1a Overall Sensitivity Rating on the Effects of Urban Heat Islands in Mvita, Mombasa

Level of Heat Stress Intolerance/Sensitivity in Mvita

Very High = 5	High=4	Moderate= 3	Low= 2	Very Low =1

	Level of Heat Stress Intolerance/Sensitivity						
Impacts of Urban Heat Islands	**Household Participants** **[Based on Mode]**	**County Physical Planner**	**County Architect**	**County Climate Change Expert**	**County Environment Officer**	**NEMA Officer**	**Public Health Practitioner**
Social Effects							
Share of Heat-Related Illnesses/Morbidity	Very High; 60.29 %	Moderate	High	Very Low	High	High	Moderate
Share of Heat-Related Deaths/Mortality [Indirect Influence]	Moderate; 45.59 %	Moderate	Moderate	Very Low	Moderate	Moderate	Moderate
Share of Outpatient Health Care/Pharmacy Visits	Moderate; 58.82 %	Moderate	High	-	High	High	Moderate
Share of Hospitalized Patients	Moderate; 63.24 %	Moderate	High	-	Moderate	High	Moderate
Influence on the Level of Activity and Productivity	High; 48.53 %	High	High	Very Low	Moderate	High	Moderate
Influence on Various Vulnerable Groups	High; 48.53 %	High	Moderate	-	Moderate	High	Very High
Frequency of External Migration to Habitable/Cooler Areas	Moderate; 35.29 %	Low	Moderate	Very Low	Moderate	Moderate	Low
Economic Effects							
Share of Electricity Energy Demand/Consumption for Cooling	Very High; 63.24 %	High	High	Moderate	High	Very High	-
Frequency of Electricity Brownouts or Blackouts	Very High; 41.18 %	Low	Low	Moderate	Low	Low	-
Level of Energy Expenditure on Building Cooling Systems	Very High; 58.82 %	High	High	Low	High	Very High	-
Share of Demand of Potable Water for Cooling	Very High; 45.59 %	High	High	Very Low	High	Very High	Very High
Share of Expenditure on Health Services	High; 35.29 %	Moderate	High	Low	High	Very High	Low
Environmental Effects							
Worsening of Anticipated Climate Observation Parameters	High; 45.49 %	High	-	Moderate	High	High	-
Deterioration of Fauna and Green Vegetation	High; 45.65 %	Low	-	Moderate	High	High	-
Deterioration of Indoor and Outdoor Air Quality	Very High; 44.12 %	High	-	Low	Moderate	Moderate	-
Influence of the Level of Food Production and Supply	High; 54.41 %	Moderate	-	Moderate	High	High	-
Impairment of Water Quality by Thermal Pollution	High; 41.18 %	Moderate	High	Low	Moderate	Low	-
Shortage of Water Supply/Inconsistent Water Supply	Very High; 51.47 %	High	-	Moderate	High	High	-
Damage to Construction Materials/Infrastructural Surfaces	High; 44.12 %	Low	-	Low	High	High	-
Hazardous Hotspots on Urban Canyons/Enclosures/Clusters	Moderate: 39.71%	High	-	Low	-	Moderate	-
Poor Ventilation and Wind/Breeze Way Aeration/Circulation	High; 52.94 %	High	-	Low	-	High	-
Institutional Effects							
Vulnerable Groups Concerns	High; 45.59 %	High	-	Moderate	Moderate	High	-
Frameworks Concerns	Low; 55.88 %	Moderate	-	High	Low	Moderate	-
Awareness Concerns	Low; 51.47 %	Moderate	-	Very High	Low	Low	-
Funding Concerns	Very Low; 47.06 %	Moderate	-	Very High	Low	Low	-

Source: (Author, 2022) Adapted from Field Work @ A3

5.2.2 Current Outdoor Clothing of the Users of Public Open Spaces

Table 5.2 discloses the current outdoor clothing of the users of public open spaces when engaged during fieldwork. Following the hot tropical coastal climate and the land surface temperature of the island, 87 per cent and 80 per cent of the cases wore short sleeved t-shirts and long pants/long skirts respectively. Only 10 per cent of cases — each — had long sleeved t-shirts and shorts/short skirts. The level of clothing serves as an indicator to the higher temperatures of the island during the hot season which usually late November to late April.

Table 5.2 Outdoor Space: User Current Clothing

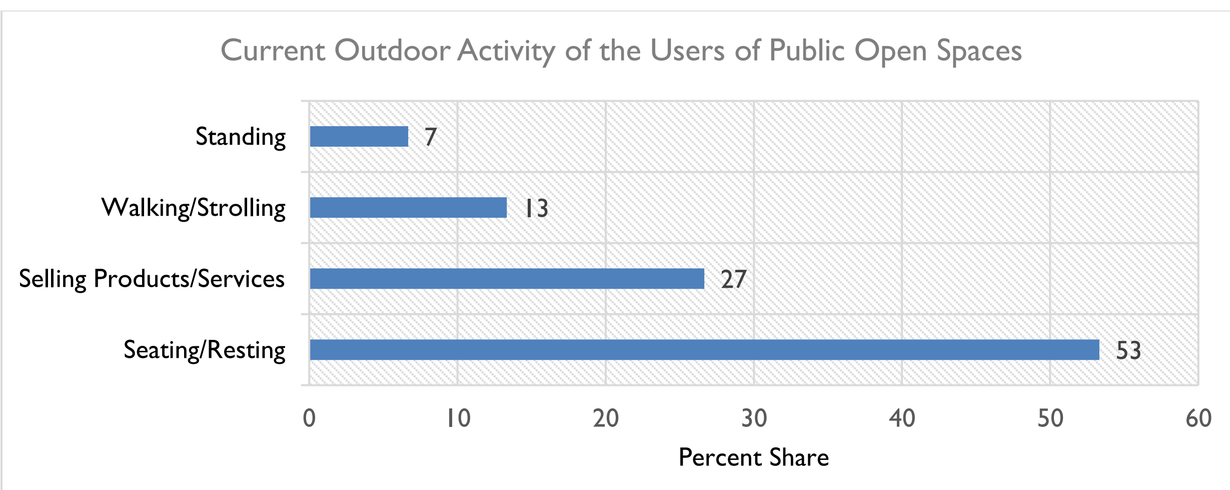
Value	Frequency	% Cases
Short Sleeved T-Shirt	26	87
Long Pants or Long Skirt	24	80
Long Sleeved T-Shirt	3	10
Shorts or Short Skirt	3	10

Source: (Author, 2022) Adapted from Field Work

5.2.3 Current Outdoor Activity of the Users of Public Open Spaces

Figure 5.11 reveals the current outdoor activity of the users of public open spaces when approached during fieldwork.

Figure 5.11 Outdoor Space: User Current Activity



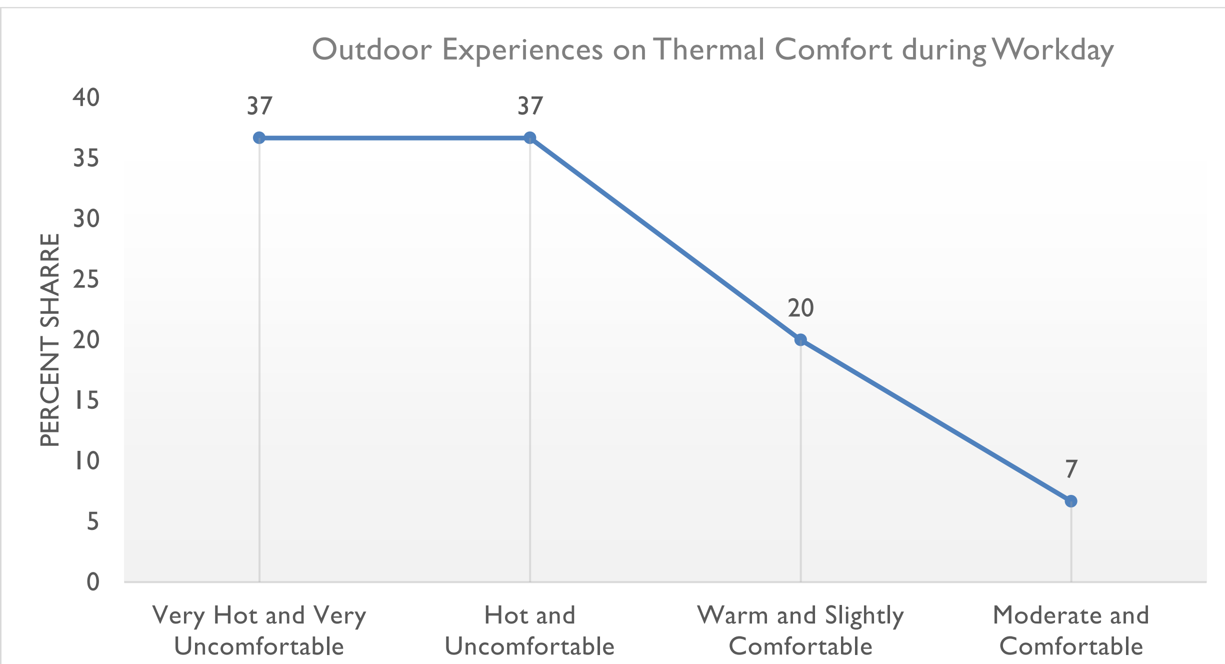
Source: (Author, 2022) Adapted from Field Work

The current type of outdoor activity serves as an indicator to working conditions, productivity and leisure. Most of the engaged users of public open spaces during the field work whom accounted at 53 per cent were seating or resting to cool off from the higher temperatures of the island, with only 13 per cent and 7 per cent were strolling and standing respectively. Other outdoor space users were selling products or services (27 per cent) during the day when engaged.

5.2.4 Outdoor Experiences on Thermal Comfort during Workday

Figure 5.12 illustrates the outdoor experiences on thermal comfort during workday mentioned by users of public open spaces. These outdoor experiences serve as indicators of conducive working conditions and hours for more productivity. A modest share of outdoor space users, each at 37 per cent, still felt very hot and very uncomfortable and hot and uncomfortable. A smaller share at 20 per cent and 7 per cent respectively perceived their outdoor work experiences as warm and slightly comfortable and moderate and comfortable.

Figure 5.12 Workday Rating on Outdoor Thermal Environment

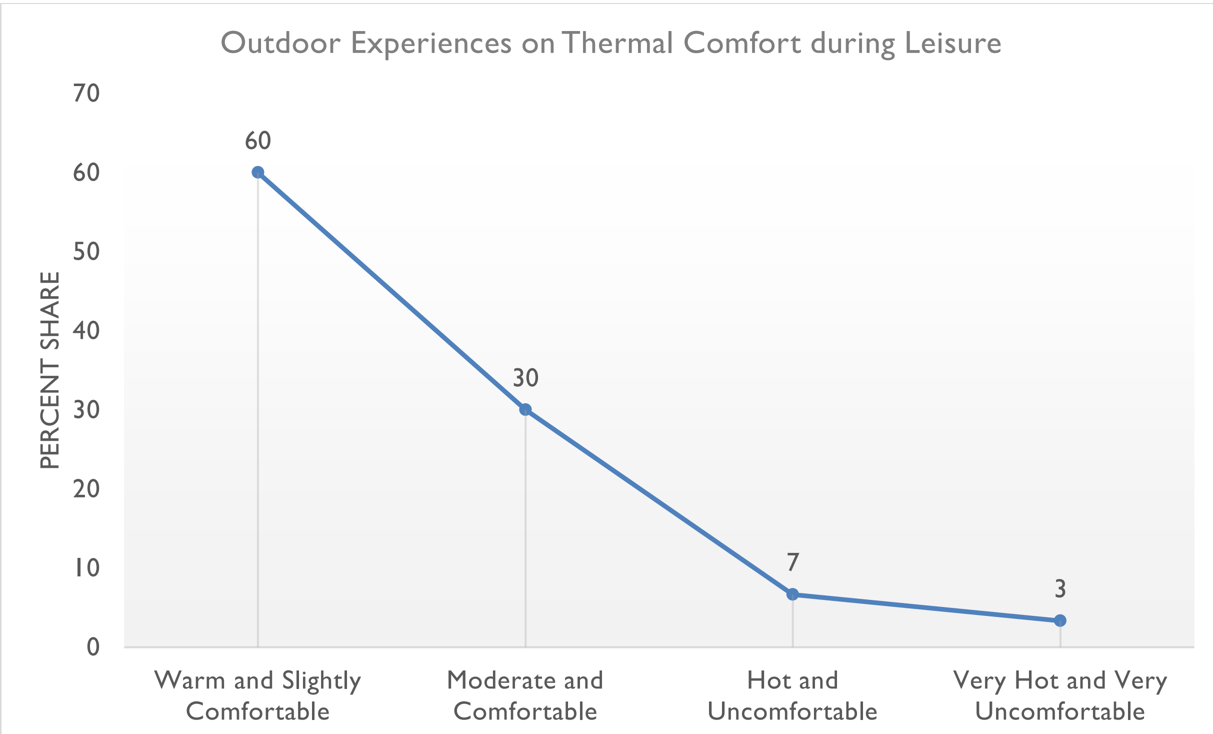


Source: (Author, 2022) Adapted from Field Work

5.2.5 Outdoor Experiences on Thermal Comfort during Leisure

Figure 5.13 demonstrates the outdoor experiences on thermal comfort during leisure articulated by users of public spaces. These outdoor experiences act as indicators of the level of comfort provided by public open spaces along the streetscapes and parks. A larger proportion of the outdoor space users at 60 per cent and a moderate share at 30 per cent claimed that they felt warm and slightly comfortable as well as moderate and comfortable in that order. About 7 per cent and 3 per cent of the users of public spaces said correspondingly that they felt hot and uncomfortable as well as very hot and very uncomfortable.

Figure 5.13 Leisure Rating on Outdoor Thermal Environment

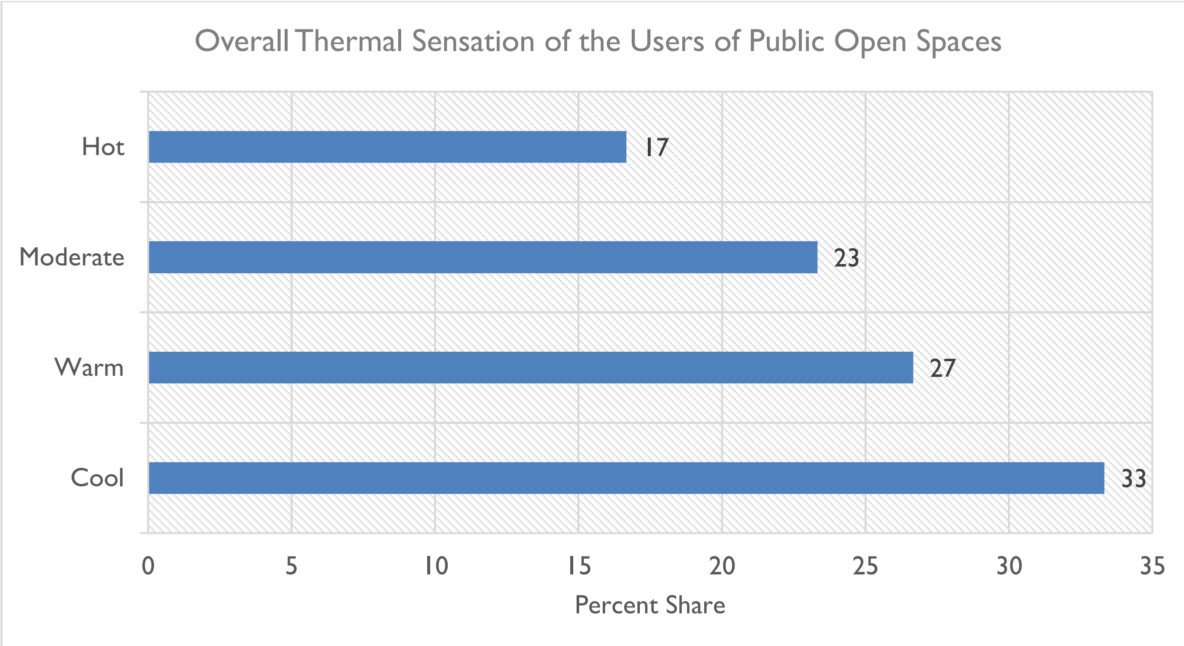


Source: (Author, 2022) Adapted from Field Work

5.2.6 Overall Thermal Sensation of the Users of Public Open Spaces

Figure 5.14 displays the overall thermal sensation of the users of public open spaces stated during the fieldwork. The parameter serves as an indicator of the level of comfort provided by public open spaces along the streetscapes and parks. A modest proportion of the outdoor space users oscillating at 33 per cent, 27 per cent, 23 per cent and 14 per cent claimed that they felt cool, warm, moderate and hot respectively, given the overall thermal sensation.

Figure 5.14 User Thermal Rating within the Public Open Space

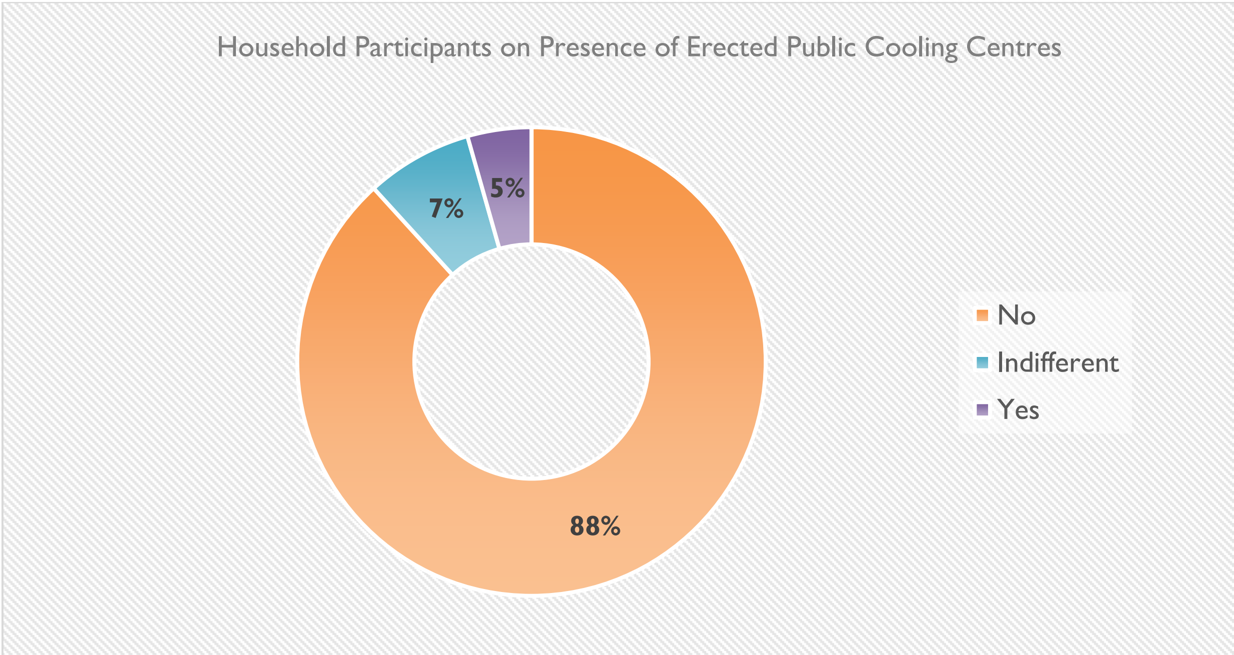


Source: (Author, 2022) Adapted from Field Work

5.2.7 Domestic Cooling Space and Cooling Reactions to Urban Heat Island Effect

All the six engaged key informants — County Physical Planner, County Architect, County Public Health Practitioner, County Climate Change Expert, County Environment Officer and National Environmental Management Authority Officer — affirmed that there were no public constructed cooling centres or erected tents for the public to regulate the outdoor thermal environment which was perceived higher in the island than adjacent outlying areas of Jomvu, Changamwe and Likoni. The County Climate Change Expert emphasized that the present urban forestry caters for the urban population. On the other hand, Figure 5.15 reveals the awareness of the household participants on the presence of public constructed cooling centres for the outdoor thermal comfort and liveability. About 88 per cent of the engaged household participants claimed that there were no public cooling centers in Mvita Island. Approximately 7 per cent and 5 per cent respectively stated that there were not aware and that one is situated at Kenya Port Authority in Shimanzi, although confirmed for workers.

Figure 5.15 Awareness on Presence of Public Cooling Centres for Thermal Comfort



Source: (Author, 2022) Adapted from Field Work

Table 5.3a and Table 5.3b reveals the cooling reactions performed by household participants and users of public spaces when experiencing higher temperatures in Mvita Island. Most households can cannot afford the ACs, hence the explanation on the rise of turning on table fans and/or celling fans at 66.18 per cent to cool the higher temperatures present in Mvita. Plate 5.12 explores some of the encountered artificial cooling systems during field work in Mvita, Mombasa. Hydration by potable water; visiting outdoor parks or green open spaces; going to the seaside/walking along promenades and beaches and swimming/taking cold showers/staying near a water source entailed as the main cross-cutting ways to cool the higher temperatures for both household participants and users of public spaces. The lesser cross-cutting reactions constituted were eating hydrating foods and wearing light clothes for both household participants and users of public spaces. Further, staying indoors was mentioned by a lower share of household participants. Urban planning should therefore focus in improving liveability of the city through considerations of not only on outdoor spaces but also attempts in indoor spaces to mitigate effects of urban heat islands.

Table 5.3a Household Participants: Cooling Reactions to Higher Temperatures in Mvita Island

Value	Frequency	% Cases
Hydration by Potable Water	52	76.47
Visiting Outdoor Parks/ Green Open Spaces	49	72.06
Turning on Fans such Tables/Ceiling Fans	45	66.18
Going to the Seaside/Walking along Promenades and Beaches	44	64.71
Swimming/Cold Showers/ Staying Near a Water Source	42	61.76
Eating Hydrating Foods	24	35.29
Wearing Light Clothes	15	22.06
Staying Indoors	15	22.06
Turning on Air-Conditioning Systems	12	17.65

Source: (Author, 2022) Adapted from Field Work

Table 5.3b Users of Public Spaces: Cooling Reactions to Higher Temperatures in Mvita Island

Value	Frequency	% Cases
Going to Seaside/Walking along the Promenades and Beaches	22	73.33
Hydration by Potable Water	21	70
Visiting Outdoor Parks/ Green Open Spaces	20	66.67
Swimming/ Cold Showers/ Staying Near an Outside Water Source	16	53.33
Eating Hydrating Foods	11	36.67
Wearing Light Clothes	5	3.33
Indifferent	1	3.33

Source: (Author, 2022) Adapted from Field Work

Plate 5.12 Illustration of Artificial Cooling Systems in Mvita Island

ACs on Building Walls

Ceiling Fan

ACs on Building Walls

Source: (Author, 2022) Adapted from Field Work

CHAPTER SIX:

IMPLICATIONS TOWARDS FORMULATING PLANNING INTERVENTIONS FOR MITIGATING URBAN HEAT ISLAND EFFECT IN MOMBASA

6.1 Perception on the Planning Interventions Towards Heat Resilience and Sustainability

Table 6.1a and 6.1b represents suggested outdoor spaces planning interventions — environmental proposals — by users of public spaces to enhance the mitigation of higher temperatures present in Mvita Island, Mombasa. A larger proportion of the cases suggested oriented on the practicality of having urban forestry, well urban ventilation, sustainable stormwater management, water urban design elements or sinks and traffic reduction and transport fuel consumption to improve the local thermal comfort in public open spaces whilst reducing the building cooling energy demand. The provisions of urban geometry, collaboration efforts, choice of materials and surfaces, sanitation as well as anticipated weather conditions and climatological parameters like precipitation, water and air quality made as lesser share of cases mentioned by the users of public open spaces.

Alternatively, Table 6.2a and 6.2b elucidates on overall adaptive capacity rating based on feasible planning interventions suggested by household participants and key informants engaged towards social and economic resilience as well as environmental and institutional resilience. The mode as a measure of central tendency for household responses was used as the main method of analysis. Panning suggestions addressed the practicality of it to be implemented and increase environment and institutional resilience given the degree of awareness and knowledge of Mvita and framework systems in place under the County Government of Mombasa and National Government. Perception concerns of the most of household participants appeared generalized and inclined more as idealists in having cooler coastal cities while those of the key informants identified as more contextualized solutions to releasing heat resilience and sustainability in Mvita Island.

The responses of the Public Health Practitioner were not rated on Table 6.2a and 6.2b, but rather are elaborated, herein, to give a full picture of the planning implications of urban heat island effect on people, health and overall well-being which are cross-cutting to other forms of resilience *-See Annex I*. On leadership and governance, policies for urban forestry were suggested to enhance the mitigation of urban heat island effect. On environment; increasing the vegetation coverage under the natural ecosystems, sustainable planning and revised zoning under built-up ecosystems which

Table 6.1a Outdoor Spaces Planning Interventions

Value	Frequency	% Cases
More Share of Parks and Open Spaces in Urban Neighborhoods	20	66.67
Green Aeration and Ventilation Corridors	20	66.67
Shading Effects of Vegetation on Buildings and Shelter Designs	18	60
Wider Open Spaces/Streets for Wind Flows and Breeze Circulations in the City	18	60
Presence of a Sustainable Stormwater Management System	17	56.67
More Water Cool Sinks and Water Urban Design Treatments/Features/Fountains	15	50
Traffic Reduction and Transport Fuel Consumption	13	43.33
Others (Specify)	11	36.67
Suitable Urban Morphology/Building Geometry to Limit Heat Trappings	5	16.67
Collaboration Efforts on Climate and Mitigation and Climate Action	5	16.67
Less Heavy and Cool Choice of Materials & Colours Buildings, Roofs, Pavements and Vehicles	5	16.67
Enforcement of the Water and Air Quality Regulations by NEMA	4	13.33

Table 6.1b Other Specified Outdoor Planning Interventions

Value	Frequency	% Cases
Solid Waste Management	2	6.67
Indifferent	2	6.67
More Rainfall	1	3.33
Increase Fresh Water Supply	1	3.33
Education and Awareness	1	3.33
Presence of Sustainable Sewerage System	1	3.33
Sustainable Solid Waste Collection	1	3.33
God's Plan: We may plan, but God has the final say	1	3.33
Awareness to Leaders on Urban Forestry	1	3.33

Source: (Author, 2022) Adapted from Fieldwork has currently reached maximum capacity as well as having constant supply water and hydrating foods were recommended by the Public Health Practitioner. On energy and expenditure on the economy, taking advantage of solar energy was suggested as a feasible planning intervention towards economic resilience.

On health workforce, there is need for trained and knowledgeable personnels to give out the full picture and linkage on heat and health association. On health information systems, there is also a prerequisite to come up with indicators for assessing and capturing heat related illnesses. On essential medical products and technologies, improvement of storage conditions and having rehydration solutions were proposed to deal with urban thermal environment. On emergency services and service delivery, having insurance waivers with aid from public institutions should be fostered on the affordability of ambulance services. Overall, on the awareness and finance, the Public Health Practitioner suggested more engagement and financing for cooling centers in the tropical coastal city of Mombasa.

Based on the situational analysis of urban heat island effect in Mombasa, all the six engaged key informants intuited the need have collaborative work and research efforts in the mitigation of urban heat effect in Mvita, Mombasa. The possibility of realizing urban forestry could be done along all higher street hierarchies and green roofs as most of the land has been developed as articulated by the County Environment Officer. Further the solutions to reduced waste heat was emphasized by the County Environment Officer to reduce the number of tuk tuks in the island and introduce a Bus Rapid Transit (BRT) system to take a large volume of passengers which is more suitable in mitigating climate change.

Table 6.2c reveals other suggested planning interventions by household participants towards heat resilience and sustainability in Mvita, Mombasa. A greater share of household participants [9559 per cent] captured or exhausted all the suggestions based on the adaptive capacity rating. Only 1.47 per cent of household participants, each, mentioned that they usually wear more light clothes, need more artificial cooling systems such as refrigerators, fans and ACs as well as need for proper housing for low-income people. On the latter, the presence of low-income people in the island attracts the rise of closely packed informal settlements — which is more evidently in upper Tudor Ward — seen as potential hotspots. With regard to the surface urban heat mapping of the Mvita, reflects very high land surface temperatures that necessitates mitigation when planning for cooler coastal cities - *See Map 4.6*. Plate 6.2 shows the informal settlement in upper Tudor Ward, adjacent to Tudor Creek encountered during field work.

Table 6.2a Overall Adaptive Capacity Rating on Feasible Planning Interventions

Ability to Implement and Increase Resilience in Mvita

🟢 1= High [feasible]	🟡 2= Medium [potentially feasible]	🔴 3= Low [not feasible]

	Ability to Implement and Increase Social Resilience						
Social Resilience Options: People, Health and Wellbeing	**Household Participants [Based on Mode]**	**County Physical Planner**	**County Architect**	**County Climate Change Expert**	**County Environment Officer**	**NEMA Officer**	**Public Health Practitioner**
More Conducive Working Conditions and Hours for More Productivity	🟢 at 76.47 %	🔴	🟡	🟡	🟡	🟡	-
Provision of Cooling Centres/Tents/Designed Sheltered Places	🟢 at 80.88 %	🟢	🟢	🔴	🟢	🟡	-
Development of Shaded Bicycle and Pedestrian Corridors	🟢 at 48.53 %	🟢	🔴	🔴	🟢	🟢	-
More Share of Parks and Open Spaces in Urban Neighborhoods	🟢 at 76.47 %	🟢	🔴	🟡	🟢	🟡	-
Constant Supply of Water	🟢 at 89.71 %	🟢	🟡	🟡	🟢	🟡	-
Constant of Supply of Hydrating Foods	🟢 at 61.76 %	🟡	🟡	🔴	🟢	🟢	-
Adequate Awareness/Knowledge and Warnings Based on the Urban Thermal Environment	🟢 at 70.59 %	🟢	🟡	-	🟢	🟢	-
	Ability to Implement and Increase Economic Resilience						
Economic Resilience Options: Energy and Expenditures	**Household Participants [Based on Mode]**	**County Physical Planner**	**County Architect**	**County Climate Change Expert**	**County Environment Officer**	**NEMA Officer**	**Public Health Practitioner**
Incentivize Installation or Retrofitting of External Air-Conditioning Systems for Energy Efficiency	🟢 at 69.12 %	🔴	🔴	🔴	🟢	🟡	-
More Share of Artificial Table/Ceiling Fans for Clean Air	🟢 at 72.06 %	🟢	🟢	🔴	🟢	🟢	-
Use of Domestic Heat Recovery Unit Systems for Ventilation	🟡 at 50.00 %	🟡	🔴	🔴	🟢	🟢	-
Installations of High-Performance Widows and Shading Devices for Windows	🟢 at 61.76 %	🟢	🔴	🔴	🟢	🟢	-
Utility Controls through Rolling Brownouts or Blackouts	🟢 at 54.41 %	🟢	🔴	🔴	🔴	🟢	-
Vegetated Buffering Around and Within Energy Intensive Buildings	🟢 at 66.18 %	🟢	🔴	🔴	🟢	🟡	-
Large Underground Cooling Water Reticulation Systems	🟢 at 45.59 %	🟢	🔴	🔴	🟢	🔴	-
Constant Supply of Electricity	🟢 at 91.18 %	🟢	🟡	🟡	🟢	🟢	-
Use of Renewable Energy Sources in Facades and Buildings Rooftops like Solar Energy	🟢 at 77.94 %	🟢	🟢	🔴	🟢	🟡	-
Use of Energy-Efficient Household Appliances and Lighting	🟢 at 75.00 %	🟢	🔴	🔴	🔴	🟡	-

Source: (Author, 2022) Adapted from Field Work @ A3

Table 6.2b Overall Adaptive Capacity Rating on Feasible Planning Interventions

Ability to Implement and Increase Resilience in Mvita

🟢 1= High [feasible]	🟡 2= Medium [potentially feasible]	🔴 3= Low [not feasible

	Ability to Implement and Increase Environmental Resilience						
Environmental Resilience Options: Natural and Built-Up Ecosystems	**Household Participants [Based on Mode]**	**County Physical Planner**	**County Architect**	**County Climate Change Expert**	**County Environment Officer**	**NEMA Officer**	**Public Health Practitioner**
More Share of Planted Greeneries around Buildings, Rooftops and Facades	🟢 at 86.76 %	🟢	🟡	🔴	🟢	🟢	-
More Share of Parks and Open Spaces in Urban Neighborhoods	🟢 at 85.29 %	🟢	🟡	🔴	🟢	🟡	-
Green Aeration and Ventilation Corridors	🟢 at 70.59 %	🟢	🟡	🔴	🟢	🟢	-
Shading Effects of Vegetation on Buildings and Shelter Designs	🟢 at 64.71 %	🟢	🟡	🔴	🟢	🟢	-
More Water Cool Sinks and Water Urban Design Treatments/Features/Fountains	🟢 at 51.47 %	🟢	🟡	🔴	🟢	🟢	-
Presence of a Sustainable Stormwater Management System	🟢 at 80.88 %	🟢	🟡	🔴	🟢	🟢	-
Suitable Urban Morphology/Geometry of Urban Canyons	🟢 at 54.41 %	🟢	🟢	🔴	🟢	🟡	-
Wider Open Spaces/Streets for Wind Flows and Breeze Circulations in the City	🟢 at 72.06 %	🟢	🔴	🔴	🟢	🟢	-
Traffic Reduction and Transport Fuel Consumption	🟢 at 82.35 %	🟢	🔴	🔴	🟢	🟡	-
Less Heavy and Cool Choice of Materials & Colours Buildings, Roofs, Pavements and Vehicles	🟢 at 61.76 %	🟢	🟢	🔴	🟢	🟢	-
Enforcement of the Water and Air Quality Regulations by NEMA	🟢 at 55.88 %	🟢	🟡	🔴	🟢	🟢	-
	Ability to Implement and Increase Environmental Resilience						
Institutional Resilience Options: Legal/Policy Frameworks, Actors and Funding	**Household Participants [Based on Mode]**	**County Physical Planner**	**County Architect**	**County Climate Change Expert**	**County Environment Officer**	**NEMA Officer**	**Public Health Practitioner**
Cooling the Urban Thermal Environment through Revised Zoning and Urban Design	🟢 at 75.00 %	🟢	🟡	🔴	🟢	🟡	-
Spatial Climate & Biodiversity Atlas and Booklet for Urban Heat Resilience & Sustainability	🟢 at 72.06 %	🟢	🟡	🔴	🟢	🟢	-
Revision of the Physical Planning Handbook to Inculcate Urban Thermal Environment	🟢 at 52.94 %	🟢	🟡	🔴	🟢	🟢	-
East African Community Protocol on Cooperation in Meteorological Services Implementation	🟡 at 47.06 %	🟢	🔴	🔴	🟢	🟢	-
Presence of a Long -Term Heat Wave Forecast & Web-Based GIS Climate Resilience Toolkit	🟢 at 58.82 %	🟢	🔴	🔴	🟢	🟢	-
Collaborative Research and Development on Urban Heat Island Effect	🟢 at 67.65 %	🟢	🔴	🔴	🟢	🟢	-
Proper Translation/Enforcement of Policies & Legislations to Heat Resilience & Sustainability	🟢 at 69.12 %	🟢	🔴	🔴	🟢	🟢	-
Undertaking of Urban Heat Islands/Thermal Stakeholder Participation & Mapping Campaigns	🟢 at 69.12 %	🟢	🟡	🔴	🟢	🟢	-
Sufficient Funding on the Climate Change and Urbanisation Impacts on Temperature	🟢 at 83.35 %	🟢	🟡	🔴	🟢	🟢	-
Adequate Capacity Building to all Relevant Stakeholders of the Urban Thermal Environment	🟢 at 64.71 %	🟢	🟡	🔴	🟢	🟢	-
Adequate Awareness/Knowledge/ Warnings Based on the Urban Thermal Environment	🟢 at 85.29 %	🟢	🟡	🔴	🟢	🟢	-

Source: (Author, 2022) Adapted from Field Work @ A3

Table 6.2c Other Specified Household Planning Interventions

Value	Frequency	Percentage
None	65	95.59
Wearing More Light Clothes	1	1.47
More Cooling Storage Areas and Having a Fan and AC.	1	1.47
Proper housing for low-income people	1	1.47

Source: (Author, 2022) Adapted from Field Work

Plate 6.2 Informal Settlement in Upper Tudor Ward

Source: (Author, 2022) Adapted from Field Work

6.2 Guiding Planning Principles for Cooler Coastal Cities

Following the undertaking of literature review, field work and situational analysis; heat resilience, sustainability, integration and collaboration emerge as formidable guiding planning principles that this research study seeks to underscore in the development of planning proposals for Mvita Island, Mombasa County. The study also premises that the successful implementation of the proposals for enhancing the mitigation of urban heat island effect will have broader and positive ramifications socially, economically, environmentally and institutionally when replicated within the rest of the tropical coastal city of Mombasa. In addition, when planning for having cooler coastal cities in the Sub-Saharan Africa.

6.2.1 Heat Resilience

The study underpins that heat resilience is key to sustainability. Thus, the planning on enhancing the mitigation of urban heat island effect should strive to attain higher position of adaptive capacity in the urban thermal environment.

6.2.2 Sustainability

Sustainability, in this study context, is seen as an outcome of heat resilience. Hence, the planning on enhancing the mitigation of urban heat island effect should strive to realize the pillars of social, economic, environmental and institutional sustainability in the urban thermal environment. A city is affirmed to be sustainable, when it has attained a higher position of adaptive capacity.

6.2.3 Integration

Integration is reflected by mainstreaming urban thermal environment into urban planning, on one hand. On the other hand, integration is realized through the combination of feasible interventions of urban planning applied when enhancing the mitigation of urban heat islands effect of which this study seeks to underscore.

6.2.4 Collaboration

To bring about heat resilience, sustainability and integration following the planning proposals for enhancing the mitigation of urban heat island effect; collaboration is at the helm and pinnacle of closing disparities in knowledge, policy and practical gaps in the urban thermal environment. Like the air we breathe, collaboration is very critical for application of resilience theory. To this effect, the study proposes collaboration theory when planning for cooler coastal cities.

6.3 Conceptual Plan Proposals

6.3.1 Forecast of Null Intervention for Urban Heat Island Effect in Mvita Island

Recalling on existence of cities as socio-ecological panarchy; the assessment of Mvita’s historical account, urbanization development, urban morphology, land use planning, weather conditions and climatology, thermal environment and governance frameworks underpinned through the literature review and field work findings indicated a stronger need for heat resilience and sustainability. The situation is that Mvita has been portraying a greater share and distribution of impermeable surfaces and low-albedo infrastructure, a lesser share and distribution of green space infrastructure and a higher by share of relative humidity from 1992 to 2022. Their scale impact on thermal environment indicates a trend of higher surface temperatures than air temperatures over the 30-year period that represents presence of higher surface urban heat islands than atmospheric urban heat islands in the tropical coastal city of Mombasa.

Thus, in order to propose planning interventions for enhancing the mitigation of urban heat island effect in Mvita, Mombasa; the projection of null intervention as a scenario has been considered as well as interpreted to necessitate the alternative strategies. These planning proposals for this study are inclined to provide broader and positive ramifications socially, economically, environmentally and institutionally when replicated in planning for cooler coastal cities. The implications of this research are urban planning interventions for heat resilience and sustainable urban development. That said, if no planning interventions are made and lest the situation analysis on urban heat island effect does continue to prevail, the study area portends a manifestation of complete picture on the creation of hazardous urban heat islands.

6.3.2 Social Resilience Model for Urban Heat Island Effect in Mvita Island

This alternative proposal focuses on attaining of a higher adaptive capacity on health, comfort and livable conditions for people when planning for cooler coastal cities. The model argues that since the coastal cities of the Sub-Saharan Africa are endowed with a rich historic socio-cultural way of life and tropical hot climate embedded in their socio-ecological panarchy, they must transform to address reverberation impacts of urbanization and climate change — the dual instigators of urban heat islands. As a result, achieve societal ambitions on heat resilience and sustainable development goals. The strategies for this social model on attaining heat resilience and sustainability for Mvita Island, Mombasa County by enhancing the mitigation of urban heat island effect entails;

The Transformation of the Built-Environment Culture. This strategy has been informed by the Holling's (1973; 2001) resilience theory and on the premise that Mvita is now undergoing urban renewal following the certainties made by County Physical Planner and County Architect, carried visual survey and reviewed Mombasa ISUDP 2035. The built-environment influences the social and physical divisions of spaces, built-form, lifestyle, behaviour, interaction, working conditions and productivity of people. Therefore, the transformation of the past and present built-environment culture for heat resilience requires a scientific, digital and socio-cultural sustainability mindset into the near inevitable hybrid and livable future of built-environment (Neubert, 2020). This is feasible when performing any design and construction; use and re-utilization, ongoing-management; urban renewal; recovery and decommissioning of developments. The precise virtual city model computes daily wind flow, temperature and solar radiation to give a detailed map of a particular city's climate over time as it is urbanizing.

Cooling coastal cities by transformation of the built-environment culture carefully encompasses virtual modelling by the City Climate Digital Twin (Chandran, 2020). This virtual model calculates and tests feasible scenarios on how each of the city’s spatial as well as design elements impacts urban heat islands before any developments are put into reality (Bloomberg Quicktake: Originals, 2021). It models city’s movement of the people, street grids, urban morphology, buildings, weather and climatology parameters, material and surface insulations and temperature that aids planners make simulations on the health, comfort and livable space conditions for the people (Bloomberg Quicktake: Originals, 2021; Poon, 2022). Such are spearheaded by the coastal cities of Singapore, Dubai and Helsinki (Poon, 2022).

Active Community Participation and Personal Exposure on the Heat Resilience. This strategy has been informed by Taru Leading Edge’s (2021) *City Heat Resilience Toolkit* and case study of urban heat island mapping campaigns across 13 cities in the USA. In addition, it has been informed by all the key informants engaged — County Physical Planner, County Architect, Public Health Practitioner, County Climate Change Expert, County Environment Officer and NEMA Officer — as well as high feasible adaptive capacity rating on thermal stakeholders’ and actors’ participation in mapping campaigns as suggested approximate 62 per cent of households. This strategy applies heat watch engagement model pioneered and advocated by Climate Adaptation Planning Analytics (CAPA) Heat Watch to aid communities in collaboration with expert organizations in identifying various areas for heat mitigation to enhance protection of people from impacts of atmospheric urban heat islands (McCartney, et al., 2020; Stevens, 2020).

First, the local engagement is conducted with identified communities and organizations to support articulated heat actions envisioned (McCartney, et al., 2020; Stevens, 2020). Secondly, before the community field participation undergoes training on using air temperature and humidity sensors mounted on vehicles/bicycles/mobile traverses to collect in-situ measurements of air temperature and humidity along the mapped routes (McCartney, et al., 2020; Stevens, 2020). Heat campaign is done in a day or within a week-span depending on the geographical latitude and conditions of the area (McCartney, et al., 2020). The data is collected 3 times a day to get the diurnal profile, but only for one hour in order to reduce the thermal drift i.e., 6-7am, 2-3pm and 6-7pm (McCartney, et al., 2020). After finalizing the outdoor heat campaign, the results from the air and humidity in-situ observations are integrated with satellite imagery and eventually heat mitigation actions are identified through a strong engagement which involves active community involvement during heat planning alongside urban planners and decision makers (McCartney, et al., 2020).

Stakeholders/Actors' Outreach, Capacity Development and Awareness on Heat Resilience. This strategy has been informed by the need to foster information, generation, dissemination and adoption of proposals for an action agenda on heat resilience to the effects of the urbanization and climate change and its related issues. Such can be done through setting of norms and standards, training and mainstreaming of urbanization and climate change concerns relevant to heat with key departments, for instance, association with medical and public health. All the six key informants engaged highly suggests bearing respective expertise in urban planning, architectural and design, environmental concerns, climate change and health concerns. The Public Health Practitioner at the Coast General Teaching and Referral Hospital assures that this strategy would promote thermal comfort awareness, considerations for heat-related mortality and morbidity, useful information on climate and urbanization to foster disease surveillance, diagnostics, early warning, preparedness and response to the extreme weather and climate change events. 70.79 per cent of the household participants recommended it as highly feasible to increase social resilience while 85.29 per cent of the household participants suggested it as highly feasible to strengthen institutional resilience. In addition, this strategy was also informed by the 3.33 per cent of users of public spaces, each, that stated the promotion of general education and awareness to the public and awareness to leaders. The means of mobilization, sensitization and dissemination can be repeatedly through media news and radio station, online and print newspapers, workshops and training courses.

Transformation of the Health Information Systems for Heat Resilience. In planning, a resilient city needs accessible and affordable healthcare, risk assessment, disease surveillance and research in relation to interrogating the indicators of heat-related illnesses and mortality as articulated by the Public Health Practitioner. These would lead to the development of early warning systems for heat-related weather conditions and climate change events and those on land surface. This strategy is considerably complemented by investment in the academia and practice and stakeholders/actors' outreach, capacity development and awareness.

6.3.3 Economic Resilience Model for Urban Heat Island Effect in Mvita Island

This alternative proposal emphasizes on attaining of a higher adaptive capacity on energy demand and energy efficiency when planning for cooler coastal cities. The model argues that there is a very strong correlation of the spatial and temporal relation between urban land use, temperature as well as energy demand and related economic expenditures. It attempts to lower energy consumptions which in turn reduces waste heat generated into the atmosphere using readily available renewable energy sources aa with a touch of a futuristic mindset to improving the liveability in the city. The strategies for this economic model on attaining heat resilience and sustainability for Mvita Island, Mombasa County through enhancing the mitigation of urban heat island effect constitute;

Adoption of an Accessible and Affordable Green Energy. In order to supplement existing and conventional households and outdoor sources of energy, clean energy is paramount in combating elevated air emissions and GHGs. Based on its hot tropical climate as well as high share of relative humidity, Mvita receives amount incoming solar radiation given its annual cloud cover average of 46.32 per cent of the time and gentle to moderate higher wind speeds according to the Beaufort wind scale. That said, use of renewable energy sources in facades and building's rooftops like solar energy would be a suitable choice on adopting an accessible and affordable green energy than the use of wind power in Mvita. The former was rated as highly feasible based on mode across the key informants and household participants.

A Business Case for Cool Pavements, Cool Roofs and White Coated Roofs Programme. The County Government of Mombasa could make a business case proposal with both corporate and individual property owners in the installation of cool surfaces in the city. The public ability, interest and willingness might prove a challenge, nonetheless, this strategy informed by literature review makes a good solution. The co-benefits are on economic returns from the reductions of ACs energy consumption and other artificial cooling systems; improved roofs and building equipment life and performance as well as increased amenity space or property value. This strategy is also an efficient and quick solution for urban areas with informal settlements, in this context upper Tudor. The five ward neighborhoods of Mvita, could capitalize on this strategy

Retrofitting of Green Walls, Façades and Roofs on the Buildings. This strategy is suitable for local climate zoned areas of compact high-rise developments like Mji wa Kale and compact mid-rise developments in Majengo. Corporate and individual property owners are key in attaining this greening strategy specially in the built-environment to mitigate the urban heat islands. It has been varyingly suggested by the key informants, users of public spaces and households on its ability to be implemented and increase heat resilience on commercial, industrial, and residential structures.

Strengthening Electricity Grid Resilience in the Generation, Transmission and Distribution. This strategy has been informed by the share cooling energy demand and expenditures deemed as high for both household participants and key informants. There needs to be a constant supply of electricity for the artificial cooling systems. Hence; considerations availability of water for power, wind power potential, solar power, maintenance of grid lines and distribution cables to the impacts of warmer temperatures needs to be factored in grid resilience.

Advocating for More Electric Private Vehicular and Public Transportation. A heat-resilient city needs reliable public transport that aids in traffic reduction and reduction of carbon emissions. This strategy has been informed through result findings from the visual survey that Mvita Island is endowed with more tuks tuks that serves the main public transportation. The suggestions of the household participants and users of public spaces accounting at 82.35 per cent and 43.33 per cent respectively on traffic reduction and transport fuel consumption, also contributed to formation of this strategy. Among the key informants, County Climate Expert and County Architect gave it a low feasibility rating to be implemented and increase resilience, as it a primary contributing source of revenue and livelihood in the island. Nevertheless, priority could be given on traffic reduction within the CBD limits to foster walkability essential for health and well-being. Going forward, this tropical coastal city of Mombasa could reap benefits through more presence of electric private and public means of transportation. The latter has commenced in Kenya by private startups like BasiGo in Kenya, an opportunity that County Government of Mombasa can tap into. The possibilities of introducing of Bus Rapid Transit, as put by the County Environment Officer can be capitalized on the wider colonial road networks in the island from the major distributors, arterials and highway.

6.3.4 Environment Resilience Model for Urban Heat Island Effect in Mvita Island

This alternative proposal focuses on attaining of a higher adaptive capacity of built environment to the temperature when planning for cooler coastal cities. The model underscores that urban green space infrastructure (GSI) which is inclusive of vegetation and water features and suitable urban morphology and appearance of the city are key in attaining resilience within the natural and built-up ecosystem. Atmospheric urban heat islands and surface heat islands can substantially decrease as a result of this model. The strategies for this environmental model on attaining heat resilience and sustainability for Mvita Island, Mombasa County through enhancing the mitigation of urban heat island effect comprise;

Urban Green Aeration and Ventilation Transportation Corridors Programme. This strategy has been highly underscored by the case of study of Stuggart, 66.67 per cent of the users of public spaces and 70.59 per cent from the household participants. To increase the share and distribution of vegetation, tree covers and grasses should be landscaped along the corridors within the median strips and shoulders depending on the topography situating the residential, collector, distributor, arterial and highway streets. Currently, Stuggart has more than 60 per cent of vegetation coverage, largely credited to green aeration corridors compared to Mvita at 10.03 per cent as biotope (total green areas) and 3.31 per cent as sociotope (total public green spaces) and entire Mombasa County at 19.26 per cent as biotope and 1.52 per cent as sociotope. Map 6.1 shows all urban green corridors based on the local residential streets, collectors and distributors, arterials and highway streets. The green corridor programme should go up to the neighborhood level.

Urban Micro-Forestry Programme on Parks, Open Spaces, Residential and Vacant Plots. This strategy has been underpinned as quite feasible by all six key informants, households and the users of public spaces engaged. The study terms it as urban micro-forestry in order to fulfil the set 10 per cent vegetation in a given plot coverage given that the sea-island of Mvita is almost at full capacity engorged with residential, commercial and industrial developments with less vegetation coverage. Parks and playgrounds should be rejuvenated with new green and heat-resilient species capturing the principles of permaculture. Vacant and abandoned plots of land ought to be converted into a micro forest in the long-term.

Allocation of Public Cooling Centres for Communities. This strategy calls for either constructed cooling centres or mobile tents that can be used on need basis and has been informed by the lack of one for the public in Mombasa and the case study of Hanoi, Vietnam. The constructed cooling centers can served be multi-purposed with serviceable facilities and amenities for comfort so that it can be used during both hot and cold seasons. Public cooling centres should be inclusive to all vulnerable people to heat especially people disabilities and elderly. The decommissioned buildings can serve as an opportunity to realize this strategy. Suitable location of public cooling centres shall be to areas not well served with parks and playgrounds in the island and accessible by most of the adjacent population - *See Map 6.1*.

Retrofitting Operational Water Urban Design Features on the Parks and Roundabouts. This strategy has been informed largely by the case study of Cape Town, South Africa and visual survey that puts only the mundane vegetation landscaping on parks and roundabouts. This strategy is feasible to cooling Mvita given the high to medium suggestions by the key informants engaged. In addition, approximate 51.47 per cent and 50 per cent of households and users of public spaces respectively acknowledge its ability to be implement and increase heat resilience in Mvita. Though fitted with water urban design features, the provision of constant supply of potable water in Uhuru Gardens and Old Railway Parks's present water urban design features remain a challenge. Water features like water fountains and spray water parks aids to lower temperature. Mainstreaming the water element with the help of Mombasa Water Supply and Sanitation Company Limited is vital in mitigating both the higher air and surface temperature experienced.

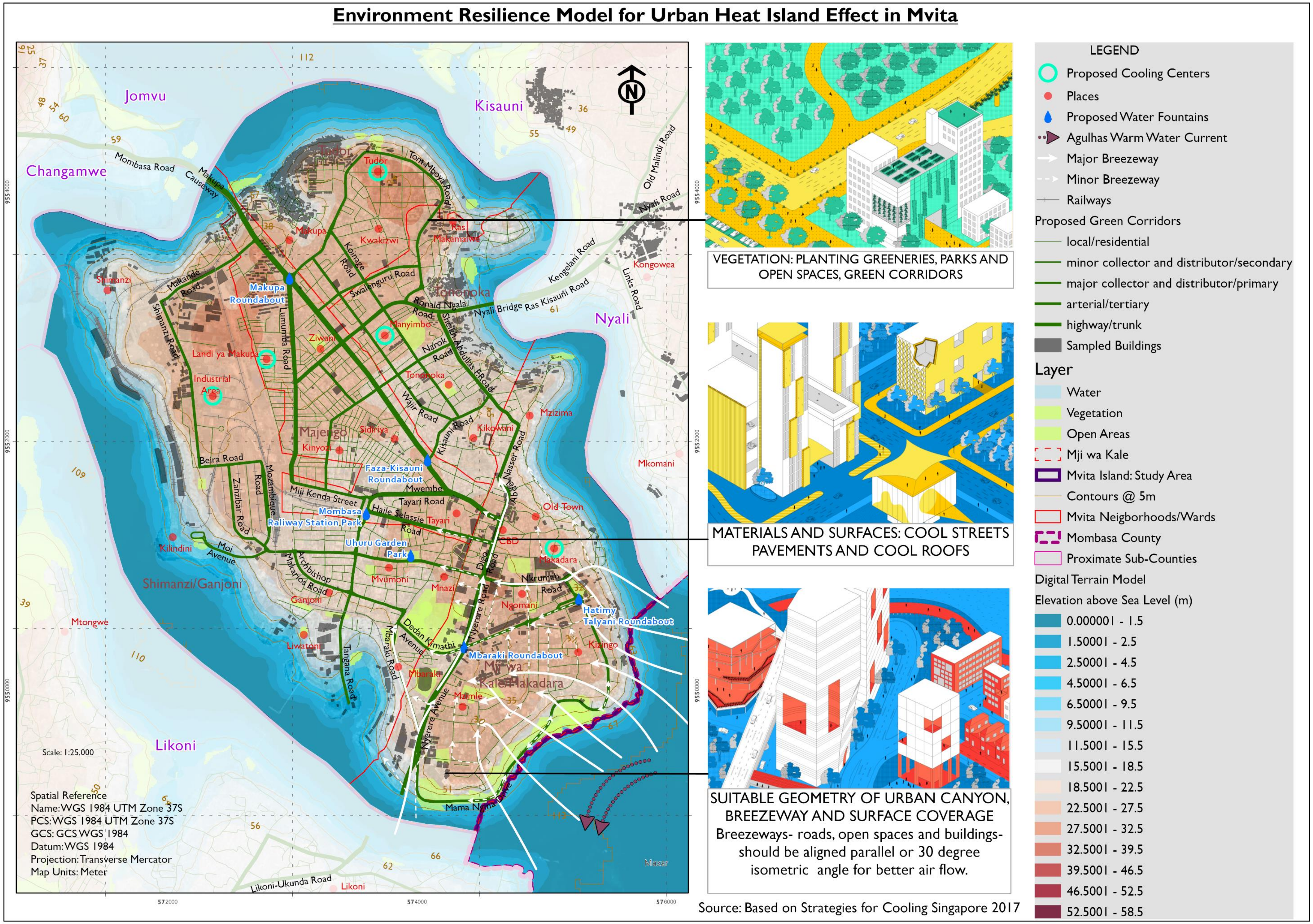
Adoption of a Green Stormwater Infrastructure and Sewerage Management System. Indeed, the presence of higher air and surface temperatures in Mvita has exacerbated the worsening other weather conditions, specially flooding as demonstrated in weather and climatology assessment. A heat-resilient city thus needs a well-functioning and sustainable drainage and sanitation systems. This strategy has been informed by suggestions of a sustainable stormwater management system by 80.88 per cent and 56.67 per cent of households and users of public spaces in that order. About 3.33 per cent the users of spaces also commented on the importance of having a sustainable solid waste collection and sustainable sewerage system. On improving comfort and liveability of Mvita, integration of urban nature with water as well as sanitation-based systems should be collaborated at the initial stages with urban planners, architects, drainage engineers, landscape architects as well as ecologists.

Use of Less Heavy Materials on Facades for Compact High-Rise Developments. Materials and surfaces such those of glazing structures should be priority when compact high-rise developments in the Central Business District to mitigate urban heat islands. This strategy has been informed the most of suggestions made by the County Architect, County Physical Planner, County Environment Officer and NEMA Officer as well as 61.76 per cent of household participants based on mode.

Building Painting Maintenance of the White Color with Egyptian Blue Edges. Based on the visual survey, Mombasa CBD in Mvita Island is characterized with white color and blue border on commercial and residential developments. Annual buildings repainting with these cool colours by County Government of Mombasa is suffice to regulate urban thermal environment, maintain the city character as well as attract investment and tourism.

Suitable Urban Geometry of the Buildings and Streets for Better Wind Flow. The land use of the island is shaped by its urban morphology of the streets, buildings and trees. Attaining a suitable geometry of the city aims to increase breezeway or air paths into the urban district or core. Mvita should thus do away with projected obstructions such as massive outdoor advertisements on the streetscapes and waterfront given its gentle to moderate wind speed and parallel wide main streets from south and south-south-east of the island. The planning of high-rise developments should be receding towards the ocean, especially in the south-south east of the island. Mvita Island seemingly observes parallel alignment or a 30 isometric angle of the breezeways — roads, open spaces and low-rise buildings corridors — to the prevailing wind direction in order to maximize penetration of wind to the urban central district, which other tropical coastal cities of the sub-Sahara African should aim to adopt. The planning flats that are more widely spaced with respect to their heights for residential development would further assists in lowering the potential for higher urban heat island intensities increasing. This strategy of suitable urban morphology was highly perceived by most of the six key informants and about 54.41 per cent of the households.

Map 6.1 Environment Resilience Model for Urban Heat Island Effect



Source: (Author, 2022) Adapted from Field Work and Ruefenacht and Acero's (2017) on Cooling Singapore @ A3

6.3.5 Institutional Resilience Model for Urban Heat Island Effect in Mvita Island

This alternative proposal emphasizes on attaining of a higher adaptive capacity via engagement in collaborative work and research and used urban governance frameworks when planning for cooler coastal cities. This model introduces collaboration planning theory Healey (1998) underpinned by the sharing and feedback communicative rationality mechanisms by Habermas (1985). As such, a collaborative approach to heat response planning aims to improve sharing and knowledge between the man-nature environment relationships for thermal comfort and liveability, of which resilience theory by Holling (1973; 2001) alone cannot accomplish. The strategies for this institutional model on attaining heat resilience and sustainability for Mvita, Mombasa County through enhancing the mitigation of urban heat island effect encompass;

Collaborative Planning for Urban Heat Resilience and Sustainability. This strategy has been informed and perceived highly based on mode by all the six key informants, households as well as the users of public spaces. The key stakeholders as well as actors on mitigating urban heat islands should be cross-disciplinary and cross-sectorial. Collaborative resource pools, cross-functional activities and information sharing should entail circles of planning, meteorology, public health and red cross and affiliated emergency agencies, geographic information systems and remote sensing, architecture and design, ecology, water and sanitation, environment, energy, emergency services, transportation, policy-making and leadership.

Development of an Urban Heat Legislation for Indoor and Outdoor Comfort. To be the first of its kind in Kenya, this national urban heat legislation shall not only cooling components but also greening components necessary to mitigate atmospheric and surface urban heat islands. It should be clear and concise pin pointing the roles of relevant actors to see through the mitigation of urban heat island effect. The Act should touch on the vegetation, urban geometry, water bodies, materials and surfaces, shading, transport, energy, public health and financing.

A Catalogue of Policy Measures on Urban Heat Resilience and Thermal Comfort. Following the Urban Heat Legislation, this county policy shall be of a handbook/booklet in nature on issues related to urban heat resilience and thermal comfort. Priority, should be given to transformation of the built environment with a scientific, digital and socio-cultural sustainability mindset. Key issues should oscillate on urban heat islands and outdoor thermal comfort effects, tropical climate, urban planning as well as the state-of-the-art research and practice when documenting the indicators of urban vegetation, urban geometry, water bodies, materials and surfaces, shading, transport, energy, public health and financing. It should be clear and concise. The proposed Coast Urban Climate Laboratory should spearhead its foundation as the urban areas and cities along the Kenyan coast have a rich and similar socio-cultural background as well as urban morphology.

Fast-tracking the Ratification Process of East African Community Protocol on Cooperation in Meteorological Services. To reiterate**,** the Government of the Republic of Kenya is required to cooperate with other ratifying East African Partner States — composed of other six countries in the African Great Lakes region in East Africa: the Democratic Republic of the Congo, the United Republic of Tanzania, the Republics of Burundi, Rwanda, South Sudan, and Uganda — to make plans, develop climate-weather networks as well as meteorological telecommunications systems (Republic of Kenya, 2020). These measures will enable computation and analysis of statistics; co-sharing of meteorological data and information and creation of early warning systems (Republic of Kenya, 2020). The households, users and public spaces as well as the key informants were not aware of this on-going strategy, however, varying intuited that its possibility would somehow be an advantage in attaining urban heat resilience and sustainability.

Tax Incentives on Green Eco-Roofs, Solar Panels and Cool Roofs Programme. The National Government and County Government of Mombasa should provide tax incentives to promote the use of renewable energy sources and installation of green-eco roofs and cool roofs thus making them more profitable to the use. The offering of incentives could be financial such as a subsidy, grant or rebate as well as non-financial like extra allowance of buildable floor area to the property owners and private real estate developers. This strategy has been informed by "perceived" barrier inclined to instituting change especially to property owners and developers and change in the built-environment culture associated with Swahili Architecture preservation and conservation.

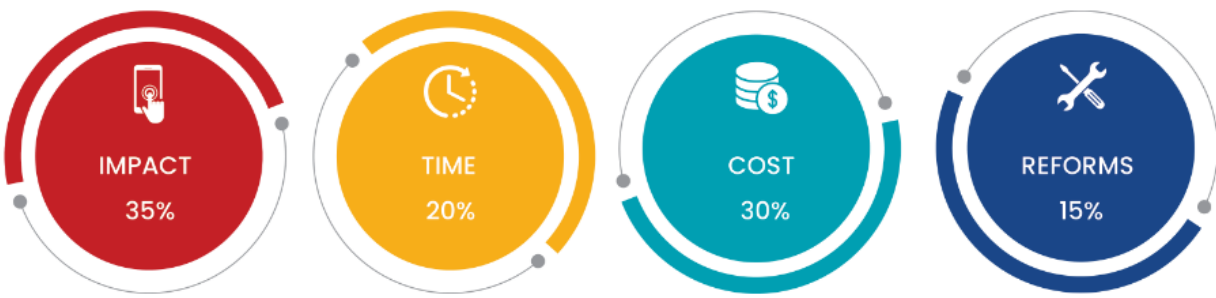
Grant Application for the Cities Climate Change Resilience and Urban Heat Island Mapping Campaigns. The tropical coastal city of Mombasa, via its County Government, could apply for grants and funds related to urban climate change resilience trust fund regionally within the sub-Sharan Africa and internationally provided by private and non-governmental donors. In addition, an urban climate change resilience trust fund is proposed under the African Union as well as East African Community in deal with urban heat island mapping campaigns. This strategy has been informed by the case of urban heat island mapping campaigns across 13 cities in 2021 by NOOA.

This strategy has also been informed by “perceived” to be enough funding allocation to address the impacts of urbanization and climate change, which as per the County Architect and County Environment instances of corruption and embezzlement still exists.

6.4 Prioritization of the Heat Mitigation and Heat Management Solutions

The evaluating criteria used to prioritize mitigation proposals was that advocated by Taru Leading Edge’s (2021) *City Heat Resilience Toolkit* that gives a weightage of 35 per cent on impact, 20 per cent of time span of implementation, 30 per cent on costing and 15 per cent on reforms in ongoing projects. Figure 6.1 give weightages for each criterion. The totality of all scores aids to prioritize the planning mitigation solutions for urban heat island effect.

Figure 6.1 Weightage Evaluation Criteria for Urban Heat Resilience



Source: (Taru Leading Edge, 2021)

Following the literature review, field work and situational analysis; heat resilience, sustainability, integration and collaboration emerge as the formidable guiding planning principles that this study seeks to underscore in the development of planning proposals for Mvita. The study premises that the successful implementation of the proposals for enhancing the mitigation of urban heat island effect will have broader and positive ramifications socially, economically, environmentally and institutionally when replicated within the rest of the coastal and tropical city of Mombasa. In addition, when planning for having cooler coastal cities in the Sub-Saharan Africa. The proposals have been informed by the reviewed case studies and secondary data; visual survey and feedbacks from the households, users of public spaces and key informants.

Table 6.3 Prioritization of the Heat Mitigation and Heat Management Strategies

Heat Mitigation and Heat Management Strategies	Impact	Time Span	Cost of Investment for County Government of Mombasa	Reforms to Existing Project / Programme	Total Score	Priority	Key Actors/Stakeholders
Careful Transformation of the Built-Environment Culture	Social, Economic, Environment and Institutional	Long-term	Cost of Virtual Modelling by the City Climate Digital Twin; Proposed Coast Urban Climate Laboratory	Planning, Design and Thermal Material Specifications under the Ongoing Physical and Land Use Planning Handbook; the Ongoing National Spatial Climate and Biodiversity Atlas; the Ongoing Urban Renewal of the Island and Mixed-Use Developments.		**13**	County Government of Mombasa; National Government, Neighborhood Communities; Proposed Coast Urban Climate Laboratory
	35	10	15	15	75		
Active Community Participation and Personal Exposure on the Heat Resilience	Social, Environment and Institutional	Short-term	Cost of Urban Heat Island Mapping Campaigns; Community Training; Space; Air Temperature and Humidity Sensors; Proposed Coast Urban Climate Laboratory	-		**17**	County Government of Mombasa; National Government; Neighborhood Communities; Proposed Coast Urban Climate Laboratory
	35	20	23	0	70		
Stakeholders/Actors' Outreach, Capacity Development and Awareness on Heat Resilience	Social, Environment and Institutional	Short-term	Cost of Mobilization and Sensitization; Experts; Research; Stationery and Graphical Outputs; Space; Proposed Coast Urban Climate Laboratory	-		**10**	County Government of Mombasa; National Government; Neighborhood Communities; Proposed Coast Urban Climate Laboratory
	35	20	23	0	78		
Transformation of the Health Information Systems for Heat Resilience	Social	Medium-term	Cost of Experts; Research and Surveys; Proposed Coast Urban Climate Laboratory	-		**11**	County Government of Mombasa; National Government; Neighborhood Communities; Proposed Coast Urban Climate Laboratory
	35	15	27	0	77		
Adoption of Accessible and Affordable Solar and Wind Green Energy	Economic and Environment	Medium-term	Cost of material; installation; labor	Ongoing Harnessing of Solar and Wind within Mombasa County		**8**	Kenya Electricity Generating Company; Kenya Power and Lighting Company; County Government of Mombasa; Neighborhood Communities; Corporate and Individual Property Owners
	30	15	25	12	82		
Making a Business Case for Cool Pavements, Cool Roofs and White Coated Roofs Programme	Economic and Environment	Medium-term	Cost of material; installation; labor	Ongoing Urban Renewal of the Island; Mixed-Use Developments; Kenya Informal Settlements Improvement Project; Affordable Housing Developments		**7**	National Government; County Government of Mombasa; Neighborhood Communities Corporate and Individual Property Owners; Real Estate Developers

	35	15	25	11	86		
Retrofitting of Green Walls, Façades and Roofs on Buildings	Economic and Environment	Medium-term	Cost of material; installation; labor	Ongoing Urban Renewal of the Island; Mixed-Use Developments;		**1**	County Government of Mombasa; Neighborhood Communities Corporate and Individual Property Owners; Real Estate Developers
	35	15	28	14	92		
Strengthening Electricity Grid Resilience in Generation, Transmission and Distribution	Economic and Environment	Short-term	Cost of material; installation; maintenance	Ongoing New Power Sub-Stations		**15**	Kenya Electricity Generating Company; Kenya Power and Lighting Company; County Government of Mombasa
	25	20	15	12	72		
Advocating for Electric Private Vehicular and Electric Public Transportation	Economic and Environment	Long-Term	Cost of infrastructural construction; public charging points	Committed Bus Rapid Transit System		**22**	Private and international startups; National Government; County Government of Mombasa
	30	10	15	10	65		
Urban Green Aeration and Ventilation Transportation Corridors Programme	Social and Environment	Medium-Term	Cost of tree nursey, grass nursey; seeds/saplings; labor	Ongoing city landscaping efforts		**2**	County Government of Mombasa; National Government; Neighborhood Communities; Civil Based Organizations, Non-Government Organizations; Private Sector
	35	15	27	14	91		
Urban Micro-Forestry Programme on Parks, Open Spaces, Residential and Vacant Plots	Social and Environment	Long-Term	Cost of tree nursey, grass nursey; seeds/saplings; labor	Ongoing city landscaping efforts; development applications		**3**	County Government of Mombasa; National Government; Neighborhood Communities; Civil Based Organizations, Non-Government Organizations; Private Sector
	35	10	30	15	90		
Allocation of Public Cooling Centres for Communities	Social and Environment	Short-Term	Cost of material and installation; labor; amenities	-		**18**	County Government of Mombasa; National Government; Neighborhood Communities; Civil Based Organizations, Non-Government Organizations; Private Sector
	30	20	19	0	69		

Retrofitting Operational Water Urban Design Features on Parks and Roundabouts	Social and Environment	Medium-Term	Cost of material and installation; labor	-		**19**	County Government of Mombasa; Civil Based Organizations, Non-Government Organizations; Private Sector
	30	15	23	0	68		
Adoption of a Green Stormwater Infrastructure and Sustainable Sewerage System	Environment	Long-Term	Cost of material and installation; way leaves	Committed stormwater and sewerage system		**20**	County Government of Mombasa; National Government; Neighborhood Communities; Civil Based Organizations, Non-Government Organizations; Private Sector
	25	15	27	10	67		
Use of Less Heavy Materials on Facades for Compact High-Rise Developments	Environment	Long-Term	Cost of material and installation	-		**21**	National Government; County Government of Mombasa; Neighborhood Communities Corporate and Individual Property Owners; Real Estate Developers
	30	10	26	0	66		
Building Painting Maintenance of the White Color with Egyptian Blue Edges	Environment	Short-Term	Cost of material; painting; labor	Recent coloring of the CBD urban fabric		**9**	County Government of Mombasa; Neighborhood Communities Corporate and Individual Property Owners; Real Estate Developers
	25	20	25	11	81		
Suitable Urban Geometry of the Buildings and Streets for Better Wind Flow	Environment	Short-Term	Cost of urban renewal, re-blocking; Proposed Coast Urban Climate Laboratory	Ongoing mixed-use developments and urban renewal in the island; finalization of Mvita land use plans under Mombasa Vision 2035 and Mombasa Gate City Master Plan		**4**	National Government; County Government of Mombasa; Neighborhood Communities Corporate and Individual Property Owners; Real Estate Developers; Proposed Coast Urban Laboratory
	35	20	20	14	89		
Collaborative Planning for Urban Heat Resilience and Sustainability	Institutional	Short-Term	Cost of Proposed Coast Urban Climate Laboratory; Range of Operational Tools and Equipment; Experts; Advisers; Proposed Coast Urban Climate Laboratory	-		**14**	County Government of Mombasa; National Government; Neighborhood Communities; Proposed Coast Urban Climate Laboratory
	35	20	18	0	73		

Development of an Urban Heat Legislation for Indoor and Outdoor Comfort	Institutional	Medium-Term	Cost of Research and Surveys; Experts; Advisers; Proposed Coast Urban Climate Laboratory	Ongoing preparation of the new Physical Planning Handbook; the not yet completed Climate Biodiversity Atlas		**6**	County Government of Mombasa; National Government; Neighborhood Communities; Proposed Coast Urban Climate Laboratory
	34	15	26	12	87		
A Catalogue Policy Measures on Urban Heat Resilience and Thermal Comfort: Urban Heat Resilience Handbook	Institutional	MediumTerm	Cost of Research and Surveys; Experts; Advisers; Proposed Coast Urban Climate Laboratory	Ongoing preparation of the new Physical Planning Handbook; the not yet completed Climate Biodiversity Atlas		**5**	County Government of Mombasa; National Government; Neighborhood Communities; Proposed Coast Urban Climate Laboratory
	35	15	26	12	88		
Fast-tracking the ratification Process of East African Community Protocol on Cooperation in Meteorological Services	Institutional	Long-Term	Cost of Research and Surveys; Experts; Advisers; Range of Operational Tools and Equipment; Proposed Coast Urban Climate Laboratory	Ongoing talks of the Protocol		**23**	County Government of Mombasa; National Government; Neighborhood Communities; Proposed Coast Urban Climate Laboratory
	30	10	15	8	63		
Tax Incentives on Green Eco-Roofs and Cool Roofs Programme	Institutional	Short-Term	Cost of Research and Surveys; Advisers; Proposed Coast Urban Climate Laboratory	-		**16**	National Government; County Government of Mombasa; Neighborhood Communities Corporate and Individual Property Owners; Real Estate Developers; Proposed Coast Urban Laboratory
	25	20	26	0	71		
Funding Application for Cities Climate Change Resilience Grants and Urban Heat Island Mapping Campaigns	Institutional	Medium-Term	Cost of applications; Proposed Coast Urban Climate Laboratory	-		**12**	National Government; County Government of Mombasa; Proposed Coast Urban Laboratory
	35	15	26	0	76		

Source: (Author, 2022) Adapted from Literature Review and Fieldwork @ A3

6.5 Planning Implications of the Urban Heat Island Effect in Coastal Cities

The ultimate traction of this study has been informed and guided by the resilience theory (Holling, 1973; 2001); reviewed literature and four case studies; remote sensing and GIS methodologies as well as feedbacks from the engaged households, users of public spaces and six key informants. Varied inferences to the planning for cooler coastal cities especially of the tropical climate as they rapidly expand in population and built-up areas whilst simultaneously decline in green vegetation are as follows;

6.5.1 Theoretical Implications of Urban Heat Island Effect

Using the tropical coastal city of Mombasa as case study, this research study puts the application of resilience theory as emphasis to attain adaptive capacity on urban heat island effect. The study premises that resilience theory alone is not enough for mitigation of UHIE in Mombasa, following that there is a poor institutional governance for heat mitigation as well as heat management. Going forward, utilization of collaborative planning theory in a cross-disciplinary manner should prove vital in supporting resilience theory in dealing with the UHIE. The linking of resilience theory (Holling, 1973; 2001) with collaborative planning theory (Healey, 1998) should prove essential in the heat resilience planning. Such has necessitated the recommendation of Coastal Urban Climate Laboratory conversed in chapter seven encompassing the circles of urban planning, public health, geographic information systems, satellite remote sensing, meteorology, ecological environment, architecture and urban design, red cross and other distinguished resilience disaster and emergency service agencies, water and sanitation, energy, transportation, policy-making, community, local leadership and governance.

6.5.2 Implications Towards Literature of Urban Heat Island Effect

UHIE is Mombasa is highly influenced by myriad of causes and effects on the built environment. Although globally there are numerous literatures on UHIE related to urbanization, climate change, greenery, coastal ecosystem, health and energy data, those localized in Mombasa are deficient and outdated to the current heat modalities. The study calls for more empirically studies to capture health and energy data and information systems relevant to the UHIE and increased publications on biodiversity to plan for in-depth understanding of the natural ecosystems and to synthesize vital information to plan actions against urban heat vulnerability in coastal ecosystems. Others include the increase of understanding and use of the Earth Observation and Earth Science on the energy budget, satellite remote sensing and GIS, weather and climatology reviews as well as urbanization and green coverage assessments in decision making. Last but not least, the urban planning arena should make proposals based on the available and localized review of literature in given contextual area/site herein, Mombasa, so as to have constructive heat vulnerability indexes (HVIs) for a more comprehensive heat map.

6.5.3 Methodological Implications of Urban Heat Island Effect

Satellite thermal remote sensing and Geographic Information Systems (GIS) have long been used to analyze and mainstream surface urban heat islands and atmospheric urban heat islands in local to global spatial scales as well as diurnal, seasonal and inter-annual temporal scales. It is thus not a new phenomenon for the Global North as opposed to the Global South. The outcome using the recent satellite thermal remote sensing — Landsat-9, a joint mission of U.S. Geological Survey (USGS) and National Aeronautics and Space Administration (NASA) and the latest in the Landsat series of remote sensing thermal satellites as of September 2021 — for estimating the land surface temperature proves attainable and a success in profiling Mombasa, as one of the tropical coastal cities in Global South. The acquisition of Landsat-9 Operational Land Image (OLI) and Thermal Infrared Sensor (TIRS) in 2022 — which is more consistent, timely providing repeatable Earth observations and detection of more subtle differences with a higher radiometric resolution than previous Landsat satellite series — has been underpinned in research methodology and design to aid other coastal cities of the tropical Sub-Saharan Africa. Its manipulation with ArcGIS Pro (2.8) on obtaining the urban built-up area, green coverage and land surface temperature (LST) offers a more recent, accurate and easier way in applying GIS methodological approaches as opposed to the outdating ArcGIS Desktop (10.8). Although the study only focused on the diurnal Landsat-9 OLI and TIRS on 8th April 2022 with less cloud cover of 0-30 percent, it underscores importance on using Landsat-9 based on seasonal and inter-annual temporal scales.

Albeit, Earth Explorer by the U.S. Geological Survey and POWER Data Access Viewer by NASA are online portals for acquisition of satellite remote sensing data and climatology data respectively, computation of the LST using Landsat and MODIS done through the Google Earth Engine (GEE) is more effectively and timely. Colloquially, GEE was used in this study though not documented as the final products were computed from the Landsat Collection 2 data obtained at Earth Explorer. Scientists, researchers and developers are nonetheless encouraged to use the GEE — a cloud based geospatial processing platform — which is free for analysis of the Earth, herein, the UHIE. NASA ARSET (2022) has provided JavaScript codes for assessing urban heat islands using satellite data through GEE for generating a graph Landsat LST time series from Landsat 8 and 9, processing a Landsat derived SUHI over any geographical area and using MODIS derived SUHI for a day and night in any urban geographical region. On the latter, Terra or Aqua MODIS satellite data can be used for deriving the daytime and nighttime historic SUHIs depending on the analysis (NASA ARSET, 2022). Plainly and simply, the computation of UHIE should employ recent methodologies that are more capable, timely and refined to give meaningful policy directions on heat mitigation.

6.5.4 Policy Implications of Urban Heat Island Effect

The study calls for policy directions that are specific, collaborative and contextualized on indoor and outdoor realities of the thermal environment of a given coastal city. From the policies reviewed in this study, it is clear that concerns of urban heat island effect and thermal environment in general have been broached broadly. There is a relevance need of an urban heat resilience handbook and the institutionalization of an Urban Climate Laboratory bearing a cross-disciplinary expertise for policy development and policy change on heat-related specifications are paramount. The aim is to provide actional knowledge on UHIE to the policymakers in influencing environmental, climate change, urban design, urbanization, transportation, energy and industrial policies.

6.5.5 Design Implications of Urban Heat Island Effect

The current and future design of the city towards heat resilience and sustainability depends on the pervious and impervious materials in the absorption, retention and reflection of solar energy. Given that Mombasa is undergoing urban renewal especially in Mvita with its rich history, the design considerations implies that the transformation of the built-environment should not only be done through a socio-cultural sustainability mindest but also a scientific and digital mindset. As such, it should support effective and efficient ways to continue green landscaping along median strips and roundabout; having green tree corridors along streetscapes and incorporating vegetation on parks and spaces. Further constituting is the blending of asphalt and cabro along streetscapes; oxidized white coral limestone, mangrove and Swahili architecture; predominant white and Egyptian border blue colour in Mombasa CBD; structural glazing and the glass facades on buildings as well as predominant concrete, brick walls and shingled roofs on buildings and settlements. Going forward, there is therefore the need of a virtual modelling of a given coastal tropical city — currently lacking

— to inform and guide the design to deal with the reverberation effects of urbanization and climate change on temperature. From the prioritized urban heat resilience handbook should aim to capture heat-related specifications for the urban design, roads, bridges as well as infrastructural services through suitable building codes and guidelines for effective performance. The transformation of the built environment should be done via a scientific, digital as well as socio-cultural sustainability mindsets.

6.5.6 Implications Towards Practice on Urban Heat Island Effect

The professionals in public and private sectors, environmental managers and policy makers require training in the use and understanding of Earth Observation and Earth Science in decision-making. The NASA Applied Remote Sensing Training Program (ARSET) offers this as an online capacity development free of charge to people regardless of their backgrounds. Further entailing is that the developers, residential home owners and industrialists are to encourage with tax incentives as well as business cases for cool infrastructure such as pavements and white-coated roofs. The urban heat island mapping campaigns are also vital in involvement of the community and experts to assess atmospheric UHIs and from decision heat maps for prioritizing green infrastructure investments at the neighborhood level.

6.5.7 Implications Towards Monitoring of Urban Heat Island Effect

First and foremost, it is imperative for scientists, researchers and developers to assess the surface UHIs not only at daytime but also during the nighttime so as portray the full picture of heat stress vulnerability and inform on heat mitigation and heat management solutions. To reiterate, the Terra or Aqua MODIS satellite data are useful for deriving the daytime and nighttime historic SUHIs depending on the analysis (NASA ARSET, 2022). Daytime surface UHIs are much as important as nocturnal surface UHIs. Secondly, it is paramount that the atmospheric UHIs be measured and integrated — subject to the availability of funding and technological expertise — to capture current air temperature and humidity data. Urban heat island mapping campaigns as a more participatory approach in measuring atmospheric UHIs using mobile sensors/traverses as seen in the case study across 13 cities in the United States than reliance of in-situ sensors.

Third is that the necessitation of better early warning and monitoring technological systems are of importance for a successfully mitigation of UHIE. As acknowledged earlier in the review of legal, policy and institutional issues; inadequate funding, limited awareness and insufficient capacity building are observed as setbacks in monitoring of UHIE. Indeed, Kenya and Mombasa does face limited technological infrastructure to non-existent heat early warning and monitoring systems. Capacity development, budget allocation and funding application for climate change resilience grants could potentially alleviate these impediments. Fourthly, empirical studies and trainings on integrating various socio-economic data with satellite imagery for constructing heat vulnerability indices (HVIs) for a more comprehensive heat map to inform decision-making are very significant. They are to be based on the characteristics of the local area in question as the parameters such on health and well-being provided by the vast literature on UHIE globally might be too generalized or outside the scope, given the type of analysis. Lastly, the study premises that in spearheading the monitoring of UHIE, there has to be a principal body, preferably an Urban Climate Laboratory as much as other governing bodies are concerned. In this case, the Kenya Metrological Department and the County Government of Mombasa as discussed earlier under the institutional issues. The constituents of the Urban Climate Laboratory have been detailed under recommendations.

6.5.8 Implications Towards Dissemination of Findings

The understanding of the study key findings inclusive of the prioritization of the heat mitigation and heat management solutions of a given location, herein, Mombasa requires dissemination to the relevant stakeholders on urban heat resilience. This forms a main component in the delivery of social resilience strategy for UHIE. Audience might be in the circles of academia and professional practice across national and sub-national levels of government, private sector, civil societies and the engaged participants. The dissemination of findings of UHIE indeed fosters awareness, policy directions and ownership of the decision-making towards heat resilience and sustainability. Such could be delivered through yearbooks, project portfolios, community briefs as well as policy briefs.

6.5.9 Implications Towards Marine Spatial Planning and Planning of Coastal Ecosystems

Climate change remains one of the growing threats to both the coastal and marine environment, ecosystems, biodiversity and resources. This inference has been put forward by the second edition of the *State of Coast Report for Kenya: Enhancing Integrated Management of Coastal and Marine Resources in Kenya* published by the National Environment Management Authority (Republic of Kenya, 2017b). Corollary to this — observed global climate change phenomena expected along the coast of Kwale, Mombasa, Malindi, Kilifi and Lamu include but limited to sea water warming, sea-level rise, coastal erosion, saltwater intrusion, ocean acidification and the upsurge of invasive species and coral bleaching. Others include the erratic and extreme weather and seasonal changes such as unpredictable rains, increasing floods and droughts and longer heatwaves. These threats are rippled by the socio-economic activities and human population increase to amount to pollution from solid waste, domestic and industrial emissions, ports shipping operations and disturbances of habitat such as tree losses that worsens the UHIE.

Going forward the following necessitations should be employed towards enhancing marine spatial planning as well as the planning of the coastal and marine environment, ecosystems, biodiversity and resources against the aforementioned threats. Enforcement of the 60m set-backline rule as a shoreline management strategy to strike a balance between the developmental and environmental interests. Full implementation of the Environment Management and Coordination (Amendment) Act 2015, Sessional Paper No. 13 of 2014 on Integrated Coastal Zone Management (ICZM) Policy and ICZM Action Plan for Kenya, 2019-2022: enhancing integrated management of Coastal and Marine Resources to realize the potential of blue economy in Kenya. Other instruments suggested include marine spatial plans, carbon sequestration through natural and planted mangroves like the Mikoko Pamoja Project in Gaza Bay, Kwale County and reforestation. A new publication of the Kenya Biodiversity Atlas should prove essential in synthesizing ecosystems information as well as planning responses against sea level rises, higher storminess, unprecedented changes in ocean currents and precipitation levels, plant productivity and heat stress vulnerability on mangroves. These should aim to address climate change mitigation and adaptation at the land-sea interface.

CHAPTER SEVEN:

CONCLUSION AND RECOMMENDATIONS

7.1 Summary of Research Findings

Using Mvita sea-island in Mombasa, Kenya as case study; satellite remote sensing for 1992, 2002 and 2022 and GIS methodological approaches; sampled households; sampled users of public open spaces; key informants — urban planner, architect, climate change expert, environmental officer at sub-national level, national environmental environment authority representative at sub-national level of government and public health practitioner — the principal aim of this study examines the planning implications of urban heat island effect in coastal cities. Such inferences are made on the prioritization of the planning proposals that the study premises to serve as broader and positive ramifications socially, economically, environmentally and institutionally when replicated within the rest of the tropical coastal city of Mombasa and when planning for cooler coastal cities in the sub-Saharan Africa. Therefore, accomplishing the subsidiary aim of the study which proposes planning interventions that can enhance the mitigation of urban heat island effect in the tropical coastal city of Mombasa. The specific research objectives of the study oscillated on mapping the surface urban heat islands in Mombasa; examining the causes of urban heat islands in Mombasa; assessing the social, economic, environmental and institutional impacts of urban heat islands in Mombasa and proposing the planning interventions for enhancing the mitigation of urban heat island effect in Mombasa. A special case underpinning this study was in testing the null hypothesis: there is no a significant relationship between the built-up area and vegetation cover with the urban heat island effect in Mvita, Mombasa.

The average trend of the air temperature in Mvita over the 30-year period observes that the higher temperatures in the atmosphere are often between late November to late April. The hottest month of the year in Mvita based on the air temperature is usually March, with an average high of 28.09^{0}C between 1990 to 2021 based on the NASA Power Data Access Viewer. Such readings portend that during the hot season of the island, the air temperatures could typically vary between a maximum of 38^{0}C and a minimum of 18^{0}C. The greater the ambient air temperatures, the more likely formation of the atmospheric urban heat islands in the city – observed nighttime, considering that an ideal urban thermal environment ranges between 20°C and 27°C. On mapping the land surface temperature, the sea-island of Mvita possesses surface urban heat islands with peak intensity variations of 8.2 to 10.7^{0}C during the day whereas the Mombasa County bears surface urban heat islands with peak magnitude variations of 21.4 to 26.2^{0}C during the day, which often worsens based on literature review at night. Based on mode, Mvita has higher surface temperatures than the outlying areas of Changamwe, Jomvu and Likoni sub-counties by 2.1 to 3.5^{0}C to the west and north-west of the island. However, the adjacent areas to the east of the island, Nyali and Kisauni sub-counties are quite hotter than Mvita despite it being a more concrete jungle by 1.4 to 6.3^{0}C because of a higher population density and urban density index.

The earth skin temperatures are higher than the ambient air temperatures at 2 meters during the hot seasons of the late November to late April based on weather conditions and climatological assessment in Mvita, with February having an average high of 30.22^{0}C between the 1992 to 2021 sourced from the NASA Power Data Access Viewer. The result findings reveals that the average variation of relative humidity is generally high throughout the year, with May recording the highest at 82.17 per cent. The land surface temperature observed from the Landsat 4 Thematic Mapper (TM) in 1992, Landsat 7 Enhanced Thematic Mapper (ETM+) in 2002 and Landsat 9 Operational Land Image (OLI) and Thermal Infrared Sensor (TIRS) in 2022 all acquired daytime, pin points increasing spatio-temporality of the surface urban heat islands by approximately 7.32^{0}C. The urban built-up density in Mvita and Mombasa County has increased by 66.7 per cent and 227.8 per cent respectively from 1992 to 2022 while population density in Mvita Island and Mombasa County has grown by 318.5 per cent and 161.9 per cent from 1992 to 2022.

On the other hand, the total share of all green areas (biotope) within the ecosystem in Mvita and Mombasa County have decreased by 68.2 per cent and 73.9 per cent from 1922 to 2022. Such alarming spatio-temporal trends of the changing patterns of the built-up area and green cover have been leading to increasing land surface temperature. Urbanization indicators of population density and urban density index have substantially impacted the vegetation coverage which in turn has been impacting the scale of temperature. The surface urban heat islands have a linear increase in developed areas and decreases logarithmically in relation to trees and other vegetation cover over the 30-year interval, from 1992 to 2022 in Mvita, Mombasa evidenced by the Pearson correlation performed between the Normalized Built Difference Index and Normalized Vegetation Difference Index with Land Surface Temperature. Thus, there is a significant relationship between the urban built up area and vegetation cover with urban heat island effect. Based on spatial calculations of the Landsat 9 Operational Land Image (OLI) and Thermal Infrared Sensor (TIRS) in 2022, the current total share of all green areas in Mvita Island and Mombasa is at 10.03 per cent and 19.26 per cent with a GSI value of 11.36 sq.m per person and 41.67 sq.m per person respectively within the biotope ecosystem. On the other hand, the current total share of all the public green areas in Mvita Island and Mombasa is at 3.31 per cent and 1.52 per cent with a GSI value of 3.75 per cent and 3.28 per cent respectively within the sociotope ecosystem based on public and recreational areas provided under Mombasa Vision 2035, albeit based on the current projected population of 2022. Taking into account that WHO (2012) recommends provision of GSI should be a minimum of 9 sq.m of green space per individual with an ideal urban GSI of 50 sq.m per capita, the situation is left wanting on especially on share and distribution of public green spaces within the sociotope ecosystem.

Following the situational analysis of weather conditions and climatology assessment, urbanization development assessment on natural landscapes as well as feedbacks from the discussions; the root causes of urban heat islands in Mvita, Mombasa have been identified as follows. A high presence of the relative humidity at 2 meters as a result of topography and geographical conditions. A high increase of surface temperature because of the impervious infrastructural surfaces and buildings dominance that has observed the sea island of Mvita as a concrete jungle. A high share of limited urban green space infrastructure and water urban design elements. A high presence of thermal heat capacity construction materials of asphalt, concrete, stones, bricks, shingled roofs and steel that absorb and store more solar energy. A high release of waste heat based on the human industrial, commercial residential and transportation land uses and activities that induces emissions of air pollutants and greenhouse gases to the atmosphere. A moderate phenomenon to the changing urban morphology (shape and geometry) of the island. A low rating of limited air-condition systems as a non-climate stressor and cooling opportunity.

On assessing the social, economic, environmental and institutional impacts of urban heat islands in Mombasa, the presence of limited research empirical evidences and lack of standardised health data affiliated directly and indirectly with the urban thermal environment remain a cross-cutting challenge. Economic impacts on the energy and expenditures as well as environmental impacts on natural and built environment have been associated with high sensitivity rating. On the other hand, social impacts based on people, health and well-being and institutional impacts based on the legal, policy, financing and players as well have been affiliated with moderate sensitivity rating.

Going forward, on proposing the planning interventions, the study prioritizes heat mitigation and heat management solutions based on Taru Leading Edge's (2021) City Heat Resilience Toolkit to enhancing the mitigation of urban heat island effect in the tropical city of Mombasa. The top-five prioritizes ranked as follows retrofitting of green walls, façades and roofs on buildings; urban green aeration and ventilation transportation corridors programme; micro-forestry programme on urban parks, open spaces, residential and vacant plots buildings; suitable urban geometry of the buildings and streets for better wind flow and a catalogue policy measures on city heat resilience and thermal comfort: urban heat resilience handbook.

7.2 Recommendations

The ultimate traction of this research study has been informed and guided by the resilience theory; literature reviews and case study reviews; satellite remote sensing and GIS applications as well as visual survey and feedbacks from the household participants, users of public spaces and six key informants engaged. A nine-complementary set of recommendations for the study in Mombasa by the principal researcher are as follows;

i. Establishment of a Coastal Urban Climate Laboratory. This would be the principal body to spearhead research, heat mitigation, heat management and climate change risks and disasters of natural and anthropogenic origins in the ecosystems in need for monitoring through Earth Science and Earth Observation. Additionally, it is set to fulfil mandates of the international, regional and local frameworks on urbanization and climate change resilience since there isn't a clear body to spearhead these frameworks as well as heat action and heat response plans at micro-scale levels. In reverence to the Urban Climate Laboratories in Kenya, they would be six based on the national development regions, namely; Tana and Athi Rivers, Lake Basin, Kerio Valley, Ewaso Ng'iro South, Ewaso Ng'iro North and the Coast Region.

ii. Incorporation of a cross-disciplinary expertise for the Coast Urban Climate Laboratory. This would include urban planning, public health, geographic information systems and remote sensing, meteorology, ecological environment, architecture and urban design, red cross and other distinguished resilience disaster and emergency service agencies, water and sanitation, energy, transportation, policy-making, community, local leadership and governance. The Urban Climate Laboratories in Kenya would be technologically-based research and practical institutes. Their technical personnels would cuts across the above-mentioned collaborative circles in exploring all matters connected on the rural-urban built environment and climate change for resilience and sustainable development.

iii. Sufficient funding for heat-related weather and climate change mitigation and climate change adaptation programmes. This would cater for the Coast Urban Climate Laboratory as well as at the National Government and County Government of Mombasa.

iv. Co-application of the resilience theory (Holling, 1973; 2001) and collaborative planning theory (Healey, 1998). This would be underpinned by sharing and feedback communicative rationality mechanisms by Habermas (1985) for mitigation of the urban heat island effect. The study premises that for heat resilience, sustainability, integration and collaboration to be attained in enhancing the mitigation of urban heat island effect, collaboration planning theory has to be applied.

v. Virtual modelling for Mombasa using Urban Digital Twin/Urban Climate Model for better heat resilience as well as sustainable planning and development. The expertise for the Coast Urban Climate Laboratory would be responsible for the Urban Climate Model tuned to the localized background and contextualized historical development and materials of the urban areas of the tropical coast.

vi. Installation of better heat early warning systems and heat monitoring systems. Currently in the sub-Saharan Africa — instrumental in reducing the impacts of climate risks especially in the horn of Africa (Sudan, South Sudan, Ethiopia, Djibouti, South Sudan, Uganda, Kenya and Somalia) — is that of the regional early situation room of the International Competition Policy Advisory Committee (ICPAC) launched in mid-2022, a specialized institution under Intergovernmental Authority on Development (IGAD). This would be vital for anticipatory actions.

vii. Preparation of heat action plans and heat response plans accounting of online portal maps for heat vulnerability indexes (HVIs) and provision of cooling centers.

viii. Launching Urban Heat Mapping Campaigns for Mombasa and other coastal cities which fosters education, training and awareness of Earth Science as well as citizen science for the ground-based measurements of air temperatures and humidity (McCartney, et al., 2020) that can be integrated with land surface temperature (LST) for a comprehensive heat map.

ix. Fast-tracking publication of the National (Kenya) Biodiversity Atlaa for a rather in-depth understanding of the natural ecosystems and to synthesize diversity as well as plan actions against urban heat vulnerability.

7.3 Conclusion

The physical and land use planning as well as developmental efforts of the city has made Mvita a concrete jungle with less vegetation potentially credited to its changing shift in socio-cultural, economic and political controlling over the centuries. This research is original since the planning implications of urban heat island effect were not previously studied in Mombasa that is not only bears a tropical climate but also the largest coastal city in Kenya. As such, this research project contributes to the existing knowledge body of literature on urbanization and climate change as well as policy and practice in mitigating the scale impacts of the urban thermal environment.

By profiling the urban thermal environment on mapping the surface urban heat islands, assessing weather conditions and climatology and making recommendations based on the feasibility of the city's heat mitigation plan proposals, the study has attempted to find solutions in dealing with the shortcomings of poor long-term heat data monitoring during the hot seasons — as acknowledged by Harrington and Otoo (2020) — which have been predominantly facing the Africa nations. The study adds knowledge following the understudied connections of urban heat islands to ecosystem services and greenery in the sub-Saharan Africa by Toit et al (2018). Such was by assessing the spatio-temporal green coverage, urbanization development and local climate zones, proposing the environmental strategy and detailing the planning implications of UHIE towards marine planning and planning of coastal ecosystem in Mombasa. The methodology based on retrieving land surface temperature from the recently launched (late 2021) Landsat 9 Operational Land Image (OLI) and Thermal Infrared Sensor (TIRS) in 2022 that offers a new and a more refined approach to linking and assessing the built-up area and vegetation with formation of the surface urban heat islands.

The prioritized heat mitigation and heat management options established on the social resilience, economic resilience, environmental resilience and institutional resilience models serves to inform and guide the policy and practice dealing with urban heat island effect. They are as to be guided by the planning principles of heat resilience, sustainability, integration and collaboration. Planning proposals suggested can serve for broader implications and positive ramifications when replicated to other tropical coastal cities of the sub-Saharan Africa as well as influence the built environment socially, economically, environmentally and institutionally. Lastly; sufficient funding, application of collaborative planning theory and establishment of an urban climate laboratory — with relevant cross-disciplinary expertise and use of Earth Science and Earth Observation — are paramount and cornerstones in decision making for heat mitigation and heat management on matters of related urbanization and climate change impacts.

7.4 Areas of Further Research

This study on the planning implications of urban heat island effect in Mombasa has necessitated the following areas of further research to be studied.

a) To explore the relationship of atmospheric urban heat islands (AUHIs) as well as nocturnal surface urban heat islands (SUHIs) on urban morphology in Mombasa. This research study vested more on daytime land surface temperatures measured using satellite data, although it elaboratively gives the ambient air temperature trends experienced in Mvita, Mombasa at 2 meters critical to the understanding of atmospheric urban heat islands, often observed during nighttime. The Terra or Aqua MODIS satellite data can be used for deriving daytime and nighttime historic SUHIs depending on the analysis (NASA ARSET, 2022). To further supplement in-situ sensors/fixed meteorological stations for measuring atmospheric UHIs, this proposed study is possible through acquiring ambient air temperatures and humidity data not only through urban heat island mapping campaigns as the AUHIs are small or non-existent in daytime but also via better early warning systems of which most of the Africa nations lacks. Reporting from the tropical coastal city of Mombasa, Kenya on why Africa needs better weather warning systems as positioned by United Nations experts, Kabukuru (2022) puts forward that a mere 22 per cent of weather stations does meet the global climate observing system requirements. Their proposed adequacy seeks to capture the ambient air temperatures, humidity, carbon levels and monitoring extreme weathers like cyclones and drought crucial understanding atmospheric heat islands in a city's size and shape over time.

b) To find out the relationship on impacts of urban heat islands on water quality and air quality in Mombasa. Urban heat islands worsen water as well as air deterioration as perceived by household and outdoor participants in the study. There is limited data on thermal pollution and its impacts on Mombasa coastal ecosystem. An empirical study may prove effective to further inform and guide on water and air quality monitoring systems and site locations to deal with the potential degraded levels of water and air.

c) A comparative study on the urban heat island governance in coastal cities for East Africa community: Mombasa and Dar es Salaam, preferably. The cases of Mombasa and Dar es Salaam as the most urbanizing tropical coastal cities of the East African Community would prove essential in the research study for a holistic governance on urban heat mitigation and heat management solutions. This is useful to strengthening institutional resilience on urban heat island effect, heat waves and global warming. Further it would be critical to informing and guiding the on-going ratification of East African Community Protocol on Cooperation in Meteorological Services.

d) To explore the relationship of extreme heat risk and spatial distribution of heat vulnerability indexes (HVIs) in Mombasa. Notably environmental vulnerability, economic vulnerability and social vulnerability. Although the study attempts to show the perception of exposure, sensitivity and adaptive capacity which are all a function of vulnerability, it falls short on integrating socio-economic data with satellite imagery for constructing heat vulnerability indexes (HVIs) as it requires further advanced research, rigorous community engagement, technological and mapping expertise as well as funding. The creation of a heat vulnerability map based on localized environmental (ecological), economic and social HVIs would be the overall decision output for prioritizing climate (green) smart investments to connect, cool, absorb and protect cities against urban heat island effect. The recent trainings by the NASA ARSET (2022) on mainstreaming socio-economic data with satellite imagery for constructing HVIs would be useful to any researcher or practitioner looking to address the urban heat island effect and its mitigation.

e) An in-depth study on the social impacts of urban heat island effect in Mombasa. In spite of the study trying to document steps to resilience particularly vulnerability as a function of exposure + sensitivity and ± adaptive capacity, it falls inadequate to attempt to perform a risk characterization matrix. Going forward for any in-depth study on the social impacts of urban heat island effect, a standard methodology of risk assessment ought to be utilitarian documenting urban heat resilience for the people in offices, industries, informal sector [jua-kali] and public transport. The relative risk can be gauged as low, medium, high and very high in determining the probability of a loss (y-axis) versus magnitude of a potential loss (x-axis) to inform and guide on the vulnerable or important-to-protect social assets, in this case, of people's health and well-being.

f) To discover the impacts of heat-related climate change impacts on the coastal mangrove ecosystems in Mombasa. On of the study's limitation is on effective detailing the planning implications of climate change induced urban heat island effect towards marine spatial planning and coastal ecosystems. A study on how such urban heat island effect contributes to the climate change mitigation and adaptation at the land-sea interface is imperative.

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Annex I: Research Tools and Instruments of the Study Area

Household Participatory Thermal Comfort Survey

PARTICIPATORY HOUSEHOLD COMFORT SURVEY
[Administration of Questionnaire]

University of Nairobi
Faculty of Built Environment and Design
Department of Urban and Regional Planning
BUR 604 Research Project

Date..............................

Study Area: Mvita, Mombasa

Title of Master's Research Project: Planning Implications of Urban Heat Island Effect in Mombasa

Declaration: This research is being carried out purely for academic purposes. All information provided in this participatory household comfort survey is confidential.

To be administered by KoboCollect.

SECTION I: ANCILLARY HOUSEHOLD AND DEMOGRAPHIC DATA

1.1	Gender of Respondent	1= Male, 2= Female
1.2	Age of Respondent	Depending on the respondent, a scale/quantitative variable.
1.3	Occupation Status	1= Employed, 2= Self=Employed, 3= Student, 4= Unemployed
1.4	Level of Education	1=Primary, 2= Secondary, 3=Tertiary 4= None
1.5	Name of Neighborhood	1= Shimanzi/Ganjoni, 2= Majengo, 3= Tononoka, 4= Mji wa kale/Makadara
1.6a	Type of Neighborhood	1= Low density, 2= Medium density, 3= High density
1.6b	Observation of neighborhood	(Take a Photo)
1.6c	Location	GPS

SECTION II: AWARENESS AND KNOWLEDGE OF URBAN HEAT ISLAND EFFECT

2.1	Are you aware about climate change and urbanization impacts on temperature/urban thermal environment in Mvita, Mombasa? 1= Yes, 2= No, 3=Indifferent
2.2	Are there higher/warmer temperatures experienced in Mvita, Mombasa than outlying areas? 1=Yes, 2= No, 3= Indifferent

SECTION III: CAUSES OF URBAN HEAT ISLANDS IN MVITA, MOMBASA

3.1 From a meteorological/climatic and surfaces modification point of view, using the table below, to what extent do you consider Mvita Sea Island as hotter/warmer than outlying areas within the socio-ecological panarchy/ecosystem?

Potential Root Causes	**Risk Exposure[1] Rating on the Intensity of Urban Heat Islands in Mvita, Mombasa**				
	Very High = 5	High = 4	Moderate = 3	Low =2	Very Low =1
Increase of Air Temperature due to More Periodic Heat Waves: Extreme Heat Related Weather Day or Monthly Events[2]					
Increase of Surface Temperature/Friction due to Impervious Infrastructural Surfaces and Buildings Dominance[3]					
Large Thermal Heat Capacity Construction Materials that Absorb and Store More Solar Energy[4]					
Limited Share of Distribution of the Urban Green Space Infrastructure and Water Urban Design Treatments[5]					
Changing Shape, Urban Morphology and Land Use of the City[6]					
Release of Waste Heat/Anthropogenic Heat[7] to the Atmosphere: Global Warming					
Limited Air-Conditioning as a Non-Climate Stressor and Cooling Opportunity					

[1] *The degree to which people and the things they value could be exposed to climate variation or change or urbanisation effects on temperature;*
[2] *Based on prevalence of calm and clear weather and tropical climate of the island.*
[3] *Increases surface runoff and degradation of water quality through thermal pollution.*
[4] *Like asphalt, concrete, stones, bricks, shingled roofs etc. Leads to increasing warmers days and nights*

1

SECTION IV: SOCIAL, ECONOMIC, ENVIRONMENTAL AND INSTITUTIONAL EFFECTS OF URBAN HEAT ISLANDS

4.1 Please, rank your experiences on these common types of heat-related illnesses and symptoms in Mvita, Mombasa?

Types of Heat-Related Illnesses and Symptoms	***Rank Number***
General Human Thermal Discomfort/Aches	
Body Weakness/ Fatigue	
Heavy Sweating	
Dehydration/Thirst/Dry Mouth	
Unconsciousness/Fainting	
Muscles Cramps and Convulsions	
Air Borne and Water Borne Diseases	
Heat Rash	
Heat Stroke	
Respiratory Diseases	
Cardiovascular Illnesses/Symptoms	
Renal Diseases	

4.2 From a meteorological/climatic and surfaces modification point of view, using the table below, to what extent do you perceive the impacts of heat stress resulting from the urban heat islands in Mvita, Mombasa?

Impacts of Heat Stress	**Sensitivity Rating[8] on the Effects of Urban Heat Islands in Mvita, Mombasa**				
4.2a Social Effects	Very High=5	High= 4	Moderate = 3	Low= 2	Very Low =1
Share of Heat-Related Illnesses/Morbidity[9]					
Share of Heat-Related Deaths/Mortality					
Share of Outpatient Health Care/Pharmacy Visits					
Share of Hospitalized Patients					
Influence on the Level of Activity and Productivity					
Influence on Various Vulnerable Groups[10]					
Frequency of External Migration to Habitable/Cooler Areas					
4.2b Economic Effects					
Share of Electricity Energy Demand/Consumption for Cooling					
Frequency of Electricity Brownouts or Blackouts					
Level of Energy Expenditure on Building Cooling Systems[11]					
Share of Demand of Potable Water for Cooling					

[5] *All forms of green-blue vegetation forms across public and private realms for cooling effects: evapotranspiration*
[6] *Due to increasing population density, narrow streets, limited mobility, high-rise buildings and developing urban canyons/enclosures. Leads to poor indoor and outdoor aeration and ventilation due to altered speeds, spread flows and direction of wind patterns.*
[7] *Emissions of air pollutants and greenhouse gases from vehicles, people, animals, air-conditioning units, buildings and industrial facilities*
[8] *The degree to which people and other assets could be harmed by heat exposure*
[9] *The types of heat illnesses are human thermal discomfort; body weakness; dehydration; unconsciousness; cramps; fainting; heat stroke; heat rash and illnesses such as air borne and water borne diseases; chronic diseases; respiratory diseases; cardiovascular diseases and renal diseases, especially to the vulnerable population*
[10] *They include infants, school children, homeless people, laborers, disabled people, street vendors, traffic police, senior citizens and animals experiencing increased risk of heat-related morbidity and even mortality.*
[11] *Electric-energy demand for air-cooling and refrigeration.*

2

Share of Expenditure on Health Services					
4.2c Environmental Effects					
Worsening of Anticipated Climate Observation Parameters[12]					
Deterioration of Fauna and Green Vegetation					
Deterioration of Indoor and Outdoor Air Quality					
Influence of the Level of Food Production and Supply					
Impairment of Water Quality by Thermal Pollution					
Shortage of Water Supply/Inconsistent Water Supply					
Damage to Construction Materials/Infrastructural Surfaces[13]					
Hazardous Hotspots on Urban Canyons/Enclosures/Clusters					
Poor Ventilation and Wind/Breeze Way Aeration/Circulation					
4.2d Institutional Effects					
Vulnerable Groups Concerns					
Frameworks Concerns					
Awareness Concerns					
Funding Concerns					

SECTION V: PLANNING FOR COOLER COASTAL CITIES AS A SOCIO ECOLOGICAL PANARCHY WITHIN THE URBAN THERMAL ENVIRONMENT

5.1	How do you react or what do you do in case of higher temperatures in Mvita, Mombasa? 1= Staying Indoors, 2= Visiting Outdoor Parks/ Green Open Spaces, 3= Going to Seaside/Walking along Promenades and Beaches, 4= Hydration by Potable Water, 5= Eating Hydrating Foods, 6= Swimming/Cold Showers/ Staying Near a Water Source, 7= Turning on Air Conditioning System, 8= Turning on Fans like Table/Ceiling Fans, 9= Turning on Heat Recovery Unit in the Residential Units, 10 =Others (Specify)
5.2	Are there any public cooling centres/tents or areas or constructed areas for the public to ensure thermal comfort? 1= Yes (Specify), 2 = No, 3= Indifferent
5.3a	To what extent do you think the following planning interventions can strive towards heat resilience and sustainability in Mombasa?

Mitigation Options	**Adaptive Capacity Rating[14] on the Mitigation of Urban Heat Islands in Mvita, Mombasa**		
Social Resilience: People, Health and Wellbeing	High= 3	Medium =2	Low =1
More Conducive Working Conditions and Hours for More Productivity			
Provision of Cooling Centres/Tents/Designed Sheltered Places			
Development of Shaded Bicycle and Pedestrian Corridors			
More Share of Parks and Open Spaces in Urban Neighborhoods			
Constant Supply of Water			
Constant of Supply of Hydrating Foods			
Adequate Awareness/Knowledge and Warnings Based on the Urban Thermal Environment			
Others (Specify)			
Economic Resilience: Energy and Expenditures			
Incentivize Installation or Retrofitting of External Air-conditioning Systems for Energy Efficiency			
More Share of Artificial Table/Ceiling Fans for Clean Air			
Use of Domestic Heat Recovery Unit Systems for Ventilation			
Installations of High-Performance Widows and Shading Devices for Windows			
Utility Controls through Rolling Brownouts or Blackouts			
Vegetated Buffering Around and Within Energy Intensive Buildings			
Large Underground Cooling Water Reticulation Systems			
Constant Supply of Electricity			
Use of Renewable Energy Sources in Facades and Buildings Rooftops like Solar Energy			
Use of Energy-Efficient Household Appliances and Lighting			
Environmental Resilience: Natural and Built-Up Ecosystems			
More Share of Planted Greeneries around Buildings, Rooftops and Facades			
More Share of Parks and Open Spaces in Urban Neighborhoods			
Green Aeration and Ventilation Corridors			
Shading Effects of Vegetation on Buildings and Shelter Designs			
More Water Cool Sinks and Water Urban Design Treatments/Features/Fountains			
Presence of a Sustainable Stormwater Management System			
Suitable Urban Morphology/Geometry of Urban Canyons			
Wider Open Spaces/Streets for Wind Flows and Breeze Circulations in the City			
Traffic Reduction and Transport Fuel Consumption			
Less Heavy and Cool Choice of Materials & Colours Buildings, Roofs, Pavements and Vehicles			
Enforcement of the Water and Air Quality Regulations by NEMA			
Institutional Resilience: Legal/Policy Frameworks, Actors and Funding			
Cooling the Urban Thermal Environment through Revised Zoning and Urban Design			
Spatial Climate & Biodiversity Atlas and Booklet for Urban Heat Resilience & Sustainability			
Revision of the Physical Planning Handbook to Inculcate Urban Thermal Environment			
East African Community Protocol on Cooperation in Meteorological Services Implementation			
Presence of a Long -Term Heat Wave Forecast & Web-Based GIS Climate Resilience Toolkit			
Collaborative Research and Development on Urban Heat Island Effect			
Proper Translation/Enforcement of Policies & Legislations to Heat Resilience & Sustainability			
Undertaking of Urban Heat Islands/Thermal Stakeholder Participation & Mapping Campaigns			
Sufficient Funding on the Climate Change and Urbanisation Impacts on Temperature			
Adequate Capacity Building to all Relevant Stakeholders of the Urban Thermal Environment			
Adequate Awareness/Knowledge/ Warnings Based on the Urban Thermal Environment			

[12] *Increased rate of evapotranspiration, relative humidity, precipitation, floods and disasters such as sea-level rise. Anticipated flooding due to sea level rise, storm surge, and precipitation.*
[13] *Melting of tar roads and damage to street pavements, buildings and piped infrastructure.*
[14] *Degree to which they could mitigate the potential for harm by taking action to reduce exposure and/or sensitivity. As such, heat vulnerability can be known and it is a function of the risk exposure, sensitivity and adaptative capacity.*

5.3b	Please, suggest any other proposals of the same to enhance the mitigation of urban heat island effect in Mvita, Mombasa?
5.3c	Are there collaborative efforts in the mitigation of urban heat island effect in Mvita, Mombasa? 1= Yes (Elaborate) 2= Own Resident Efforts (Elaborate] 3= No, 4 = Indifferent.
5.4d	Is there anything that you would care to add which I haven't asked on the urban heat island effect in Mvita, Mombasa? 1= Yes (Elaborate), 3= No (Captured Everything)

Thank You very much for participating in this survey!

Outdoor Participatory Thermal Comfort Survey

OUTDOOR THERMAL COMFORT SURVEY

[Users of Urban Public Open Spaces]

University of Nairobi
Faculty of Built Environment and Design
Department of Urban and Regional Planning
BUR 604 Research Project

Date..............................

Study Area: Mvita, Mombasa

Title of Master's Research Project: Planning Implications of Urban Heat Island Effect in Mombasa

Declaration: This research is being carried out purely for academic purposes. All information provided in this participatory household comfort survey is confidential.

To be administered by KoboCollect.		
1.1	GPS Location	Five Locations: Mombasa Road [Northern Side], Moi Avenue [Centrally Positioned], Uhuru Gardens [Centrally Positioned], Fort Jesus Park [Western Side] and Mama Ngina Azania Drive [Southern Side] of Mvita Sea-Island
1.2	Gender of Respondent	1= Male, 2= Female
1.3	User Current Activity	1= Seating/Resting, 2= Walking/Strolling, 3= Standing, 4= Exercising, 5= Selling Products/Services 6= Others (Specify)
1.4	User Current Clothing (Check all that apply)	1= Short Sleeved T-Shirt 2= Long Sleeved T-Shirt 3= Long Pants or Long Skirt 3= Shorts or Short Skirt 4= Vest 5= Jacket
1.5	Are you aware about climate change and urbanization impacts on temperature/urban thermal environment in Mvita, Mombasa? 1= Yes, 2= No, 3=Indifferent	
1.6	Are there higher/warmer temperatures experienced in Mvita, Mombasa than outlying areas? 1=Yes, 2= No, 3= Indifferent	
1.7	Please, rate your workday outdoor experiences on thermal comfort in Mvita, Mombasa. 4= Very Hot and Very Uncomfortable, 3= Hot and Uncomfortable, 3= Warm and Slightly Comfortable 1= Moderate and Comfortable	
1.8	Please, rate your leisure outdoor experiences on thermal comfort in Mvita, Mombasa. 4= Very Hot and Very Uncomfortable, 3= Hot and Uncomfortable, 2= Warm and Slightly Comfortable 1= Moderate and Comfortable	
1.9	Please, describe your overall current thermal sensation or rate how you feel at this moment in this public open space? 5= Hot, 4= Warm, 3= Moderate 2= Cool 1= Cold	

1

2.1 Please, describe your acceptable levels or preferences based on the following meteorological parameters on the current outdoor thermal environment in Mvita, Mombasa?

Temperature	3= Higher	2= Unchanged	1= Lower
Wind Speed and Air Movement	3= Stronger	2= Unchanged	1= Weaker
Relative Humidity	3= Damper	2= Unchanged	1= Drier
Solar Radiation	3= Stronger	2= Unchanged	1= Weaker
Air Quality	3= Fresh	2= Unchanged	1= Stuffy
Water Quality	3= Fresh	2= Unchanged	1= Impaired

2.2	Which outdoor spaces or how do you resort to cooling off from the higher temperatures in Mvita, Mombasa when outside the house? 1= Visiting Outdoor Parks/ Green Open Spaces, 2= Going to Seaside/Walking along the Promenades and Beaches, 3= Hydration by Potable Water, 4= Eating Hydrating Foods, 5= Swimming/ Cold Showers/Staying Near an Outside Water Source, 6 =Others (Specify)
2.3	Please, suggest any outdoor space/environment proposal to enhance the mitigation of higher temperatures in Mvita, Mombasa? 1= More Share of Parks and Open Spaces in Urban Neighborhoods 2= Green Aeration and Ventilation Corridors 3= Shading Effects of Vegetation on Buildings and Shelter Designs 4= More Water Cool Sinks and Water Urban Design Treatments/Features/Fountains 5= Presence of a Sustainable Stormwater Management System 6= Suitable Urban Morphology/Building Geometry to Limit Heat Trappings 7= Wider Open Spaces/Streets for Wind Flows and Breeze Circulations in the City 8= Traffic Reduction and Transport Fuel Consumption 9= Less Heavy and Cool Choice of Materials & Colours Buildings, Roofs, Pavements and Vehicles 10= Enforcement of the Water and Air Quality Regulations by NEMA 11= Collaboration Efforts on Climate Mitigation and Climate Action 12= Other (specify)

Thank You very much for participating in this survey!

2

County Physical Planner; Department of Lands, Planning and Housing

COUNTY PHYSICAL PLANNING OFFICER GUIDE

[Dept. Lands, Housing and Physical Planning]

University of Nairobi
Faculty of Built Environment and Design
Department of Urban and Regional Planning
BUR 604 Research Project

Date..............................

Study Area: Mvita, Mombasa

Title of Master's Research Project: Planning Implications of Urban Heat Island Effect in Mombasa

Declaration: This research is being carried out purely for academic purposes. All information provided in this key informant guide is confidential.

1	Are you aware about climate change and urbanization impacts on temperature/urban thermal environment in Mvita, Mombasa? 1= Yes, 2= No, 3=Indifferent
2	Do you perceive that there are higher/warmer temperatures experienced in Mvita, Mombasa than outlying areas? 1=Yes, 2= No, 3= Indifferent
3a	With respect to the intensity of urban heat islands in Mvita Sea Island, Mombasa, what is your opinion of the following risks of heat exposure?

Potential Root Causes	**Risk Exposure[1] Rating on the Intensity of Urban Heat Islands in Mvita, Mombasa**				
	Very High= 5	High= 4	Moderate = 3	Low= 2	Very Low= 1
Increase of Air Temperature due to More Periodic Heat Waves: Extreme Heat Related Weather Day or Monthly Events[2]					
Increase of Surface Temperature/Friction due to Impervious Infrastructural Surfaces and Buildings Dominance[3]					
Large Thermal Heat Capacity Construction Materials that Absorb and Store More Solar Energy[4]					
Limited Share of Distribution of the Urban Green Space Infrastructure and Water Urban Design Treatments[5] [Share?]					
Changing Shape, Urban Morphology and Land Use of the City[6]					
Release of Waste Heat/Anthropogenic Heat[7] to the Atmosphere: Global Warming					
Limited Air-Conditioning as a Non-Climate Stressor and Cooling Opportunity					

	From planning point of view, comment/elaborate on the following to the causes of urban heat islands in Mvita Sea Island, Mombasa?
3b	**Geometry of Urban Canyons** (Sky View Factor, Aspect Ratio, Mean Building/Tree Height, Building Forms, Housing Typologies, Variations between Building Heights and Wider/Narrow Streets)
	Surface Coverage (Urban Density by Local Climate Zones[8], Population Density, Green Plot Ratio, Topography, Building Surface Fraction)
	Choice of Materials and Surfaces (Streets and Open Spaces, Facades, Roofs, Colours, Windows and Buildings in General)
	Urbanization and Development (Growth of Urban Population, Rural-Uban Migration, Increased Economic Activities and Changes to Urban Morphology)
	Impacts of Different Land Uses and Activities on Temperature (10 land uses, transport corridors traffic capacity and pollution, energy and fuel consumption, Waste/Anthropogenic Heat)
3c	From a planning point of view, are there any other causes of urban heat islands in Mvita Sea Island, Mombasa?

4. Rate the following impacts of heat stress	**Sensitivity Rating[9] on the Intensity of Urban Heat Islands in Mvita, Mombasa**				
4a Social Effects	Very High= 5	High= 4	Moderate = 3	Low= 2	Very Low= 1
Share of Heat-Related Illnesses/Morbidity[10]					
Share of Heat-Related Deaths/Mortality					
Share of Outpatient Health Care/Pharmacy Visits					
Share of Hospitalized Patients					
Influence on the Level of Activity and Productivity					
Influence on Various Vulnerable Groups[11]					
Frequency of External Migration to Habitable/Cooler Areas					
4b Economic Effects					
Share of Electricity Energy Demand/Consumption for Cooling					
Frequency of Electricity Brownouts or Blackouts					
Level of Energy Expenditure on Building Cooling Systems[12]					
Share of Demand of Potable Water for Cooling					
Share of Expenditure on Health Services					

[1] *The degree to which people and the things they value could be exposed to climate variation or change or urbanisation effects on temperature;*
[2] *Based on prevalence of calm and clear weather and tropical climate of the island.*
[3] *Increases surface runoff and degradation of water quality through thermal pollution.*
[4] *Like asphalt, concrete, stones, bricks, shingled roofs etc. Leads to increasing warmers days and nights*
[5] *All forms of green-blue vegetation forms across public and private realms for cooling effects: evapotranspiration*
[6] *Due to increasing population density, narrow streets, limited mobility, high-rise buildings and developing urban canyons/enclosures. Leads to poor indoor and outdoor aeration and ventilation due to altered speeds, spread flows and direction of wind patterns.*
[7] *Emissions of air pollutants and greenhouse gases from vehicles, people, animals, air-conditioning units, buildings and industrial facilities*

1

[8] *Based on the properties of surface structure (e.g., building and tree height & density) and surface cover (pervious vs. impervious). Compact high-rise 1, Compact midrise 2, Compact low-rise 3, Open high-rise 4, Open midrise 5 Open low-rise 6 Lightweight low-rise 7, Large low-rise 8, Sparsely built 9, Heavy industry 10, Dense trees A, Scattered trees B, Bush/scrub C, Low plants D, Bare rock or paved E, Bare soil or sand F Water G.*
[9] *The degree to which people and other assets could be harmed or affected by heat exposure*
[10] *The types of heat illnesses are human thermal discomfort; body weakness; dehydration; unconsciousness; cramps; fainting; heat stroke; heat rash and illnesses such as air borne and water borne diseases; chronic diseases; respiratory diseases; cardiovascular diseases and renal diseases, especially to the vulnerable population*
[11] *They include infants, school children, homeless people, laborers, disabled people, street vendors, traffic police, senior citizens and animals experiencing increased risk of heat-related morbidity and even mortality.*
[12] *Electric-energy demand for air-cooling and refrigeration.*

2

4c Environmental Effects					
Worsening of Related Climate Observation Parameters[13]					
Deterioration of Fauna and Green Vegetation					
Deterioration of Indoor and Outdoor Air quality					
Influence of the Level of Food Production and Supply					
Impairment of Water Quality by Thermal Pollution					
Shortage of Water Supply/Inconsistent Water Supply					
Damage to Construction Materials/Infrastructural Surfaces[14]					
Hazardous Hotspots on Urban Canyons/Enclosures/Clusters					
Poor Ventilation and Wind/Breeze Way Aeration/Circulation					
4d Institutional Effects					
Vulnerable Groups Concerns					
Present Frameworks Concerns					
Awareness Concerns					
Funding Concerns					

5.	Are they any public cooling centres/tents or areas or constructed areas for the public to ensure thermal comfort? 1= Yes (Specify), 2 = No, 3= Indifferent
6	a) Is there a land use plan for Mvita? 1= Yes (Specify), 2 = No, 3= Indifferent b) Has it been revised to bind the urban thermal environment? 1= Yes (Specify), 2 = No, 3= Indifferent
10	a) How does the Department engage in awareness of the urban thermal environment to citizens, politicians, urban planners, urban designers, health experts, environmental officers, fellow climate experts and vulnerable groups, especially urban heat island effect? b) Are there any urban heat island mapping campaigns undertaken in Mvita or at the coast region of Mombasa)? 1= Yes (Specify), 2 = No, 3= Indifferent
11	Which specific policies and legislations bind architectural and urban designing to mitigate urban heat island effect in Mombasa?
12	a) Which institutions do you think are tasked or should be tasked with enhancing the mitigation of urban heat island effect towards heat resilience and urban sustainable development, and why? b) Are there collaborative efforts in the mitigation of urban heat island effect in Mvita, Mombasa? 1= Yes (Elaborate) 2= Own Resident Efforts (Elaborate] 3= No, 4 = Indifferent
13	From a planning point of view, what do can you suggest to enhance the mitigation of urban heat island effect in coastal cities including capacity issues?

[13] *Increased rate of evapotranspiration, relative humidity, precipitation, floods and disasters such as sea-level rise. Anticipated flooding due to sea level rise, storm surge, and precipitation.*
[14] *Melting of tar roads and damage to street pavements, buildings and piped infrastructure.*

14	To what extent do you think the following planning interventions can strive towards heat resilience and sustainability?

Mitigation Options (Ideas/Actions from Residents)	**Adaptive Capacity Rating[15] on the Intensity of Urban Heat Islands in Mvita, Mombasa**		
14a Social Resilience: People, Health and Wellbeing	High= 3	Medium = 2	Low = 1
More Conducive Working Conditions and Hours for More Productivity			
Provision of Cooling Centres/Tents/Designed Sheltered Places			
Development of Shaded Bicycle and Pedestrian Corridors			
More Share of Parks and Open Spaces in Urban Neighborhoods			
Constant Supply of Water			
Constant of Supply of Hydrating Foods			
Adequate Awareness/Knowledge and Warnings Based on the Urban Thermal Environment			
14b Economic Resilience: Energy and Expenditures			
Incentivize Installation or Retrofitting of Air-conditioning/Buildings Systems for Energy Efficiency			
Use of Heat Recovery Unit Systems for Ventilation			
Installations of High-Performance Widows and Shading Devices for Windows			
Utility Controls through Rolling Brownouts or Blackouts			
Vegetated Buffering Around and Within Energy Intensive Buildings			
Large Underground Cooling Water Reticulation Systems			
Constant Supply of Electricity			
Use of Renewable Energy Sources in Facades and Buildings Rooftops like Solar Energy			
Use of Energy-Efficient Household Appliances and Lighting			
14c Environmental Resilience: Natural and Built-Up Ecosystems			
More Share of Planted Greeneries around Buildings, Rooftops and Facades			
More Share of Parks and Open Spaces in Urban Neighborhoods			
Green Aeration and Ventilation Corridors			
Shading Effects of Vegetation on Buildings and Shetler Designs			
More Water Cool Sinks and Water Urban Design Treatments/Features/Fountains			
Presence of a Sustainable Stormwater Management System			
Suitable Urban Morphology/Geometry of Urban Canyons			
Wider Open Spaces/Streets for Wind Flows and Breeze Circulations in the City			
Traffic Reduction and Transport Fuel Consumption			
Less Heavy and Cool Choice of Materials & Colours Buildings, Roofs, Pavements and Vehicles			
Enforcement of the Water and Air Quality Regulations by NEMA			
14d Institutional Resilience: Legal/Policy Frameworks, Actors & Funding			
Cooling the Urban Thermal Environment through Revised Zoning and Urban Design			
Spatial Climate & Biodiversity Atlas/Booklet for Urban Heat Resilience & Sustainability			
Revision of the Physical Planning Handbook to Inculcate Urban Thermal Environment			
East African Community Protocol on Cooperation in Meteorological Services Implementation			
Presence of a Long-Term Heat Wave Forecast & Web-Based GIS Climate Resilience Toolkit			
Collaborative Research and Development on Urban Heat Island Effect			
Proper Translation/Enforcement of Policies & Legislations to Heat Resilience & Sustainability			
Undertaking of Urban Heat Islands/Thermal Stakeholder Participation & Mapping Campaigns			
Sufficient Funding on the Climate Change and Urbanisation Impacts on Temperature			
Adequate Capacity Building to all Relevant Stakeholders of the Urban Thermal Environment			
Adequate Awareness/Knowledge/Warnings Based on the Urban Thermal Environment			

14e	Is there anything that you would care to add which I haven't asked on the urban heat island effect in Mvita, Mombasa? 1= Yes (Elaborate), 3= No (Captured Everything)

Thank You very much for participating in this survey!

[15] *Degree to which they could mitigate the potential for harm by taking action to reduce exposure and/or sensitivity. As such, heat vulnerability can be known and it is a function of the risk exposure, sensitivity and adaptative capacity.*

County Architect; Department of Transport, Infrastructure & Public Works

COUNTY URBAN DESIGNER/ARCHITECT GUIDE

[Dept. Transport, Infrastructure & Public Works]

University of Nairobi
Faculty of Built Environment and Design
Department of Urban and Regional Planning
BUR 604 Research Project

Date..............................

Study Area: Mvita, Mombasa

Title of Master's Research Project: Planning Implications of Urban Heat Island Effect in Mombasa

Declaration: This research is being carried out purely for academic purposes. All information provided in this key informant guide is confidential.

1	Are you aware about climate change and urbanization impacts on temperature/urban thermal environment in Mvita, Mombasa? 1= Yes, 2= No, 3=Indifferent
2	Do you perceive that there are higher/warmer temperatures experienced in Mvita, Mombasa than outlying areas? 1=Yes, 2= No, 3= Indifferent
3a	With respect to the intensity of urban heat islands in Mvita Sea Island, Mombasa, what is your opinion of the following risks of heat exposure?

Potential Root Causes	Risk Exposure[1] Rating on the Intensity of Urban Heat Islands in Mvita, Mombasa				
	Very High= 5	High= 4	Moderate = 3	Low= 2	Very Low= 1
Increase of Air Temperature due to More Periodic Heat Waves: Extreme Heat Related Weather Day or Monthly Events[2]					
Increase of Surface Temperature/Friction due to Impervious Infrastructural Surfaces and Buildings Dominance[3]					
Large Thermal Heat Capacity Construction Materials that Absorb and Store More Solar Energy[4]					
Limited Share of Distribution of the Urban Green Space Infrastructure and Water Urban Design Treatments[5] [Share?]					
Changing Shape, Urban Morphology and Land Use of the City[6]					
Release of Waste Heat/Anthropogenic Heat[7] to the Atmosphere: Global Warming					
Limited Air-Conditioning as a Non-Climate Stressor and Cooling Opportunity					

	From an architectural and urban design point of view, comment/elaborate on the following to the causes of urban heat islands in Mvita Sea Island, Mombasa?

[1] *The degree to which people and the things they value could be exposed to climate variation or change or urbanisation effects on temperature;*
[2] *Based on prevalence of calm and clear weather and tropical climate of the island.*
[3] *Increases surface runoff and degradation of water quality through thermal pollution.*
[4] *Like asphalt, concrete, stones, bricks, shingled roofs etc. Leads to increasing warmers days and nights*
[5] *All forms of green-blue vegetation forms across public and private realms for cooling effects: evapotranspiration*
[6] *Due to increasing population density, narrow streets, limited mobility, high-rise buildings and developing urban canyons/enclosures. Leads to poor indoor and outdoor aeration and ventilation due to altered speeds, spread flows and direction of wind patterns.*
[7] *Emissions of air pollutants and greenhouse gases from vehicles, people, animals, air-conditioning units, buildings and industrial facilities*

1

3b	**Geometry of Urban Canyons** (Sky View Factor, Aspect Ratio, Mean Building/Tree Height, Building Forms, Housing Typologies, Variations between Building Heights and Wider/Narrow Streets)
	Surface Coverage (Urban Density by Local Climate Zones[8], Population Density, Green Plot Ratio, Topography, Building Surface Fraction)
	Choice of Materials and Surfaces (Streets and Open Spaces, Facades, Roofs, Colours, Windows and Buildings in General)
	Urbanization and Development (Growth of urban population, Rural-Uban Migration, Increased Economic Activities and Changes to Urban Morphology)
	Impacts of Different Land Uses and Activities on Temperature (10 land uses, transport corridors, traffic capacity, energy and fuel consumption, Waste/Anthropogenic Heat)
3c	From an architectural and urban design point of view, are there any other causes of urban heat islands in Mvita Sea Island, Mombasa?

4. Rate the following impacts of heat stress	Sensitivity Rating[9] on the Intensity of Urban Heat Islands in Mvita, Mombasa				
4a Social Effects	Very High= 5	High= 4	Moderate = 3	Low= 2	Very Low= 1
Share of Heat-Related Illnesses/Morbidity[10]					
Share of Heat-Related Deaths/Mortality					
Share of Outpatient Health Care/Pharmacy Visits					
Share of Hospitalized Patients					
Influence on the Level of Activity and Productivity					
Influence on Various Vulnerable Groups[11]					
Frequency of External Migration to Habitable/Cooler Areas					
4b Economic Effects					
Share of Electricity Energy Demand/Consumption for Cooling					
Frequency of Electricity Brownouts or Blackouts					
Level of Energy Expenditure on Building Cooling Systems[12]					
Share of Demand of Potable Water for Cooling					

[8] *Based on the properties of surface structure (e.g., building and tree height & density) and surface cover (pervious vs. impervious). Compact high-rise 1, Compact midrise 2, Compact low-rise 3, Open high-rise 4, Open midrise 5 Open low-rise 6 Lightweight low-rise 7, Large low-rise 8, Sparsely built 9, Heavy industry 10, Dense trees A, Scattered trees B, Bush/scrub C, Low plants D, Bare rock or paved E, Bare soil or sand F Water G.*
[9] *The degree to which people and other assets could be harmed or affected by heat exposure*
[10] *The types of heat illnesses are human thermal discomfort; body weakness; dehydration; unconsciousness; cramps; fainting; heat stroke; heat rash and illnesses such as air borne and water borne diseases; chronic diseases; respiratory diseases; cardiovascular diseases and renal diseases, especially to the vulnerable population*
[11] *They include infants, school children, homeless people, laborers, disabled people, street vendors, traffic police, senior citizens and animals experiencing increased risk of heat-related morbidity and even mortality.*
[12] *Electric-energy demand for air-cooling and refrigeration.*

2

County Public Health Practitioner, Coast General Teaching & Referral Hospital

PUBLIC HEALTH OFFICER/ HEALTH EXPERT GUIDE
[Mombasa County, Mvita Sub-County, Dept. Health]

University of Nairobi
Faculty of Built Environment and Design
Department of Urban and Regional Planning
BUR 604 Research Project

Date..............................

Study Area: Mvita, Mombasa

Title of Master's Research Project: Planning Implications of Urban Heat Island Effect in Mombasa

Declaration: This research is being carried out purely for academic purposes. All information provided in this key informant guide is confidential.

1	Are you aware about climate change and urbanization impacts on temperature/urban thermal environment in Mvita, Mombasa? 1= Yes, 2= No, 3=Indifferent
2	Do you perceive that there are higher/warmer temperatures experienced in Mvita, Mombasa than outlying areas? 1=Yes, 2= No, 3= Indifferent
3	From a health and wellbeing point of view, what are the common types of heat-related illnesses and symptoms that people experience in Mvita, Mombasa?
4	What are the various vulnerable groups affected by heat-related illnesses and symptoms within Mombasa?
5	From a health and wellbeing point of view, to what extent do you perceive the following social impacts of heat stress resulting from the urban heat islands in Mvita, Mombasa?

Impacts of Heat Stress	Sensitivity Rating[1] on the Intensity of Urban Heat Islands in Mvita, Mombasa				
Social Effects	Very High= 5	High= 4	Moderate = 3	Low= 2	Very Low= 1
Share of Heat-Related Illnesses/Morbidity[2]					
Share of Heat-Related Deaths/Mortality [Number]					
Share of Outpatient Health Care/Pharmacy Visits [Number]					
Share of Hospitalized Patients [Number]					
Influence on the Level of Activity and Productivity					
Influence on Various Vulnerable Groups[3]					
Frequency of External Migration to Habitable/Cooler Areas					
Share of Demand of Potable Water for Cooling					
Share of Expenditure on Health Services [Estimation]					

[1] *The degree to which people and other assets could be harmed by heat exposure*
[2] *The types of heat illnesses are human thermal discomfort; body weakness; dehydration; unconsciousness; cramps; fainting; heat stroke; heat rash and illnesses such as air borne and water borne diseases; chronic diseases; respiratory diseases; cardiovascular diseases and renal diseases, especially to the vulnerable population*
[3] *They include infants, school children, homeless people, laborers, disabled people, street vendors, traffic police, senior citizens and animals experiencing increased risk of heat-related morbidity and even mortality.*

1

6	Are they any public cooling centres/tents or areas or constructed areas for the public to ensure thermal comfort? 1= Yes (Specify), 2 = No, 3= Indifferent		
7a	Based on health system capacity and heat resilience, what do you think can be done to enhance the mitigation of urban heat island effect in Mvita, Mombasa?		
	Leadership and Governance		
	Environment:	**Natural Ecosystems**	
		Built-up Ecosystems	
		Food and Water Supply	
	Energy and Expenditures on the Economy		
	Health Workforce		
	Health Information Systems		
	Essential Medical Products and Technologies		
	Emergency Services and Service Delivery		
	Awareness		
	Financing		
7b	Are there collaborative efforts in the mitigation of urban heat island effect in Mvita, Mombasa? 1= Yes (Elaborate) 2= Own Resident Efforts (Elaborate] 3= No, 4 = Indifferent		
7c	Is there anything that you would care to add which I haven't asked on the urban heat island effect in Mvita, Mombasa? 1= Yes (Elaborate), 3= No (Captured Everything)		

Thank You very much for participating in this survey!

2

County Environment Officer; Department of Environment Compliance

COUNTY ENVIRONMENTAL OFFICER/EXPERT GUIDE

[Dept. Environment, Waste Management and Energy]

University of Nairobi
Faculty of Built Environment and Design
Department of Urban and Regional Planning
BUR 604 Research Project

Date..............................

Study Area: Mvita, Mombasa

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2	Do you perceive that there are higher/warmer temperatures experienced in Mvita, Mombasa than outlying areas? 1=Yes, 2= No, 3= Indifferent
3	a) What percentage/share of urban green areas and distribution[1] of urban green areas does Mvita Sea-Island have? b) Why do you think the situation happens to be like this? c) What would be the likely impact of this situation to temperature/urban thermal environment over the years?
3a	With respect to the intensity of urban heat islands in Mvita Sea Island, Mombasa, what is your opinion of the following risks of heat exposure?

Potential Root Causes	Risk Exposure[2] Rating on the Intensity of Urban Heat Islands in Mvita, Mombasa				
	Very High= 5	High= 4	Moderate = 3	Low= 2	Very Low= 1
Increase of Air Temperature due to More Periodic Heat Waves: Extreme Heat Related Weather Day or Monthly Events[3]					
Increase of Surface Temperature/Friction due to Impervious Infrastructural Surfaces and Buildings Dominance[4]					
Large Thermal Heat Capacity Construction Materials that Absorb and Store More Solar Energy[5]					
Limited Share of Distribution of the Urban Green Space Infrastructure and Water Urban Design Treatments[6]					
Changing Shape, Urban Morphology and Land Use of the City[7]					
Release of Waste Heat/Anthropogenic Heat[8] to the Atmosphere: Global Warming					
Limited Air-Conditioning as a Non-Climate Stressor and Cooling Opportunity					

[1] *Name of the Various and Locations the Private/Public Share of Parks and Open Spaces*
[2] *The degree to which people and the things they value could be exposed to climate variation or change or urbanisation effects on temperature;*
[3] *Based on prevalence of calm and clear weather and tropical climate of the island.*
[4] *Increases surface runoff and degradation of water quality through thermal pollution.*
[5] *Like asphalt, concrete, stones, bricks, shingled roofs etc. Leads to increasing warmers days and nights*

1

3b	From an environmental and ecosystem point of view, are there any other causes of urban heat islands in Mvita Sea Island, Mombasa?
4	Using the table below, to what extent do you perceive the following impacts of heat stress resulting from the urban heat islands in Mvita, Mombasa?

Impacts of Heat Stress	Sensitivity Rating[9] on the Intensity of Urban Heat Islands in Mvita, Mombasa				
4a Social Effects	Very High= 5	High= 4	Moderate = 3	Low= 2	Very Low= 1
Share of Heat-Related Illnesses/Morbidity[10]					
Share of Heat-Related Deaths/Mortality					
Share of Outpatient Health Care/Pharmacy Visits					
Share of Hospitalized Patients					
Influence on the Level of Activity and Productivity					
Influence on Various Vulnerable Groups[11]					
Frequency of External Migration to Habitable/Cooler Areas					
4b Economic Effects					
Share of Electricity Energy Demand/Consumption for Cooling					
Frequency of Electricity Brownouts or Blackouts					
Level of Energy Expenditure on Building Cooling Systems[12]					
Share of Demand of Potable Water for Cooling					
Share of Expenditure on Health Services					
4c Environmental Effects					
Worsening of Related Climate Observation Parameters[13]					
Deterioration of Fauna and Green Vegetation					
Deterioration of Indoor and Outdoor Air quality					
Influence of the Level of Food Production and Supply					
Impairment of Water Quality by Thermal Pollution					

[6] *All forms of green-blue vegetation forms across public and private realms for cooling effects: evapotranspiration*
[7] *Due to increasing population density, narrow streets, limited mobility, high-rise buildings and developing urban canyons/enclosures. Leads to poor indoor and outdoor aeration and ventilation due to altered speeds, spread flows and direction of wind patterns.*
[8] *Emissions of air pollutants and greenhouse gases from vehicles, people, animals, air-conditioning units, buildings and industrial facilities*
[9] *The degree to which people and other assets could be harmed or affected by heat exposure*
[10] *The types of heat illnesses are human thermal discomfort; body weakness; dehydration; unconsciousness; cramps; fainting; heat stroke; heat rash and illnesses such as air borne and water borne diseases; chronic diseases; respiratory diseases; cardiovascular diseases and renal diseases, especially to the vulnerable population*
[11] *They include infants, school children, homeless people, laborers, disabled people, street vendors, traffic police, senior citizens and animals experiencing increased risk of heat-related morbidity and even mortality.*
[12] *Electric-energy demand for air-cooling and refrigeration.*
[13] *Increased rate of evapotranspiration, relative humidity, precipitation, floods and disasters such as sea-level rise. Anticipated flooding due to sea level rise, storm surge, and precipitation.*

2

Shortage of Water Supply/Inconsistent Water Supply					
Damage to Construction Materials/Infrastructural Surfaces[14]					
Hazardous Hotspots on Urban Canyons/Enclosures/Clusters					
Poor Ventilation and Wind/Breeze Way Aeration/Circulation					
4d Institutional Effects					
Vulnerable Groups Concerns					
Present Frameworks Concerns					
Awareness Concerns					
Funding Concerns					

5	From environmental and ecosystem point of view, which other impacts of urban heat islands can you mention that occurs within Mvita Sea Island, Mombasa?
6	Which methods does this Department of Environment, Waste Management and Energy use to monitor and address the urban thermal environment in Mvita, Mombasa?
7	Is there a Web-Based GIS Climate Resilience Toolkit embedded with ancillary data for population, health, spatial distribution of natural and built-up ecosystems in assessing heat vulnerability as a function of risk exposure, sensitivity and adaptive capacity in Mombasa, County or Kenya? 1= Yes, 2= No, 3=Indifferent
8	Is there a prepared Spatial Climate & Biodiversity Atlas/Booklet for Urban Heat Resilience & Sustainability based on the action strategies from the ratified international frameworks on diversity, environment and climate change? 1= Yes, 2= No, 3=Indifferent
9	Are they any public cooling centres/tents or areas or constructed areas for the public to ensure thermal comfort? 1= Yes (Specify), 2 = No, 3= Indifferent
10	How does this Department of Environment, Waste Management and Energy engage in awareness of the urban thermal environment to citizens, politicians, urban planners, urban designers, health experts, environmental officers, fellow climate experts and vulnerable groups, especially urban heat island effect?
11.	Which specific policies and legislations bind this Department Environment, Waste Management and Energy to mitigate urban heat island effect in Mombasa?

[14] *Melting of tar roads and damage to street pavements, buildings and piped infrastructure.*

12.	a) Which institutions do you think are tasked or should be tasked with enhancing the mitigation of urban heat island effect towards heat resilience and urban sustainable development, and why? b) Are there collaborative efforts in the mitigation of urban heat island effect in Mvita, Mombasa? 1= Yes (Elaborate) 2= Own Resident Efforts (Elaborate] 3= No, 4 = Indifferent.
13.	From an environmental and ecosystem point of view, what do can you recommend to enhance the mitigation of urban heat island effect in coastal cities including capacity issues?
14.	To what extent do you think the following planning interventions can strive towards heat resilience and sustainability?

Mitigation Options (Ideas/Actions from Residents)	**Adaptive Capacity Rating[15] on the Intensity of Urban Heat Islands in Mvita, Mombasa**		
14a Social Resilience: People, Health and Wellbeing	High= 3	Medium = 2	Low = 1
More Conducive Working Conditions and Hours for More Productivity			
Provision of Cooling Centres/Tents/Designed Sheltered Places			
Development of Shaded Bicycle and Pedestrian Corridors			
More Share of Parks and Open Spaces in Urban Neighborhoods			
Constant Supply of Water			
Constant of Supply of Hydrating Foods			
Adequate Awareness/Knowledge and Warnings Based on the Urban Thermal Environment			
14b Economic Resilience: Energy and Expenditures			
Incentivize Installation or Retrofitting of Air-conditioning/Buildings Systems for Energy Efficiency			
Use of Heat Recovery Unit Systems for Ventilation			
Installations of High-Performance Widows and Shading Devices for Windows			
Utility Controls through Rolling Brownouts or Blackouts			
Vegetated Buffering Around and Within Energy Intensive Buildings			
Large Underground Cooling Water Reticulation Systems			
Constant Supply of Electricity			
Use of Renewable Energy Sources in Facades and Buildings Rooftops like Solar Energy			
Use of Energy-Efficient Household Appliances and Lighting			
14c Environmental Resilience: Natural and Built-Up Ecosystems			
More Share of Planted Greeneries around Buildings, Rooftops and Facades			
More Share of Parks and Open Spaces in Urban Neighborhoods			
Green Aeration and Ventilation Corridors			
Shading Effects of Vegetation on Buildings and Shetler Designs			
More Water Cool Sinks and Water Urban Design Treatments/Features/Fountains			
Presence of a Sustainable Stormwater Management System			
Suitable Urban Morphology/Geometry of Urban Canyons			

[15] *Degree to which they could mitigate the potential for harm by taking action to reduce exposure and/or sensitivity. As such, heat vulnerability can be known and it is a function of the risk exposure, sensitivity and adaptative capacity.*

County Urban Climate Change; Department of Climate Change

URBAN CLIMATE EXPERT
[Mombasa Office]

University of Nairobi
Faculty of Built Environment and Design
Department of Urban and Regional Planning
BUR 604 Research Project

Date..............................

Study Area: Mvita, Mombasa

Title of Master's Research Project: Planning Implications of Urban Heat Island Effect in Mombasa

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1	Are you aware about climate change and urbanization impacts on temperature/urban thermal environment in Mvita, Mombasa? 1= Yes, 2= No, 3=Indifferent
2	Do you perceive that there are higher/warmer temperatures experienced in Mvita, Mombasa than outlying areas? 1=Yes, 2= No, 3= Indifferent
3a	With respect to the intensity of urban heat islands in Mvita Sea Island, Mombasa, what is your opinion of the following risks of heat exposure?

Potential Root Causes	Risk Exposure[1] Rating on the Intensity of Urban Heat Islands in Mvita, Mombasa				
	Very High= 5	High= 4	Moderate = 3	Low= 2	Very Low= 1
Increase of Air Temperature due to More Periodic Heat Waves: Extreme Heat Related Weather Day or Monthly Events[2]					
Increase of Surface Temperature/Friction due to Impervious Infrastructural Surfaces and Buildings Dominance[3]					
Large Thermal Heat Capacity Construction Materials that Absorb and Store More Solar Energy[4]					
Limited Share of Distribution of the Urban Green Space Infrastructure and Water Urban Design Treatments[5]					
Changing Shape, Urban Morphology and Land Use of the City[6]					
Release of Waste Heat/Anthropogenic Heat[7] to the Atmosphere: Global Warming					
Limited Air-Conditioning as a Non-Climate Stressor and Cooling Opportunity					

3b	From a meteorological/climatic and surfaces modification point of view, are there any other causes of urban heat islands in Mvita Sea Island, Mombasa?

[1] *The degree to which people and the things they value could be exposed to climate variation or change or urbanisation effects on temperature;*
[2] *Based on prevalence of calm and clear weather and tropical climate of the island.*
[3] *Increases surface runoff and degradation of water quality through thermal pollution.*
[4] *Like asphalt, concrete, stones, bricks, shingled roofs etc. Leads to increasing warmers days and nights*
[5] *All forms of green-blue vegetation forms across public and private realms for cooling effects: evapotranspiration*
[6] *Due to increasing population density, narrow streets, limited mobility, high-rise buildings and developing urban canyons/enclosures. Leads to poor indoor and outdoor aeration and ventilation due to altered speeds, spread flows and direction of wind patterns.*
[7] *Emissions of air pollutants and greenhouse gases from vehicles, people, animals, air-conditioning units, buildings and industrial facilities*

1

4	Using the table below, to what extent do you perceive the following impacts of heat stress resulting from the urban heat islands in Mvita, Mombasa?

Impacts of Heat Stress	Sensitivity Rating[8] on the Intensity of Urban Heat Islands in Mvita, Mombasa				
4a Social Effects	Very High= 5	High= 4	Moderate = 3	Low= 2	Very Low=1
Share of Heat-Related Illnesses/Morbidity[9]					
Share of Heat-Related Deaths/Mortality					
Share of Outpatient Health Care/Pharmacy Visits					
Share of Hospitalized Patients					
Influence on the Level of Activity and Productivity					
Influence on Various Vulnerable Groups[10]					
Frequency of External Migration to Habitable/Cooler Areas					
4b Economic Effects					
Share of Electricity Energy Demand/Consumption for Cooling					
Frequency of Electricity Brownouts or Blackouts					
Level of Energy Expenditure on Building Cooling Systems[11]					
Share of Demand of Potable Water for Cooling					
Share of Expenditure on Health Services					
4c Environmental Effects					
Worsening of Related Climate Observation Parameters[12]					
Deterioration of Fauna and Green Vegetation					
Deterioration of Indoor and Outdoor Air quality					
Influence of the Level of Food Production and Supply					
Impairment of Water Quality by Thermal Pollution					
Shortage of Water Supply/Inconsistent Water Supply					
Damage to Construction Materials/Infrastructural Surfaces[13]					
Hazardous Hotspots on Urban Canyons/Enclosures/Clusters					
Poor Ventilation and Wind/Breeze Way Aeration/Circulation					
4d Institutional Effects					
Vulnerable Groups Concerns					
Present Frameworks Concerns					
Awareness Concerns					
Funding Concerns					

5	From a meteorological/climatic and surfaces modification point of view, are there any other impacts of urban heat islands in Mvita Sea Island, Mombasa?
6	How many in-situ sensors/fixed meteorological stations and mobile transverses are there in Mombasa, County or Kenya to measure atmospheric urban islands?

[8] *The degree to which people and other assets could be harmed or affected by heat exposure*
[9] *The types of heat illnesses are human thermal discomfort; body weakness; dehydration; unconsciousness; cramps; fainting; heat stroke; heat rash and illnesses such as air borne and water borne diseases; chronic diseases; respiratory diseases; cardiovascular diseases and renal diseases, especially to the vulnerable population*
[10] *They include infants, school children, homeless people, laborers, disabled people, street vendors, traffic police, senior citizens and animals experiencing increased risk of heat-related morbidity and even mortality.*
[11] *Electric-energy demand for air-cooling and refrigeration.*
[12] *Increased rate of evapotranspiration, relative humidity, precipitation, floods and disasters such as sea-level rise. Anticipated flooding due to sea level rise, storm surge, and precipitation.*
[13] *Melting of tar roads and damage to street pavements, buildings and piped infrastructure.*

2

7	In measuring of surface urban heat islands or land surface temperature, which methods does this Meteorological Department use to monitor in Mombasa, County or Kenya?
8	Is there a Web-Based GIS Climate Resilience Toolkit embedded with ancillary data for population, health, spatial distribution of natural and built-up ecosystems in assessing heat vulnerability as a function of risk exposure, sensitivity and adaptive capacity in Mombasa, County or Kenya? 1= Yes, 2= No, 3=Indifferent
9	How far is the Implementation of the East African Community Protocol on Cooperation in Meteorological Services?
10	Is there a prepared Spatial Climate & Biodiversity Atlas/Booklet for Urban Heat Resilience & Sustainability based on the action strategies from the ratified international frameworks on diversity, environment and climate change? 1= Yes, 2= No, 3=Indifferent
11	Are they any public cooling centres/tents or areas or constructed areas for the public to ensure thermal comfort? 1= Yes (Specify), 2 = No, 3= Indifferent
12	a) How does the Meteorological Department engage in awareness of the urban thermal environment to citizens, politicians, urban planners, urban designers, health experts, environmental officers, fellow climate experts and vulnerable groups, especially urban heat island effect? b) Have there been any urban heat island mapping campaigns in Kenya, especially the coastal region? 1= Yes (Specify), 2 = No, 3= Indifferent
13	Which specific policies and legislations bind the Meteorological Department to mitigate urban heat island effect in Mombasa?
14	a) Which institutions do you think are tasked or should be tasked with enhancing the mitigation of urban heat island effect towards heat resilience and urban sustainable development, and why? b) Are there collaborative efforts in the mitigation of urban heat island effect in Mvita, Mombasa? 1= Yes (Elaborate) 2= Own Resident Efforts (Elaborate] 3= No, 4 = Indifferent.
15	From a meteorological/climatic and surfaces modification point of view, what do can you suggest to enhance the mitigation of urban heat island effect in coastal cities including capacity issues?
16	To what extent do you think the following planning interventions can strive towards heat resilience and sustainability?

3

Mitigation Options (Ideas/Actions from Residents)	Adaptive Capacity Rating[14] on the Intensity of Urban Heat Islands in Mvita, Mombasa		
16a Social Resilience: People, Health and Wellbeing	High= 3	Medium = 2	Low =1
More Conducive Working Conditions and Hours for More Productivity			
Provision of Cooling Centres/Tents/Designed Sheltered Places			
Development of Shaded Bicycle and Pedestrian Corridors			
More Share of Parks and Open Spaces in Urban Neighborhoods			
Constant Supply of Water			
Constant of Supply of Hydrating Foods			
Adequate Awareness/Knowledge and Warnings Based on the Urban Thermal Environment			
16b Economic Resilience: Energy and Expenditures			
Incentivize Installation or Retrofitting of Air-conditioning/Buildings Systems for Energy Efficiency			
Use of Heat Recovery Unit Systems for Ventilation			
Installations of High-Performance Widows and Shading Devices for Windows			
Utility Controls through Rolling Brownouts or Blackouts			
Vegetated Buffering Around and Within Energy Intensive Buildings			
Large Underground Cooling Water Reticulation Systems			
Constant Supply of Electricity			
Use of Renewable Energy Sources in Facades and Buildings Rooftops like Solar Energy			
Use of Energy-Efficient Household Appliances and Lighting			
16c Environmental Resilience: Natural and Built-Up Ecosystems			
More Share of Planted Greeneries around Buildings, Rooftops and Facades			
More Share of Parks and Open Spaces in Urban Neighborhoods			
Green Aeration and Ventilation Corridors			
Shading Effects of Vegetation on Buildings and Shetler Designs			
More Water Cool Sinks and Water Urban Design Treatments/Features/Fountains			
Presence of a Sustainable Stormwater Management System			
Suitable Urban Morphology/Geometry of Urban Canyons			
Wider Open Spaces/Streets for Wind Flows and Breeze Circulations in the City			
Traffic Reduction and Transport Fuel Consumption			
Less Heavy and Cool Choice of Materials & Colours Buildings, Roofs, Pavements and Vehicles			
Enforcement of the Water and Air Quality Regulations by NEMA			
16d Institutional Resilience: Legal/Policy Frameworks, Actors & Funding			
Cooling the Urban Thermal Environment through Revised Zoning and Urban Design			
Spatial Climate & Biodiversity Atlas/Booklet for Urban Heat Resilience & Sustainability			
Revision of the Physical Planning Handbook to Inculcate Urban Thermal Environment			
East African Community Protocol on Cooperation in Meteorological Services Implementation			
Presence of a Long-Term Heat Wave Forecast & Web-Based GIS Climate Resilience Toolkit			
Collaborative Research and Development on Urban Heat Island Effect			
Proper Translation/Enforcement of Policies & Legislations to Heat Resilience & Sustainability			
Undertaking of Urban Heat Islands/Thermal Stakeholder Participation & Mapping Campaigns			
Sufficient Funding on the Climate Change and Urbanisation Impacts on Temperature			
Adequate Capacity Building to all Relevant Stakeholders of the Urban Thermal Environment			
Adequate Awareness/Knowledge/Warnings Based on the Urban Thermal Environment			

16e	Is there anything that you would care to add which I haven't asked on the urban heat island effect in Mvita, Mombasa? 1= Yes (Elaborate), 3= No (Captured Everything)
	Thank You very much for participating in this survey!

[14] *Degree to which they could mitigate the potential for harm by taking action to reduce exposure and/or sensitivity. As such, heat vulnerability can be known and it is a function of the risk exposure, sensitivity and adaptative capacity.*

4

National Environmental Management Authority Officer, NEMA

NATIONAL ENVIRONMENTAL OFFICER/EXPERT GUIDE
[NEMA, Mombasa/Nairobi Office]

University of Nairobi
Faculty of Built Environment and Design
Department of Urban and Regional Planning
BUR 604 Research Project

Date..............................

Study Area: Mvita, Mombasa

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3	a) What percentage/share of urban green areas and distribution[1] of urban green areas does Mvita Sea-Island have? b) Why do you think the situation happens to be like this? c) What would be the likely impact of this situation to temperature/urban thermal environment over the years?
3a	With respect to the intensity of urban heat islands in Mvita Sea Island, Mombasa, what is your opinion of the following risks of heat exposure?

Potential Root Causes	Risk Exposure[2] Rating on the Intensity of Urban Heat Islands in Mvita, Mombasa				
	Very High = 5	High = 4	Moderate =3	Low= 2	Very Low= 1
Increase of Air Temperature due to More Periodic Heat Waves: Extreme Heat Related Weather Day or Monthly Events[3]					
Increase of Surface Temperature/Friction due to Impervious Infrastructural Surfaces and Buildings Dominance[4]					
Large Thermal Heat Capacity Construction Materials that Absorb and Store More Solar Energy[5]					
Limited Share of Distribution of the Urban Green Space Infrastructure and Water Urban Design Treatments[6]					
Changing Shape, Urban Morphology and Land Use of the City[7]					
Release of Waste Heat/Anthropogenic Heat[8] to the Atmosphere: Global Warming					
Limited Air-Conditioning as a Non-Climate Stressor and Cooling Opportunity					

[1] *Name of the Various and Locations the Private/Public Share of Parks and Open Spaces*
[2] *The degree to which people and the things they value could be exposed to climate variation or change or urbanisation effects on temperature;*
[3] *Based on prevalence of calm and clear weather and tropical climate of the island.*
[4] *Increases surface runoff and degradation of water quality through thermal pollution.*
[5] *Like asphalt, concrete, stones, bricks, shingled roofs etc. Leads to increasing warmers days and nights*

1

3b	From an environmental and ecosystem point of view, are there any other causes of urban heat islands in Mvita Sea Island, Mombasa?
4	Using the table below, to what extent do you perceive the following impacts of heat stress resulting from the urban heat islands in Mvita, Mombasa?

Impacts of Heat Stress	Sensitivity Rating[9] on the Intensity of Urban Heat Islands in Mvita, Mombasa				
4a Social Effects	Very High= 5	High= 4	Moderate = 3	Low= 2	Very Low= 1
Share of Heat-Related Illnesses/Morbidity[10]					
Share of Heat-Related Deaths/Mortality					
Share of Outpatient Health Care/Pharmacy Visits					
Share of Hospitalized Patients					
Influence on the Level of Activity and Productivity					
Influence on Various Vulnerable Groups[11]					
Frequency of External Migration to Habitable/Cooler Areas					
4b Economic Effects					
Share of Electricity Energy Demand/Consumption for Cooling					
Frequency of Electricity Brownouts or Blackouts					
Level of Energy Expenditure on Building Cooling Systems[12]					
Share of Demand of Potable Water for Cooling					
Share of Expenditure on Health Services					
4c Environmental Effects					
Worsening of Related Climate Observation Parameters[13]					
Deterioration of Fauna and Green Vegetation					
Deterioration of Indoor and Outdoor Air quality					
Influence of the Level of Food Production and Supply					
Impairment of Water Quality by Thermal Pollution					

[6] *All forms of green-blue vegetation forms across public and private realms for cooling effects: evapotranspiration*
[7] *Due to increasing population density, narrow streets, limited mobility, high-rise buildings and developing urban canyons/enclosures. Leads to poor indoor and outdoor aeration and ventilation due to altered speeds, spread flows and direction of wind patterns.*
[8] *Emissions of air pollutants and greenhouse gases from vehicles, people, animals, air-conditioning units, buildings and industrial facilities*
[9] *The degree to which people and other assets could be harmed or affected by heat exposure*
[10] *The types of heat illnesses are human thermal discomfort; body weakness; dehydration; unconsciousness; cramps; fainting; heat stroke; heat rash and illnesses such as air borne and water borne diseases; chronic diseases; respiratory diseases; cardiovascular diseases and renal diseases, especially to the vulnerable population*
[11] *They include infants, school children, homeless people, laborers, disabled people, street vendors, traffic police, senior citizens and animals experiencing increased risk of heat-related morbidity and even mortality.*
[12] *Electric-energy demand for air-cooling and refrigeration.*
[13] *Increased rate of evapotranspiration, relative humidity, precipitation, floods and disasters such as sea-level rise. Anticipated flooding due to sea level rise, storm surge, and precipitation.*

2

Shortage of Water Supply/Inconsistent Water Supply					
Damage to Construction Materials/Infrastructural Surfaces[14]					
Hazardous Hotspots on Urban Canyons/Enclosures/Clusters					
Poor Ventilation and Wind/Breeze Way Aeration/Circulation					
4d Institutional Effects					
Vulnerable Groups Concerns					
Present Frameworks Concerns					
Awareness Concerns					
Funding Concerns					

5	From environmental and ecosystem point of view, which other impacts of urban heat islands can you mention that occurs within Mvita Sea Island, Mombasa?
6	a) Is NEMA exclusively in charge of mitigating the impacts of the urban thermal environment, herein, urban heat island effect? 1= Yes, 2= No, 3=Indifferent b) Which institutions do you think are tasked or should be tasked with enhancing the mitigation of urban heat island effect towards heat resilience and urban sustainable development, and why? c) Are there collaborative efforts in the mitigation of urban heat island effect in Mvita, Mombasa? 1= Yes (Elaborate) 2= Own Resident Efforts (Elaborate] 3= No, 4 = Indifferent
7	Is there a Web-Based GIS Climate Resilience Toolkit embedded with ancillary data for population, health, spatial distribution of natural and built-up ecosystems in assessing heat vulnerability as a function of risk exposure, sensitivity and adaptive capacity in Mombasa, County or Kenya? 1= Yes, 2= No, 3=Indifferent
8	Is there a prepared Spatial Climate & Biodiversity Atlas/Booklet for Urban Heat Resilience & Sustainability based on the action strategies from the ratified international frameworks on diversity, environment and climate change? 1= Yes, 2= No, 3=Indifferent
9	Are they any public cooling centres/tents or areas or constructed areas for the public to ensure thermal comfort in Mombasa, Kenya? 1= Yes (Specify), 2 = No, 3= Indifferent
10	a) How does NEMA engage in awareness of the urban thermal environment to citizens, politicians, urban planners, urban designers, health experts, environmental officers, fellow climate experts and vulnerable groups, especially urban heat island effect? b) Have there been any urban heat island mapping campaigns in Kenya, especially the coastal region? 1= Yes (Specify), 2 = No, 3= Indifferent

[14] *Melting of tar roads and damage to street pavements, buildings and piped infrastructure.*

11.	Which specific policies and legislations bind this NEMA to mitigate urban heat island effect in Mombasa?
12	From an environmental and ecosystem point of view, what do can you recommend to enhance the mitigation of urban heat island effect in coastal cities including capacity issues?
13	To what extent do you think the following planning interventions can strive towards heat resilience and sustainability?

Mitigation Options (Ideas/Actions from Residents)	Adaptive Capacity Rating[15] on the Intensity of Urban Heat Islands in Mvita, Mombasa		
13a Social Resilience: People, Health and Wellbeing	High =3	Medium = 2	Low = 1
More Conducive Working Conditions and Hours for More Productivity			
Provision of Cooling Centres/Tents/Designed Sheltered Places			
Development of Shaded Bicycle and Pedestrian Corridors			
More Share of Parks and Open Spaces in Urban Neighborhoods			
Constant Supply of Water			
Constant of Supply of Hydrating Foods			
Adequate Awareness/Knowledge and Warnings Based on the Urban Thermal Environment			
13b Economic Resilience: Energy and Expenditures			
Incentivize Installation or Retrofitting of Air-conditioning/Buildings Systems for Energy Efficiency			
Use of Heat Recovery Unit Systems for Ventilation			
Installations of High-Performance Widows and Shading Devices for Windows			
Utility Controls through Rolling Brownouts or Blackouts			
Vegetated Buffering Around and Within Energy Intensive Buildings			
Large Underground Cooling Water Reticulation Systems			
Constant Supply of Electricity			
Use of Renewable Energy Sources in Facades and Buildings Rooftops like Solar Energy			
Use of Energy-Efficient Household Appliances and Lighting			
13c Environmental Resilience: Natural and Built-Up Ecosystems			
More Share of Planted Greeneries around Buildings, Rooftops and Facades			
More Share of Parks and Open Spaces in Urban Neighborhoods			
Green Aeration and Ventilation Corridors			
Shading Effects of Vegetation on Buildings and Shetler Designs			
More Water Cool Sinks and Water Urban Design Treatments/Features/Fountains			
Presence of a Sustainable Stormwater Management System			
Suitable Urban Morphology/Geometry of Urban Canyons			
Wider Open Spaces/Streets for Wind Flows and Breeze Circulations in the City			
Traffic Reduction and Transport Fuel Consumption			

[15] *Degree to which they could mitigate the potential for harm by taking action to reduce exposure and/or sensitivity. As such, heat vulnerability can be known and it is a function of the risk exposure, sensitivity and adaptative capacity.*

Less Heavy and Cool Choice of Materials & Colours Buildings, Roofs, Pavements and Vehicles			
Enforcement of the Water and Air Quality Regulations by NEMA			
13d Institutional Resilience: Legal/Policy Frameworks, Actors & Funding			
Cooling the Urban Thermal Environment through Revised Zoning and Urban Design			
Spatial Climate & Biodiversity Atlas/Booklet for Urban Heat Resilience & Sustainability			
Revision of the Physical Planning Handbook to Inculcate Urban Thermal Environment			
East African Community Protocol on Cooperation in Meteorological Services Implementation			
Presence of a Long-Term Heat Wave Forecast & Web-Based GIS Climate Resilience Toolkit			
Collaborative Research and Development on Urban Heat Island Effect			
Proper Translation/Enforcement of Policies & Legislations to Heat Resilience & Sustainability			
Undertaking of Urban Heat Islands/Thermal Stakeholder Participation & Mapping Campaigns			
Sufficient Funding on the Climate Change and Urbanisation Impacts on Temperature			
Adequate Capacity Building to all Relevant Stakeholders of the Urban Thermal Environment			
Adequate Awareness/Knowledge/Warnings Based on the Urban Thermal Environment			

13e	Is there anything that you would care to add which I haven't asked on the urban heat island effect in Mvita, Mombasa? 1= Yes (Elaborate), 3= No (Captured Everything)

Visual Survey Checklist

VISUAL SURVEY CHECKLIST

[Observation]

University of Nairobi
Faculty of Built Environment and Design
Department of Urban and Regional Planning
BUR 604 Research Project

Date..............................

Study Area: Mvita, Mombasa

Title of Master's Research Project: Planning Implications of Urban Heat Island Effect in Mombasa

Declaration: This research is being carried out purely for academic purposes. All information provided in this visual survey checklist is confidential.

Item No.	Observation Remarks/Take Photographs (state/types/conditions/capacity/use/services)	
1.	Urban Impervious Surfaces *Streets/pavements/roofs/ façades/walls/parking lots* *Asphalt, concrete, stones, bricks, shingled roofs, permeable surfaces/vegetation/soil, cool (white coated) roofs, cool (foam coated/sprayed polyurethane) roofs, cool pavements, built-up roofing systems made up of base sheet layers, fabric reinforcement layers, and protective surface layers, solar parks/panels.* *[To be Primarily Supported by Secondary Data]*	
2.	Urban Green Space Infrastructure *Green-blue vegetation forms across public and private realms: urban forests, street trees, open parks and gardens, waterways and habitat corridors such as mangrove, the active recreation areas, green roofs, walls and facades, water sensitive urban design treatments and other vegetated streetside treatment like shading of streets.* *[To be Primarily Supported by Secondary Data]*	

3.	Anthropogenic/Human Activities and Developments *Types of land uses (land use plan) especially residential, commercial, industrial and transport/vehicular; artificial cooling (air-conditioners); electricity usage, spatial distribution and connectivity* *[To be Primarily Supported by Secondary Data]*	
4.	Urban Geometry/Morphology of the City *Widths and heights of streets and buildings respectively, urban canyons/ enclosures, ventilation corridors, stormwater management/ water drainage systems* *[To be Primarily Supported by Secondary Data]*	
5.	Weather and Climatic Conditions *Near-surface average air temperature, humidity, solar radiation, cloud cover, precipitation, wind speed and direction and atmospheric pressure* *Sea-level rise, submergence, floods* *[To be Primarily Observed by Secondary Data]*	
6.	Natural Geographical Landmarks *Ground elevation, terrain, contour, presence of water bodies, higher grounds.* *[To be Primarily Observed by Secondary Data]*	

Thank You very much for participating in this survey!

Participant Information Sheet

PARTICIPANT INFORMATION SHEET

[Key Informants & Households]

University of Nairobi
Faculty of Built Environment and Design
Department of Urban and Regional Planning
BUR 604 Research Project

Date..............................

Study Area: Mvita, Mombasa

Title of Master's Research Project: Planning Implications of Urban Heat Island Effect in Mombasa

Declaration: This research is being carried out purely for academic purposes. All information provided in this research study is confidential.

You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

Abstract of the study

Empirically, the spotlight on declining green vegetation coverage as built-up landscapes expands in towns and cities following urbanization, portends the hazard of heat stress on the human life as well as environment. Coupled by higher magnitudes of land and ocean temperatures as a consequent of climate change, this phenomenon is acutely felt more in urban built-up areas than their proximate suburban areas and countrysides, hence, the term Urban Heat Island Effect (UHIE). In spite of its advantage of warming winter/cold nights and seasons, UHIE is overshadowed by multiplicities of increased risk of heat-related stress on the human health and comfort, increased energy consumption, impaired water quality through thermal pollution and elevated emissions of air pollutants and greenhouse gases (GHGs). Towards heat resilient and sustainable coastal cities especially of the tropical Sub-Saharan Africa countries, sadly, little is known to influence and prioritize the planning for having cooler cities while they are rapidly-urbanizing. The reverberation effects of urbanization on the natural landscapes leaves out to wonder what can be done about it in cities and what is the scale of this impact on temperature that is profoundly higher in their urban centers than outlying areas. Therefore, to adequately address the gravity of this situation, planning for cooler cities has been increasingly of concern to urban planners world-wide, given the cumulative intensities of urban heat islands (UHIs), currently overlooked in the coastal cities of the tropical Sub-Saharan Africa. In essence, there has been an amplified appreciation of the social, economic, environmental as well as institutional resilience to mitigate the UHIE. Using Mvita sea-island, Mombasa, Kenya as case study and both community involvement and remote sensing and GIS and as vital methodological approaches — the primary aim of this study is to examine the planning implications of urban heat island effect in coastal cities. A subsidiary aim of this research study is to propose planning interventions that can enhance the mitigation of urban heat island effect in Mombasa.

Objectives of the study

To map the surface urban heat islands in Mombasa.
To examine the causes of urban heat islands in Mombasa.
To assess the social, economic, environmental and institutional effects of urban heat islands in Mombasa.
To propose planning interventions for enhancing the mitigation of urban heat island effect in Mombasa.

Justification and significance of the study

The rationale of this research study is derived from the need to add knowledge and fill policy gap on UHIE and its planning implications in the rapidly urbanizing coastal cities of which are often overlooked in the coastal cities of the tropical Sub-Saharan Africa. It also seeks to enhance the mitigation of UHIE which has been lacking influence as well as prioritization in many of their urban policy domains earlier designed and planned by the colonial governments and independent city governments in realizing of heat-resilient and sustainable city systems.

The significance of the study lies within proposing the planning interventions for enhancing the mitigation of urban heat island effect in Mombasa. In essence, the broader planning implications proposed in the context of social, economic, environmental and institutional resilience needs to be inculcated in natural and built-up ecosystems when planning for cooler coastal cities of the tropical Sub-Saharan Africa.

1

Why have I been invited to participate?

You are being invited to participate in the research because you are considered as having vital information and opinions relevant to the objectives of the study, especially on the awareness and understanding the urban thermal environment, herein, the urban heat island effect. Consequent to this, could inform and guide in the planning for cooler coastal cities.

Do I have to take part?

It is up to you to decide whether or not to take part. As a key informant, if you decide to take part you will be given this information sheet to keep and be asked to sign a consent form. As a resident, if you consent to take part your name will be collected and stored within the Web Kobo Toolbox Repository. Nonetheless, you are still free to make a withdraw at any time, without giving a reason.

What are the possible disadvantages and risks of taking part?

This 30-minutes or less survey has no potential risk to participants.

What are the possible benefits of taking part?

It aids in the awareness and understanding of the urban thermal environment, the urban heat island effect that is caused by the dual consequences of urbanization as well as climate change. The expectations are to enhance heat resilience and sustainable coastal cities from the planning interventions through mitigation of the urban heat island effect.

Will what I say in this study be kept confidential?

This research study will comply with The Data Protection Act, 2019 of Kenya. Privacy will be protected by ensuring that as a respondent your information remains confidential. The data generated by the study will adhere with University of Nairobi's policy on Academic Integrity. It will be kept securely for academic purposes within university's electronic system.

What will happen to the results of the research study?

As the principal investigator, I will disseminate and present the findings for examination at the Department of Urban and Regional Planning. If, well received, I will generate two journal articles from this research study.

Organizing and funding the research

This is research is being conducted by me as a Master's researcher in the Department of Urban and Regional Planning, University of Nairobi, Nairobi, Kenya. The research is open to any financial support from institutions.

Approval of the Study

This research has approved by the Department of Urban and Regional Planning, University of Nairobi, Nairobi, Kenya. I have been issued with a research permit by the Chair of the Department. Kindly contact durp@uonbi.ac.ke

Contacts of Supervisory Team for Further Information

If you have any further questions regarding this research, please contact my supervisor on the addresses below: -

Supervisor/Lecturer,
Dr. Munyua Mwaura
Department of Urban and Regional Planning,
Faculty of Built Environment and Design
University of Nairobi
amwaura@uonbi.ac.ke
+254 72272 4288

Supervisor/Lecturer
Dr. Philip Olale
Department of Urban and Regional Planning
Faculty of Built Environment and Design
University of Nairobi
polale@uonbi.ac.ke
+254 72522 8091

Thank you very much for taking time to read this information sheet.

Principal Investigator
Mark Mbatha Mutua
Department of Urban and Regional Planning
Faculty of Built Environment and Design
University of Nairobi
markmbatha@students.uonbi.ac.ke
+254 74230 6870

The field work would take place within March 28th and April 2nd, 2022

2

Anonymity and Consent Form

ANONYMITY AND CONSENT FORM

[Key Informants]

University of Nairobi
Faculty of Built Environment and Design
Department of Urban and Regional Planning
BUR 604 Research Project

Date..............................

Study Area: Mvita, Mombasa

Title of Master's Research Project: Planning Implications of Urban Heat Island Effect in Mombasa

Declaration: This research is being carried out purely for academic purposes. All information provided in this research study is confidential.

You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

Name, position and contact address of Researcher

Mark Mbatha Mutua, Master's Researcher. Principal Investigator of the Study. markmbatha@students.uonbi.ac.ke +254 742306870. Department of Urban and Regional Planning, Faculty of Built Environment and Design. University of Nairobi

Please Tick Box

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason. ☐

3. I agree to take part in the above study. ☐

	Yes	**No**
4. I agree to the interview being audio recorded.	☐	☐
5. I agree to the use of anonymized quotes in publications.	☐	☐
6. I agree that my data gathered in this study may be stored (after it has been anonymized) in a specialized data centre and may be used for future research.	☐	☐

______________	______________	______________
Name of Participant	Date	Signature
Mark Mbatha Mutua		
______________	______________	______________
Name of Researcher	Date	Signature

Department of Urban and Regional Planning, University Research Permit

University of Nairobi

Department of Urban and Regional Planning

Faculty of the Built Environment and Design

P.O. Box 30197, 00100 GPO Nairobi, Kenya

e-mail:durp@uonbi.ac.ke

28th March, 2022

TO WHOM IT MAY CONCERN

RE: <u>RESEARCH PROJECT – MARK MBATHA – B63/37815/2020</u>

This is to confirm that Mark Mbatha, is a M.A (Planning Student) in the Department of Urban & Regional Planning, University of Nairobi.

As part of the Masters of Arts in Planning programme, the students are required to acquire training in data collection, analysis and report writing in the field of Urban and Regional Planning.

We wish to request you to allow Mark to access your Institution/neighbourhood in order to collect data for his research project titled "***Planning Implications of Urban Heat Island Effect in Mombasa***".

Any assistance accorded to him will be highly appreciated.

University Of Nairobi
Faculty of Built Environment & Design
Department Of Urban And Regional Planning
CHAIRMAN
P.O. Box 30197 - 00100 Nairobi

<u>DR. FRIDAH W. MUGO</u>

CHAIR - DEPARTMENT OF URBAN & REGIONAL PLANNING

County Government of Mombasa, Research Permit from County Secretary

COUNTY GOVERNMENT OF MOMBASA
RECEIVED
30 MAR 2022
OFFICE OF THE COUNTY SECRETARY
& HEAD OF PUBLIC SERVICE
P. O. Box 90440 - 80100, MOMBASA

Mark Mbatha Mutua
markmbatha@students.uonbi.ac.ke
(+254) 742306870

March, 30, 2022

To: The County Secretary,
County Government of Mombasa,

RE: PERMISSION TO CARRY OUT MASTER'S RESEARCH PROJECT IN MOMBASA

I am writing to apply for permission to carry out my Master's Research Project in Mombasa. My name is Mark Mbatha Mutua, a finalist Master's student at the Department of Urban and Regional Planning, University of Nairobi. My research project entitled is **Planning Implications of Urban Heat Island Effect.**

I'm required to acquire data and information through household administration of questionnaires and interviewing of key informants from 30th March 2022, to 3rd April, 2022. The latter are, namely; County Physical Planning Officer, Architect/Urban Designer, Environment Officer, Climate Expert and Public Health Officer. The purpose is purely for academic so that I can qualify to graduate this September, 2022.

Thank you for taking time to review my application worthiness.

Yours Sincerely,

Mark Mbatha Mutua

Enclosure: University of Nairobi Research Permit