INFLUENCE OF URBAN FORM ON CLIMATE CHANGE VULNERABILITY IN THE CITY COUNTY OF NAIROBI

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Influence of Urban Form on Climate Vulnerability in the City County of Nairobi

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Signature…………..……………………. Date……………………….................

Sunday Julius Abuje

This thesis has been submitted for examination with our approval as the university supervisors.

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DEDICATION

This work is dedicated to my son Liam Dezi Abuje.

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I remain solely responsible for all errors and omissions.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAT_n	Average Annual Minimum Temperatures
AAT_x	Average Annual Maximum Temperatures
CBD	Central Business District
DEM	Digital Elevation Model
HAT	Highest Annual Temperatures
IPCC	Intergovernmental Panel on Climate Change
IUET	Integrated Urban Ecosystems Theory
JICA	Japan International Cooperation Agency's
JKIA	Jomo Kenyatta International Airport
KALRO	Kenya Agricultural and Livestock Research Organization
KNBS	Kenya National Bureau of Statistics
LC	Landcover
LAT	Lowest Annual Temperatures
NDVI	Normalized Difference Vegetation Index
OSN	Open Space Network
RCMRD	Regional Centre for Mapping of Resource for Development
SPSS	Statistical Package for Social Sciences
UHI	Urban Heat Island
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

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ABSTRACT

Urban form has the potential to influence urban climate. This in turn affects climate vulnerability. Urbanization characteristics pertinent to this relationship include imperviousness, reduced concentration of vegetation, increased density of built-up areas, and a socio-economically vulnerable population. The City County of Nairobi is rapidly urbanizing more reactive than through anticipatory physical planning regime. Together with the city's unique biophysical and socioeconomic dynamics, Nairobi has remained susceptible to climate related hazards. The objectives of the study included examining the evolution of Nairobi's urban form, the climatic trends and patterns, and the relationship between urban form and climate. The study hypothesized that urban form significantly influences climate vulnerability. The survey used a descriptive case study design for the period between 1988 and 2018. The main variables were urban form, socioeconomic characteristics, and climate. The elements of urban form were landcover, soil, elevation, slope, and Normalized Difference Vegetation Index. The parameters of climate were average annual maximum, average annual minimum, highest annual and lowest annual temperatures, and rainfall. With the unit of analysis as sublocations, data were collected using observation checklists, self-administered questionnaires, and archival review. Data analysis methods included cross-tabulation, change detection analysis, time-series analysis, correlation, and regression. Hypothesis was tested at 95% confidence interval. The findings revealed an evolving urban form and changing climatic patterns. Urban form evolution manifested as 147% increase in built-up areas, 46% reduction in vegetation cover, and a 21% reduction in the Normalized Difference Vegetation Index. With the current trends held constant, 2048 projections revealed 21% reduction in open space, 60% reduction in Normalized Difference Vegetation Index and 44% increase in Built-Up Area. Climatic trends and patterns showed a 1.5℃ rise in average annual minimum and lowest annual temperatures between 1988 and 2018 with 5% - 14% increase in the minimum and extreme temperature values for the year 2048. The correlation and regression analyses showed, in descending order, Normalized Difference Vegetation Index, Forest and Built-Up Area as the influencers of climate. These relationships led to varying levels of flooding and thermal stress vulnerability at the sublocation level. Ninety five percent of the sublocations showed moderate to very high thermal stress vulnerability while only 13% showed low vulnerability to flooding. The study findings strongly by supported the Integrated Urban Ecosystems Theory and advocated for the triangulation research approach in climate vulnerability assessment studies. It recommended an overall strategy of ecosystem-based urban planning and development to take advantage of ecosystem services offered by the green urban systems. These would be realized through distributive open space planning, green and blue system planning.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Climate change risks all life on earth. The world has experienced conspicuous climatic anomalies in the recent past, mostly linked to a changing climate and variability. Climate anomalies threaten all countries irrespective of the level of development. For instance, between 2007 and 2009, the United States of America (U.S.A.) underwent the worst floods since 1993, Kenya and China had the worst drought in 20 years, and 50 years respectively and Southern Australia had the highest temperatures in 70 years (McMullen & Jabbour, 2009). Reid et al. (2009) further argues that the change is inevitable as we are beyond the tipping point. Even if all emissions ceased, climate change shall occur, and its impacts will be felt for time to come.

Notwithstanding, the countries exhibiting the highest vulnerability are in the developing world (Hoornweg, 2012). For example, in Africa, the Intergovernmental Panel on Climate Change, (IPCC; 2007a) estimated that in the year 2020, over 75 million people were affected by climate change. The average temperature increase is expected to be one and a half times higher than global averages (Cavan et al., 2014). The most likely to be afflicted are the poorest and marginalized communities because of their vulnerable geographic locations and low adaptive capacity (Reid et al., 2009).

Urban areas are at the core of climate action since they host large population densities, contribute to and are affected by climate anomalies (UN-Habitat, 2011; Solecki et al., 2015; Bai et al., 2018). This is besides the challenges of urbanization in compounding environmental degradation (Dame, Schmidt, Müller, & Nüsser, 2019). Urban areas' contribution to climate change includes the release of Green House Gas (GHG) emissions, hosting of the most vulnerable populations and reduction of carbon sinks (Solecki et al., 2015; United Nations ; 2015). Nonetheless, they remain susceptible to climate change and variability because of the manifestations of urbanization (Grimmond et al., 2010; Zhou, Leng, Su, & Ren, 2019).

Urbanization has 2 facets: a rise in urban populace and land-use changes. The global population in urban areas was 30% in 1950, 54% in 2018, and projected to reach 66% by 2050 (UN, 2015). Accelerated urbanization has contributed to a rise in urban land area by a factor of five since the mid-20th Century. This has led to urban sprawl (Yuan et al., 2019).

The rates of urbanization are highest in low and middle-income countries mostly in Africa, parts of Asia and Latin America. Their rapid growth has occurred over a brief time frame (Hoornweg, 2012). For instance, up to the 1900s, Africa only had two major cities but between 1950 and 2000, this number grew to 37. In Asia and Latin America, the growth of the number of cities rose from 28 to 192 and 7 to 51 respectively in the same period (Satterthwaite, Huq, Pelling, Reid, & Lankao, 2007a).

The traditional driver of urbanization has been rural-urban migration in search of employment opportunities (Jayawardhan, 2017). However, there is an emerging trend of climate change driven urbanization where people migrate from rural zones to avoid the impacts of climate change such as drought (Wilkinson, 2016).

Economic rather than social and environmental goals have shaped the urban surroundings. All urban neighbourhoods have in response to urbanization, modified their environments (Satterthwaite, Huq, Pelling, Reid, & Lankao, 2007b). These modifications include topographical changes, clearing of vegetation, paving of surfaces, and location of structures that then result in precise geometric patterns (Gill, Handley, Ennos, & Pauleit, 2007). Forests, grasslands and streams are replaced with deficient natural environments (Whitford, Ennos, & Handley, 2001; Hough, 2004; Yao, Cao, Wang, Zhang, & Wu, 2019). This affects the climate, hydrology, and biodiversity (Whitford et al., 2001). It alters biodiversity typologies resulting in a wide variety of native and foreign species and habitats (Müller, Ignatieva, Nilon, Werner, & Zipperer, 2013).

The spatial configuration of urban areas, their physical structure, utilization and development of land influence how they react to climatic parameters and in part contributes to a unique urban climate (Stead, 2014; Environmental Protection Agency, 2008a; Bridgman, Warner, & Dodson, 1995). For instance, the urban buildings' complex geometry influences increased heat storage from concrete surfaces. The conversion from soil and vegetation to impervious materials decreases latent heat fluxes (Oke, 1988; Erell, Pearlmutter, & Williamson, 2012). It also leads to a gain in solar radiation absorption because of the lower albedo of urban surfaces and reduced wind speeds caused by the rougher urban fabric (Oke, 1995). The solar gain alongside other factors leads to the Urban Heat Island effect (Fokaides, Kylili, Nicolaou, & Ioannou, 2016).

Urbanization also alters hydrological processes with a higher probability of precipitation in a city because of urban-modified atmospheric gases which increase the condensation nuclei (Lu et al., 2019). Reduced vegetation cover results in less evapotranspiration and rainfall interception. Greater surface sealing decreases infiltration thereby increasing speed, volume and appearance time of runoff (Gill et al., 2007). This enhances the risk of both riverine flooding and sewer overflows (Bridgman et al., 1995).

Climate change causes occurrences of extreme weather events such as prolonged and heavy rainfall, longer drought, cold waves and heat waves (Hoornweg, 2012; Henson, 2011; Konisky, Hughes, & Kaylor, 2016). The interactions between urbanization, unique urban climate and climate change contribute to undermining sustainable development since the ecosystem services control household air and water (Bolund, 1999; McDonald, Marcotullio, & Güneralp, 2013). This is shown by a study that claimed that 29 largest cities in the Baltic Sea region required ecosystem support of areas at least 500 – 1000 times larger than the area of the cities themselves (Folke, Jansson, Larsson, & Costanza, 1997). The dynamics that occur in urban areas influence rural areas through the ecological footprint (Lambin & Geist, 2008). Urbanization determines how climate manifests in urban areas and the ways urban dwellers experience the impacts.

1.2 Problem Statement

Rapid urbanization comes with the conversion of urban surfaces from permeable vegetated zones to built-up impervious surfaces. Global statistics quantify the increase of impervious surfaces at 50% (Gong et al., 2020). The reduced vegetation and increased imperviousness expose cities to environmental degradation and unique urban climatic patterns.

This situation is further aggravated by climate change and localized climate variability. Climate change and variability manifest as extremes of precipitation and temperature. These interact with the urban fabric at the levels of landuses and landcover. Therefore, inadequacies in one system confound the climate-related hazards. Large vulnerable urban population in the developing world worsens the risk.

Kenya is experiencing an increase in average annual minimum temperatures, reduced rainfall in the long rainy seasons and increased rainfall in the short rainy seasons. These changes can be traced back to the 1960s. Nairobi, Kenya's capital, is the largest and among the fastest-growing cities in East and Central Africa. It has similar characteristics to other cities in the developing world such as rapid population growth, increasing vulnerable urban population, increasing impervious surfaces, and reducing vegetated areas.

Nairobi is experiencing instances of flooding and increase in minimum temperatures. The rapid population growth has led to urban sprawl and infill development in lower-density areas such as Upper Hill, Kilimani and Lavington neighbourhoods. Impervious paving and structures have replaced previously vegetated surfaces. Buildings materials within the Central Business District (CBD) have changed over time from concrete to glass facades that reflect solar radiation thereby increasing air temperatures. The impermeable surfaces increase urban temperatures, reduce stormwater percolation and limit evapotranspirative cooling. For instance, the city has experienced an average increase of 2 ºC in annual minimum temperatures between 1960 and 2000 (Makokha & Shisanya, 2010). Surface sealing has resulted in about 43% chance of flooding every two years (Muli, 2011).

Notwithstanding the climatic challenges, there are global gaps in practical and theoretical approaches to managing climate change. From the practical perspective, the focus has been on coastal cities at the expense of inland cities which also host enormous populations. The theoretical deficiency is the lack of a strong linkage between urban form and the role played by ecosystems in managing climate and climate change impacts.

Current studies, reports, and policies on local climate impacts and adaptation have identified general impacts and vulnerabilities that affect the entire country. Those that have looked at specific sectors have concentrated on agriculture and tourism. Investigation of climate vulnerability and adaptation in urban areas by among others Awuor, Orindi, and Adwera, (2008) and Opijah, Mukhabana and Ng'ang'a (2007) have focused on coastal towns or identified the relationship between human activities and changing urban climatic trends.

Kenya's disaster management system faces challenges of inadequate information and data, legal and institutional frameworks, human capacity, equipment, and poor integration. The Kenya National Adaptation Plan has also identified a gap in the enabling policy for adaptation in the sector of population, urbanization, and housing. Planning in Nairobi has mostly been reactive. For instance, the current city masterplan was due for review and revision in the year 2000. Curiously, the succeeding masterplan which was completed in 2014 has not been gazetted for implementation.

The close link between regional climate, Nairobi's climate variability and urbanization patterns are expected to intensify the city's vulnerability. The improvement of urban climate resilience requires a clear understanding of the nature, location, and magnitude of vulnerability. The study sought to investigate how Nairobi's urban form is influencing its climate.

1.3 Purpose of the Study

The empirical findings of the study, gained through case study survey, are useful in understanding the relationship between urban form development and climate vulnerability, thereby contributing to sustainable development.

1.4 Research Objectives

1.4.1 Main Objective

To investigate the influence of Nairobi's urban form on climate change vulnerability between 1988 and 2018.

1.4.2 Specific Objectives

The specific objectives of this study were:

(i) To examine the evolution of urban form within the City County of Nairobi between the years 1988 and 2018.

(ii) To assess climate trends and pattens in the City County of Nairobi between the years 1988 and 2018.

(iii) To determine the relationship between urban form and climate change in the City County of Nairobi between the years 1988 and 2018

(iv) To develop a climate adaptation strategy for the City County of Nairobi.

1.5 Study Hypothesis

With the relationship between urban form and climate expressed in Equation 1.1, the null hypothesis (H_o [Equation 1.2]) portends that urban form does not significantly influence climate change vulnerability in the City County of Nairobi. The alternate hypothesis (H_a [Equation 1.3]) portends that urban form influences climate change vulnerability in the City County of Nairobi.

$$CV = a0 + \beta_1 BuiltUp\ Area + \beta_2 Forest + \beta_3 Open\ Space + \beta_1 NDVI + e \quad (1.1)$$

Where:

- CV is climate vulnerability.
- a is a constant
- NDVI is Normalized Difference vegetation Index.
- e is error.

$$H_o: \beta = 0\ for\ all\ regression\ coefficients\ of\ climate \quad (1.2)$$

$$H_o: \beta \neq 0\ for\ at\ least\ one\ regression\ coefficient \quad (1.3)$$

1.6 Study Significance

Previous studies in Kenya have focused on nationwide climate vulnerability. This leaves a gap in medium-scale climate adaptation recommendations. This study meets that gap by looking at climate change vulnerability at the smallest administrative unit (the sublocation). At this scale, the recommendations range from small to medium scale and therefore easy to implement. Implementations can be at the household, community, neighbourhood, or city scale.

As a developing country, Kenya experiences a deficit in research outputs focused on solving climate-related challenges as pointed out in Sessional Paper no. 3 of 2016. This policy paper advocates for increased research and development on climate change adaptation and mitigation. The study focuses on adaptation in urban areas as one of the main climate action initiatives significant for the country's development.

The study exposes the role of both Geographic Information Systems (GIS) and census statistics in environmental and physical planning. It also explores diverse thematic areas of urban ecology, urban planning and design and climatic modelling. The review of various cross-cutting themes assists in the generation of recent knowledge for academia and theoretical approaches. With a philosophical approach of positivism, the empirical data will add to the pool of information on climate change and metropolitan planning issues.

Among the gaps and limitations identified are the coverage and consistency of meteorological data for the city of Nairobi. Further planning for extensive and efficient collection, storage, and analysis of climatic statistics is advocated for. This will aid in continuous analysis of vulnerability and a review of adaptation approaches based on established vulnerabilities.

1.7 Study Justification

Climate change is leading to an increased occurrence of disasters and hazards. For instance, Nairobi has experienced an alternating flood and drought events and a shift in established climatic patterns that affect human comfort. The study's recommendations on adaptation are ideal in increasing the resilience of both the urban dwellers and urban infrastructure.

The country is reviewing policy, institutional and legal frameworks to be in tandem with the Constitution of Kenya 2010. This review is geared towards aligning the policies to new tenets of development and the shift into a devolved system of governance. This is, therefore, an opportune time to mainstream climate change adaptation strategies into different policy, institutional and legal frameworks.

The study seeks to fill a gap that was identified by the Kenya National Adaptation Policy as the lack of enabling policy, especially in the population, urbanization, and housing sectors. This is through the recommendations on urban planning and development models sensitive to the effects of climate change in urban areas and climate change adaptation mechanisms.

The solution to urban problems requires the collaboration of various decision-makers: urban managers, planning professionals, sociologists, architects, and politicians. The study takes a comprehensive approach. The combination of biophysical and socioeconomic characteristics of urban areas covers all aspects of urbanization.

The City County of Nairobi hosts about a tenth of the country's population. Most of this population is classified as vulnerable even before the consideration of climate change due to the geographic and socioeconomic structure that exposes them to multiple risks. Urban dwellers make up a critical population whose resilience is important.

It is argued that the next global conflict will be about water. Climate change affects the distribution of water thereby influencing rapid rural-urban migration. This increases the vulnerable urban populations. Such distress has the potential to cause social and political conflict. The adaptation approaches recommended by the study would improve the resilience of urban areas, minimizing the chances of social and political conflict.

Climate-related disasters have been on the rise and causing immense damage to property, livelihoods, and loss of life. Locally it is posing challenges to the attainment of Kenya's Vision 2030; specifically, the economic and social pillars by compromising economic development and sustainable environment for social justice (Government of Kenya, 2016c). This study identifies the location, nature, and magnitude of vulnerabilities and recommends precise urban infrastructure adaptation and resilience thereby protecting the foundations of economic development.

The most climate-vulnerable communities or populations are also the most at risk socioeconomically. Their empowerment requires a clear identification of their vulnerabilities. The study investigates the socioeconomic vulnerabilities of urban communities in Nairobi and recommends adaptation approaches that would help reduce the vulnerability of these social groups.

Urban areas are argued to be major contributors to climate change but also opportune centres for innovation on climate change action technologies. This study provides a basis for the development of such innovations as it outlines area-specific vulnerabilities for the city of Nairobi. This allows for the generation of very distinct technological approaches that would be used in solving specific challenges facing individual communities or locales as advocated for in the Sessional Paper No. 3 of 2016.

The Constitution of Kenya 2010 guarantees citizens a clean and healthy environment and the right to life among other rights under the bill of rights. Increased vulnerability to flooding and extreme temperatures exposes people to hazards that compromise those rights. The recommendations of this study would, therefore, help in protecting the rights of urban dwellers. They would also assist in environmental protection through the adoption of environmentally sensitive approaches to development.

The study shall provide a basis for the revision and improvement of policy, legal and institutional frameworks for climate action in Nairobi and other urban areas. It shall also provide a baseline for future studies in climate change vulnerability in Nairobi. The baseline data can also be used in future development of vulnerability indices for the city and the country.

1.8 Study Assumptions

i. Climate change is past the tipping point as noted by Reid et al., (2009). As such, the climate change impacts will be felt even if mitigation is undertaken. Climate change adaptation is therefore not in vain. In addition, climate change adaptation approaches can also aid in general climate amelioration in case climate change is fully mitigated.
ii. The city is a hotspot for environmental consequences of human activities and the emerging challenges whether global or regional are best mitigated locally (Hultman, 1993). The location specific approaches to urban resilience are therefore more effective than global or regional approaches.
iii. Direct observation of the urban form parameters for ground truthing offered no inference, and as a result, minimized the possible error associated with the classification method of determining landuse (Haynes & O'Brien, 2003). However, this was only applicable to the 2018 epoch which was the basis for vulnerability assessment.
iv. The time series and forecasting method assumes that the recorded patterns will continue without any drastic changes outside the noted upper and lower confidence levels (Goodchild, 2005). The projected urban form and climate trends between 2018 and 2048 follow this argument.
v. The relationship between urban form and climate as well as the relationship between urban form and vulnerability is linear. This assumption is based on theory as argued by Mahmood et al., (2010).

1.9 Scope and Limitations of the Study

1.9.1 Spatial-Temporal Scope

The geographical scope of the study was the City County of Nairobi as delineated by the boundary of the City County of Nairobi County. The unit of analysis adopted was the administrative sublocation boundary. The duration of interest was a 30 year period between 1988 and 2018.

1.9.2 Theoretical Scope

The theory of good urban/city form and the Integrated Urban Ecosystem Theory (IUET) formed the theoretical underpinning of the study. The theory of good urban form guided the operationalization of urban form and its elements. Key constructs of the study were urban biophysical character, urban systems, and ecosystems. The key variables included Nairobi's biophysical, climatic, and socio-economic characteristics.

1.9.3 Methodological Scope

The study was a descriptive case study research. It used both qualitative and quantitative approaches. The positivist and empiricist philosophical school of thought guided this combination.

1.9.4 Study Limitations

I. The distribution of weather stations around the city is not even. For instance, the central business district expected to have a unique micro-climate does not have a weather station. The interpolation approach is limited in its representation of the climatic patterns of Nairobi.

II. Climatic data had gaps in some stations for certain months and years of interest. This was reduced by increasing the number of epochs from 10 years to 5 years to establish non-biased trends.

III. The findings and recommendations of the study are not open to generalization due to the case study research design and purposive sampling undertaken.

1.10 Study Outline

The study is organized into five chapters. The first chapter, introduction, provides a background to the study that highlights aspects of the key variables. It also states the problem, the research objectives, hypothesis, justification, significance, assumptions, limitations, delimitations, and scope of the study. The second chapter, literature review, entails a comprehensive critical review of literature on the topics of urban planning and form, urban climate, climate change vulnerability assessment, and climate change adaptation. The theoretical and conceptual frameworks discuss the evolution of concepts and their operationalization, respectively. The third chapter, research methodology, presents the study area, research approach, design, methods, techniques, data selection and processing procedure. It concludes with approaches to ensuring data reliability and validity. Chapter four details the study results and discussion. It explains the findings while referring to global approaches and the reviewed literature. It also analyses the opportunities of urban resilience and adaptation in Nairobi. The final chapter concludes the study and makes recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter critically reviews the literature on four key components: urban form and climate, climate change, vulnerability assessment, and adaptation approaches. The study discusses the relationship between urban form and climate. The chapter then concludes with a review of the key theories pertinent to the generation of concepts and a proposed conceptual framework based on the concepts.

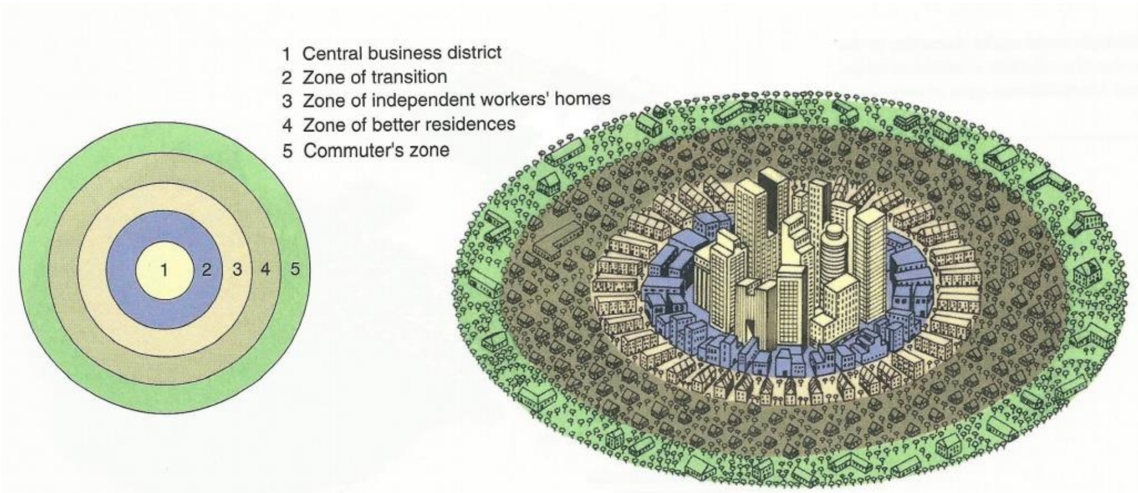
The chapter addresses three key gaps. First is that climate change response studies have focused on larger sectoral aspects such as agriculture, tourism, and health (Government of Kenya, 2010; Government of Kenya, 2016). This omits medium and small-scale aspects such as urban development. Secondly, research on the effects of climate change in urban areas has been focused on coastal urban areas (Awour, Adwera & Orindi, 2008; Njoroge, 2015). This leaves a major gap on large inland urban areas such as Nairobi that are also experiencing the impacts of climate change. Third, Nairobi's urban plans from the 1898 Railway town to 2014 Nairobi Integrated Urban Development Master Plan either lack or have minimal consideration of climate response strategies (JICA & JST, 2014).

2.2 Urban Planning Models and Form

2.2.1 Historical Urban Planning Models and Patterns

Urban areas start spontaneously or as planned human settlements. In both cases, they evolve through an urbanization process based on various physical, environmental, political, and economic parameters. This process gives rise to urban settlements that in most cases, Rubenstein (2016) argues, are distinguished by social and physical characteristics such as large size, social heterogeneity, and high density. Sociologists, economists, and geographers have over time developed models that attempt to explain the distribution of the various social and economic structures within an urban area. Some models proposed by the Chicago School include the concentric zone, the sector, and multiple nuclei models (Rubenstein, 2016; Hall & Barrett, 2018; Simmonds, 1988).

In 1923, Burgess developed the concentric model. It was the first to explain the distribution of different social groups within urban areas (Rodrigue, Comtois, & Slack, 2013). It argued that the city grows from the centre outwards in concentric rings (Figure 2.1) of varying sizes and widths (Rubenstein, 2016; Burgess, 2008).

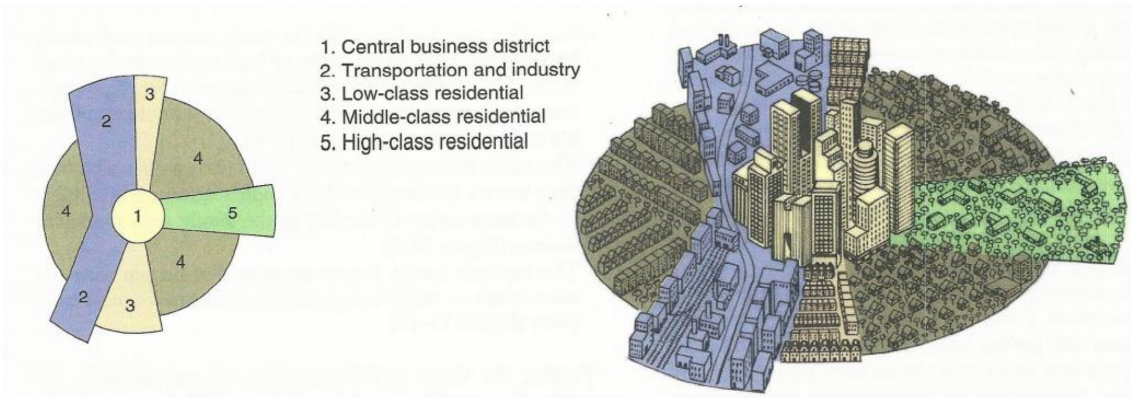


Source Rubenstein (2016)

Figure 2.1: The Concentric Model

This model has faced criticisms and modifications. For instance, it is argued to be deficient in outlining how the settlement process responded to the physical characteristics and constraints of the land as it assumed among other things a uniform land surface (Dear & Flusty, 1998). As a result of such criticisms, it gave rise to the Sector and the Multiple Nuclei Models (Gonzalez & Medina, 2014).

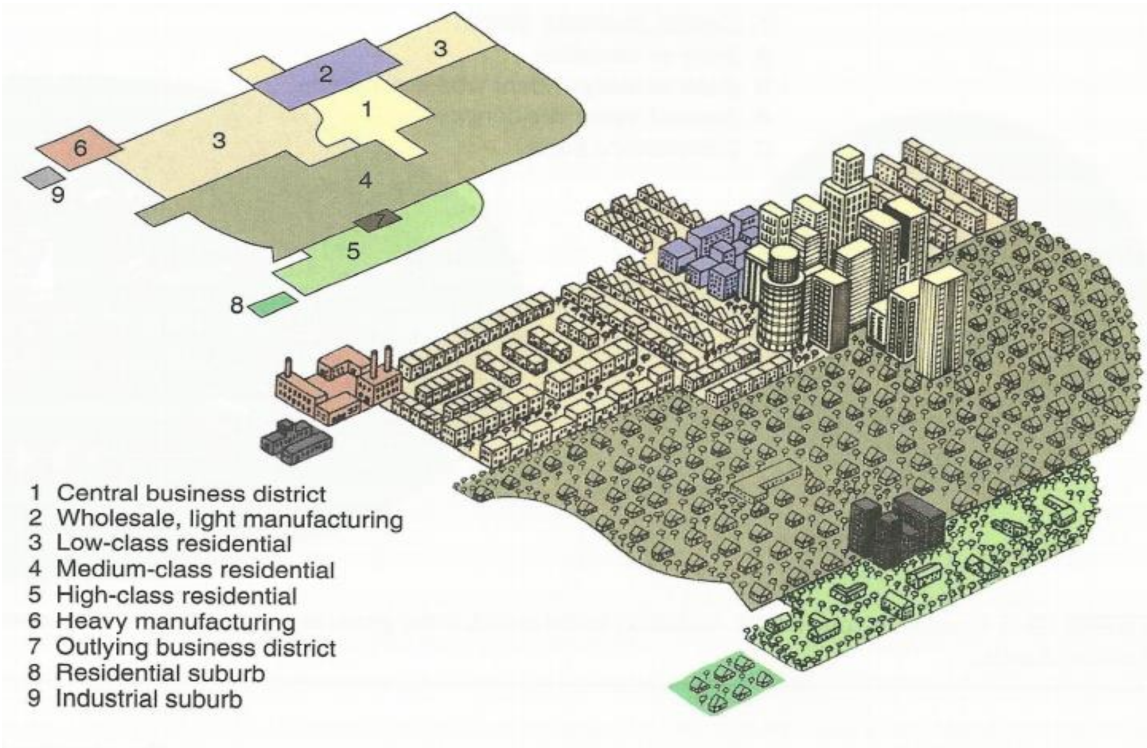
Homer Hoyt developed the Sector model as a modification of the concentric zone model in 1939 (Simmonds, 1988). It proposed that cities developed in a series of sectors and not rings (Figure 2.2). Hoyt argued that different activities were attracted to different areas of the city either due to environmental conditions, transportation opportunities or by mere chance (Rubenstein, 2016). This appreciates the role played by environmental factors on the development of various landuses.



Source: Rubenstein (2016)

Figure 2.2: Sector Model

The multiple nuclei model advanced in 1945 portends that the city structure is more complex and consists of multiple centres around which different activities develop (Figure 2.3).



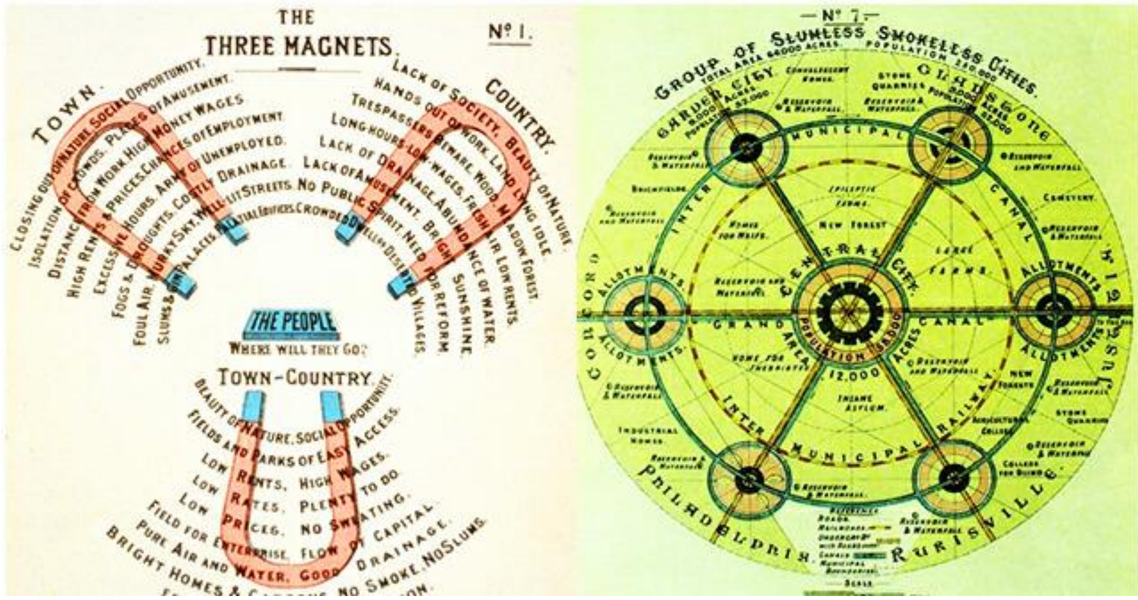
Source: Rubenstein (2016)

Figure 2.3: Multiple Nuclei Model

The Multiple Nuclei theory, as discussed by Rubenstein (2016), notes that certain activities are attracted to certain nodes while others are repelled by them, resulting in different centres of growth. As such, the resultant composition of urban elements and densities also vary from place to place.

In a comparative study of the applications of the three models from the Chicago School, outside of American cities, Rubenstein (2016) agrees that they may not be a replica but should not be fully discarded as there are strong similarities and minor modifications in the patterns in Europe, Africa, and Asia.

Other than the Chicago School arguments, the other compelling urban development model proposed was the garden city concept (Figure 2.4). Proposed by Ebenezer Howard, it proposed the marriage between the town and rural areas laid out in a circular plan with six wards divided by six major streets (Sharifi, 2015).



Source: Gardenvisit (2020)

Figure 2.4: The Garden City Concept

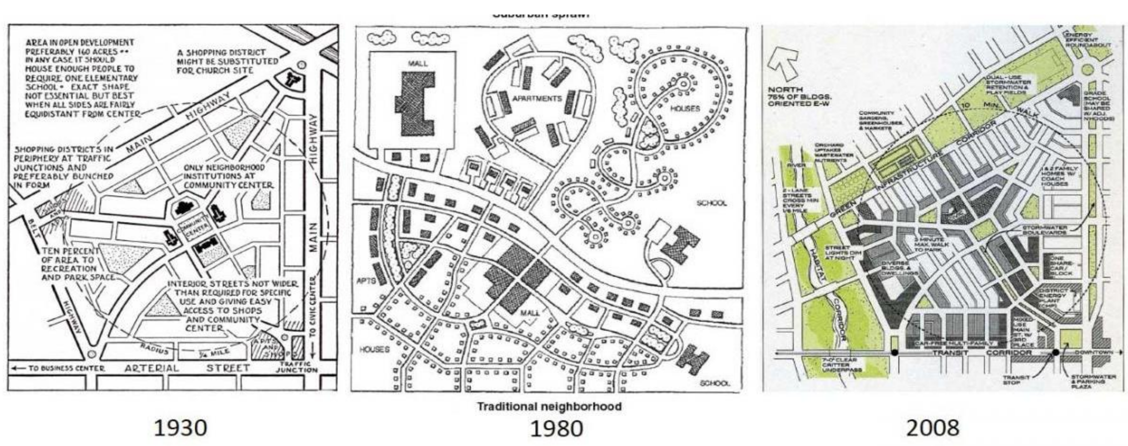
It evolved out of the need to solve urban degradation brought about by the industrial revolution of the late 1800 to early 1900 (Parsons & Schuyler, 2004). It faced criticisms which included urban sprawl and intense negative impacts on resources and the environment and the ‘overlooking of the greenbelts approach because of the high cost of land within urban areas’ (Sharifi, 2015).

The original models and concepts did not consider the influence of climate in decision making at the time. Nonetheless as noted by Hall and Barrett (2018), climate plays a notable role in determining some of the urban development components and urban human comfort. The different layout, when viewed alongside later discussions by authors such as Erell, Pearlmutter, and Williamson (2011); Hough (2004), Oke, Mills, Christen, and Voogt (2017) reveal influences that such models have on localized urban climates. For instance, the multiple nuclei model is inclined to have a rougher aerodynamic composite due to the different centres of density that would influence wind flow patterns and surface temperature.

2.2.2 Emerging Urban Planning Models

The emergence of new urban planning models and approaches was prompted by the inadequacies of the historical models. Some of the emerging approaches, it has been argued, are speculative innovations rather than conventional solutions (Mostafavi & Doherty, 2010). The ideas include new urbanism, landscape urbanism, and eco/ green cities approach. Due to their sustainability considerations, they are superior to the older models in managing environmental and social urbanization challenges (Sharifi, 2015).

New urbanism is an urban design ideology and approach that proposes a variety of building types, mixed uses, housing mixes of different economic status, and a strong provision for the public realm (Fainstein, 2000). It was developed as a critique of the traditional American suburbia which suffered from the negative effects of urban sprawl (Bhatta, 2010). Its main principles (Figure 2.5) include walkability, connectivity, mixed-use and density, mixed housing, quality architecture and urban design, traditional neighbourhood structure, sustainability, density, and smart transportation (Congress for the New Urbanism [CNU] and U S Department of Housing and Urban Development [HUD], 2000). The principles guide development within the regional, suburban, and urban renewal domains.



Source: Steuteville (2017)

Figure 2.5: Transition from Neighbourhood Unit to Sustainable Neighbourhood

Landscape urbanism emerged in the 1990s. It merges the fields of urban ecology and landscape urbanism. Landscape urbanism recommends landscape elements to be the structuring element in urban planning as opposed to new urbanism where green spaces were more of left-over spaces unsuitable for construction. It also ropes in urban ecology (Figure 2.6) that considers how people interact with other people, and the built and natural environment (Steiner, 2011).

Source: Barista (2015)

Figure 2.6: The New York Highline Project, an Example of Landscape Urbanism.

Green and eco cities (Figure 2.7) approaches embrace sustainable development paradigms. They endeavour to develop in an environmentally sensitive or green way (El Ghorab & Shalaby, 2016). The seven concepts associated with green/ eco cities include compactness, sustainable transport, density, mixed land use, diversity, passive solar design and greening as essential for sustainable urban form. However, Tratalos, Fuller, Warren, Davies, and Gaston (2007) caution that density directly impacts the environmental quality and ecosystem services. The green and eco cities approach is being applied in Europe with success.


Source: Studio A+H (2020)

Figure 2.7: Binhai Eco City Master Plan

The main principles of the new urbanism, eco cities and landscape urbanism consider sustainability as a key element. In some instances, they also include green economy as a concept (Moughtin & Shirley, 2005). This is critical in development of holistic urban areas and neighbourhoods. There is also a crosscutting theme of nature-based planning and design. This change in approach is not only ideal for sustainable development but also for combating emerging climate-oriented challenges.

2.2.3 Urban Form Elements

Urban form and morphology are often interchangeably used by different authors (Oliveria, 2018; Stangl, 2018; Chiaradia, 2019). Broad classification of the core aspects of urban form outlines them as natural and built environment (Kropf, 2018). The natural environment encompasses geology, plants, landform, and water. The built environment components are streets, open spaces, and buildings. The significance of urban form is the physical street layout, use of spaces, buildings, and expression of the cultural, and social aspects of life (Barke, 2018). It impacts planning, urban conservation, sustainability, crime, and public health (Barke, 2018; Javanroodi, Mahdavinejad, & Nik, 2018).

Urban form has undergone both positive and negative transformations. The positive transformations were geared towards aiding urban functionality such as easy construction of buildings and infrastructure (Sattethwaite, Huq, Reid, Pelling, & Lankao, 2009). The negative effects of such transformations include sealing of urban surfaces and replacement of vegetation with buildings (Gill, Handley, Ennos, & Pauliet, 2007). This compromises the ecological performance of urban areas (Whitford, Ennos, & Handley, 2001).

Other transformations have also been time sensitive. For instance, the 19th-century planning was more climate-sensitive compared to the 20th-century ones where buildings and street spacing appear similar in both warm and cold climates (Bosselmann, Arens, Dunker, & Wright, 1995). The delinking of urban form from climate-sensitive design has gone on despite the global appreciation of the effect that urban form has on local and global climate and vice versa. This effect is shown in arguments by Brown, Katscherian, Carter, and Spickett (2013) when they study the role of trees in developing cool urban communities. This is further supported by Lindén, Fonti, & Esper, (2016) in their Germany experiment.

The predominant classifications of urban form follow either density, architype, or Landuse/Landcover (Gu, 2019; Oliveira, 2016). Density is characterized as either sprawl or compact (Schwarz, 2010). Despite the variety in the classification of urban form or form, Stangl (2018) points out that two schools of thought have emerged. The English focus on the street, building and plot patterns and the Italian which focuses on building types (Osmond, 2010; Caniggia and Maffei, 2001).

Viewed from the perspective of climatic interaction, the typological approach is the most ideal as it considers the elements of urban form that either impact or are impacted by climatic parameters (Lindén et al., 2016). For instance, Stone, Hess, and Frumkin (2010) puts forward a case for how urban sprawl can increase the UHI effect through the replacement of green systems with hardscapes and how that same urban sprawl can also increase surface runoff through surface sealing.

Oliveira (2016) enumerates the urban form elements like the street, the plot and the building or the constructed and open space, a position supported by Conzen (2018). Examples of these spaces are squares, parks, and streets differentiated by the patterns of function according to Krier (1979). Based on this classification, the study considered the urban form elements as open spaces, buildings, and streets/ plazas.

2.2.3.1 Open Space in Urban Areas

The definition of open spaces is wide and based on a myriad of factors (Table 2.1).

Table 2.1: Typology of Urban Open Spaces at Different Forms and Scales.

Form	Scale		
	City	Intermediate	Neighbourhood
Street	Boulevards and highways	Streets	Alleys and paths
Plaza	Large city plazas	Small neighbourhood plazas	Courtyards
Recreation	Stadiums, Parks and Greenbelts	Sports grounds, parks, institutional grounds, empty lots, and cemeteries	Private gardens and yards
Incidental	Natural features and semi wild areas	Empty lots	Marginalized spaces between buildings
Urban Agriculture	Agricultural fields	Grazing grounds and gardens	Kitchen gardens

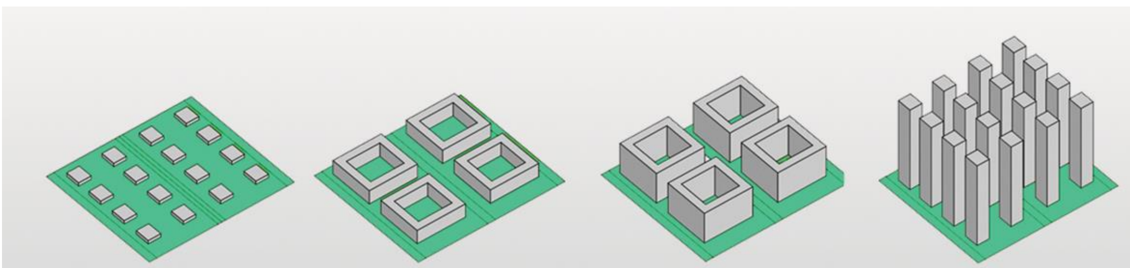
Note: Adapted from Stanley, Stark, Johnston, and Smith (2012)

For instance, they can be function-based according to Valente-Pereira (1982), typology as argued by Lynch (1981) and Moughtin and Shirley (2005), scale as forwarded by Krier (1979) and surface materials according to Woolley (2003). Nonetheless, the most common definition is that they cover any space other than the built-up areas and include parks, plazas, squares, greenways, courtyards, and streets (Krier, 1979; Valente-Pereira, 1982;

Byrne & Sipe, 2011). The typology classification is comprehensive as it combines both the scale, material, and amenities according to Byrne and Sipe (2011). The open spaces can either be forested or open grasslands (Stanley, Stark, Johnston, & Smith, 2012; Woolley, 2003; Yilmaz & Mumcu, 2016).

2.2.3.2 Buildings in Urban Areas

Buildings are the most visible elements yet the least permanent; they come in various shapes and sizes (Figure 2.8).



Source: Shishegar (2020)

Figure 2.8: Housing Typologies in Urban Areas

They change as development, regeneration, renewal, and revitalization occurs (Sandalack & Uribe, 2010). Their sections and elevations affect how they relate to outdoor space (Krier, 1979; Sandalack & Uribe, 2010). This relationship controls both the functionality and microclimate of the spaces determined by plan density, building heights, height uniformity and materials (Erell, Pearlmutter, & Williamson, 2011; Allmendinger, 2017). High densities of concrete and masonry edifices exacerbate the UHI effect (Oke R. T., 1987; Oke, Mills, Christen, & Voogt, 2017; Hu, White, & Ding, 2016). Reflective surfaces such as glazed facades increase the glare at the street level, raising temperatures as well (Roof, Crichton, & Nicol Fergus, 2005).

2.2.3.3 Streets and Plazas

The term street is used to encompass other typologies of circulation routes in urban areas. Under a landcover-based typology, plazas and squares can also be classified under streets as they have similar physical characteristics (Figure 2.9).

Source: National Association of City Transportation Officials (2020)

Figure 2.9: Urban Street and Plaza

Streets define the dimension and geometry of buildings thereby controlling the integration of buildings and open spaces (Oliveira, 2016; Valente-Pereira, 1982). They also impact the social and environmental aspects of urban life (Southworth & Ben-Joseph, 2003).

Design of streets often considers its dimensions, intended uses, construction materials, the relationship between streets, street furnishings and plantings. These parameters determine morphological aspects such as a street canyon character. This influences the street's impact on the microclimate by influencing factors such as solar access (Chatzidimitrious & Yannas, 2015; Louafi-Bellara & Abdou, 2016; Shafaghat et al., 2016; Taleghani, Kleerekoper, Tenpierik, & van den Dobbelsteen, 2015).

Within a climatic context, streets can be used to maximize shelter of street users, maximize pollutant dispersion, enhance thermal comfort, and solar access (Oke T. R., 1988). As such creating a street-level microclimate (Bosselmann, Arens, Dunker, & Wright, 1995;

Brown, Katscherian, Carter, & Spickett, 2013). The micro-climate can be tapped to enhance human comfort (Krier, 1979; Ragheb, El-Darwish, & Ahmed, 2016; Sodoudi, Zhang, Chi, Müller, & Li, 2018).

The type of urban form elements and the interconnected nature between the street, building and open space typologies point to an equally interconnected influence these elements are likely to have on climate parameters. Surface properties such as albedo, permeability, and thermal capacity of materials influence air temperatures and stormwater runoff (Chatzidimitrious & Yannas,2015; Coseo & Larsen, 2015).

The determination of the magnitude of this influence, therefore, requires proper measurement of urban form and its elements. Song and Knaap (2004) propose consideration of key elements such as circulation systems, density, and landuse. Recent approaches have introduced terminologies such as landcover in consideration of climate modifications (Findell et al., 2017). This is momentous particularly when using Geographic Information Systems in mapping and quantifying urban form (Lambin & Geist, 2008; Pradhan, 2006; Mölders, 2011). The landuse/ land cover provides the closest quantitative measure of urban form relevant to climatic studies. It considers the components of the natural and built environment characteristics through spatial and temporal measures that are suggested by Boeing, (2018). The scales at which these parameters can be measured are proposed by Kotharkar, Bahadure, and Sarda (2014) to be individual buildings, street, urban block, neighbourhood, and city-wide scale.

2.3 Urban Climate

Climate and weather can be studied and analysed at different temporal and spatial scales (Table 2.2). Nonetheless, basic climatic models anticipate three variables in the study of urban climate; the macroclimate, differences caused by location and the urbanization effect (Landsberg, 1981). The relationship between the micro and macro climate is in two ways: the macroclimate provides the basic climatic inputs into the urban areas while the urban areas by their unique biophysical characteristics have certain subtle modifications on the microclimate (Salata, Golasi, de Lieto Vollaro, & de Lieto Vollaro, 2015; Gill, Handley, Ennos, & Pauliet, 2007).

Table 2.2: Scale Dynamics of Weather and Climate

	SCALE (Km)		PAST CLIMATE		WEATHER				FUTURE CLIMATE		
Characteristic Space Scale			Normal Climate	Recent Climate	Recent Weather	Current Weather	Now Casting	Forecasting	Seasonal – Inter-annual Climate Prediction	Decadal Climate Prediction	Climate Change Projections
	+10000	Global									
	1000 - 10000	Continental									
	100-1000	Synoptic									
	10-100	Meso									
	1-10	Local									

Note: Adapted from World Bank (2016)

The basic elements of weather namely solar radiation, wind, humidity, temperature, and precipitation are affected by the elements of the land such as slope, landform, water, and plants alongside the urban form, built materials, vegetation, and human activities (Oke, 1987; Hough, 2002; Grimmond, et al., 2010). The nature of this interaction is defined by aspects of albedo, permeability, and heat capacity and conductivity of specific locations (Chen et al., 2019; Mohajerani, Bakaric, & Jeffrey-Bailey, 2017; Wu, Liu, Yang, & Bai, 2016). Therefore, this implies that the localized weather manifestations can be manipulated by changing the reflectivity, permeability, and heat retention ability of different surfaces.

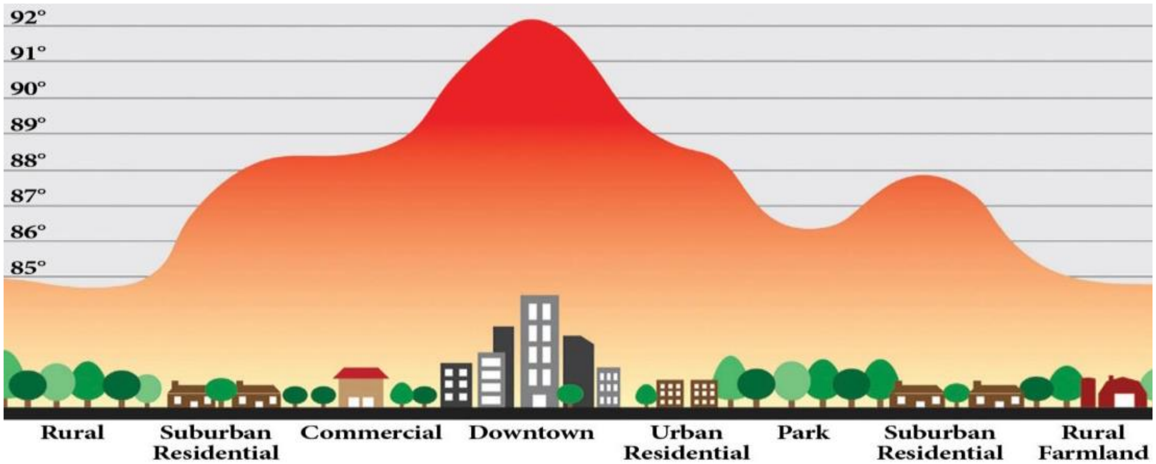
The interaction of climatic parameters and urban surfaces can be summarized as energy balances. They manifest as inflows, outflows, storage and production of water and energy (Demuzere et al., 2017; Hertel & Schlink, 2019). The energy flows also occur on a global scale. This informs the difference between global, regional, and local weather patterns.

The energy balances have the potential to affect local and regional climates thereby creating unique urban climates (Grimmond, et al., 2010; Lambin & Geist, 2006). The energy and water balances that determine urban climate are influenced by physical elements: construction materials, aerodynamic roughness, solar radiation, precipitation, and air quality (Hough, 2002; Oke, 1987; Landsberg, 1981). As such, manipulation of the physical properties of the physical elements has the potential to influence the impacts of weather.

2.3.1 Solar Radiation and the Urban Heat Island Effect

Urban areas are exposed to air temperature, surface, and subsurface temperatures (Grimmond et al., 2010). Air temperature is the temperature above the ground: either in the Urban Canopy Layer or the Urban Boundary Layer. Surface temperature is the temperature of the urban surface including vegetation, paving, building, water, and bare ground. Subsurface temperature is the temperature beneath the urban surface namely soil, and basements (Oke, Mills, Christen, & Voogt, 2017). Urban temperatures are determined by solar radiation, urban form, water availability, and surface properties. They affect the received, reflected, re-reflected, and absorbed radiation (Coutts, Tapper, Beringer, Loughnan, & Demuzere, 2012; Hough, 2002).

The Urban Heat Island (UHI) is a phenomenon (Figure 2.10) where urban areas exhibit heat differences of sometimes 10 ℃ with the neighbouring rural areas (Environmental Protection Agency, 2008a; Stone, Hess, & Frumkin, 2010). This is attributed to human modifications of the geometry, surface materials, population, canopy typology, and vegetation of urban areas. (Oke, Mills, Christen, & Voogt, 2017; Ningrum, 2018; Ward, Lauf, Kleinschmit, & Endlicher, 2016).



Source: Velazquez (2020)

Figure 2.10: The Urban Heat Island Effects

Impervious surfaces and concrete building surfaces store and conduct heat much faster compared to soil and vegetation. This raises surface temperatures in urban areas compared to rural zones (Hough, 2002; Wilby, 2007). UHI is the best example of inadvertent climatic change (Oke, 1995). It has become one of the most important factors to consider in urban design especially in a changing climate (Pattacini, 2012).

2.3.2 Wind

The urbanization process impacts the interaction between urban areas and wind based on urban form. Urban densities exhibit varying vertical and horizontal morphologies that influence roughness dynamics (Allegrini, Dorer, & Carmeliet, 2015). In most cases these result in slower wind speeds on a city-wide scale according to Wilby, (2007). This scenario is referred to as Urban Wind Island effect (Droste, Steeneveld, & Holtslag, 2018). Nonetheless, localized speeds are higher in specific areas depending on the urban forms (Hough, 2002).

These flow patterns are characterized by vortices at the edges of buildings and intersections (Grimmond et al., 2010). Withal, there are scenarios where the prevailing high wind speeds translate to higher wind speeds in the urban canopy layer either through the downward deflection by tall buildings or the tandem orientation of the streets to the prevailing wind directions (Oke R. T., 1987). Street orientation and widths affect wind flow patterns in urban areas, influencing local urban temperatures with notable input from the distance between buildings (Grimmond et al., 2010; Allegrini, Dorer, & Carmeliet, 2015). As such, areas that show decreased wind speeds have higher surface temperatures (Yang et al., 2019).

2.3.3 Precipitation

Precipitation is any form of water particles that falls from the atmosphere and reaches the ground (Ahrens & Henson, 2015). Precipitation in urban areas is varied in temporal, spatial and state dynamics; falls as hail, rain or snow and is usually either detained or let to flow into natural and designed waterways (Grimmond et al., 2010). Some of the factors that work either in isolation or in tandem to control this variability include elevations, presence of water bodies, the UHI effect and pollution (McLeod, Shepherd, & Konrad II, 2017; Zhu et al., 2019).

Urban areas impact and are impacted by precipitation through convection, urban surface roughness and surface materials. Air pollutants provide nuclei for cloud formation and the UHI changes air pressures above the urban canopy layer (Oke, 1987). There is increased consensus that the resulting rain often falls down-wind. These result in about 28% more rainfall in 30-60 km downwind region of the city (Solecki & Marcotullio, 2013). Even so, depending on the topographical orientations of the entire region, the surface runoff can sometimes make its way to the urban areas without there being any rain in the urban areas. Impervious surfaces cause rapid run-off (Chithra, Nair, Amarnath, & Anjana, 2015; Ferreira et al., 2019; Haidu & Ivan, 2016). As a result, rainwater is neither intercepted before it reaches the ground nor infiltrated (Whitford, Ennos, & Handley, 2001).

2.4 Relationship Between Urban Form and Climate

The correlation between urban form and climate run both ways. On the one hand, urban form components such as density and types of landcover influence temperature, wind patterns, precipitation, and water flow (IPCC, 2014a). On the other hand, the design of historical urban form elements such as street orientations has been influenced by prevailing climatic conditions (Hebbert, 2014).

Winds and urban form interactions are based on two components; aerodynamic roughness caused by the varying heights of buildings particularly in the high-density areas and orientation of the urban voids in comparison to the prevailing wind directions (Oke R. T., 1987; Hough, 2002). The success of outdoor spaces in the context of airflow and wind patterns has led to some standards being developed, for example, the Gandmer and Guyot (1976) that proposed a maximum wind speed of 5 m/s as quoted by (Szucs, 2013).

Solar radiation which affects surface temperatures and evaporation rates manifests differently in different urban areas. The manifestation is influenced by the quality of urban surfaces and regional radiation patterns (Chang, Saha, Castro-Lacouture, & Yang, 2019). For example, road networks produce the highest thermal emissivity followed by industrial and commercial developments. Vegetated surfaces have the lowest thermal emissivity (Xiao, Li, & Wang, 2011). Overglazed building facades pose major thermal issues as they not only lead to overheating in both the internal and external environments but also increase light energy use within buildings as the blinds are often drawn (Roof, Crichton, & Nicol Fergus, 2005).

Interaction between urban areas, and precipitation occurs at two distinct levels: the effect urban areas have on precipitation dynamics and what happens to the precipitation once it reaches the ground. First, urban areas control the regional climate and local wind patterns through convection and surface roughness (Oke T. R., 1988). Secondly, the perviousness of urban surfaces determine runoff; the more impervious a surface, the more the runoff (Chithra et al., 2015; Ferreira et al., 2019; Haidu & Ivan, 2016). For instance, transportation systems become the first casualty of flooding (Figure 2.11) as most drainage systems exist alongside them and their imperviousness (Singh, Sinha, Vijhani, & Pahuja, 2018). This implies that poorly designed and/ maintained and inadequately provided drainage systems exacerbate the flooding potential of roads and other paved surfaces. Other factors that would impact precipitation but not easily discernible at the urban form level include slope and soil drainage properties (Bathrellos, Karymbalis, Skilodimou, Gaki-Papanastassiou, & Baltas, 2016; Gigovich, Pamvear, Bajic, & Drobnjak, 2017).

Source: Angote (2018)

Figure 2.11: Flooded Street in the City County of Nairobi

There are also inter-relationships between the different parameters. This is based on the water-energy balance equation. For instance, Water availability determines local temperatures through evaporation or evapotranspiration (Oke, 1988; Coutts, Tapper, Beringer, Loughnan, & Demuzere, 2012).

The interactions between urban surfaces, plants, and the atmosphere are complex that minor changes in any of the urban form components can result in major changes in the local climate (Bruse & Fleer, 1998). The process of urbanization which has been notated to carry the greatest negative impact on biodiversity also compromises the ecosystem services of natural systems thus aggravating challenges of climate in urban areas (Lyu, Zhang, Xu, & Li, 2018; Palomo, 2017; Breuste, Haase, & Elmqvist, 2010).

The relationship between climate and urban form is based on the physical characteristics of the urban form elements. These are dominantly manifest as landcover. As such, the management of climatic manifestations and impacts is can be enhanced through manipulation of the physical characteristics of urban form. This would include changing the permeability, conductivity, and emissivity of different urban surfaces.

2.5 Climate Change and Vulnerability Assessment

2.5.1 Climate Change Effects and Impacts in Urban Areas

The two widely used definitions of climate change are by the Intergovernmental Panel on Climate Change (IPCC) and The United Nations Framework Convention on Climate Change (UNFCCC). The IPCC defines it as any change in climate over time, whether due to natural variability or because of human activity (IPCC, 2007b). The UNFCCC defines it as the change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods (UNFCCC, 1992).

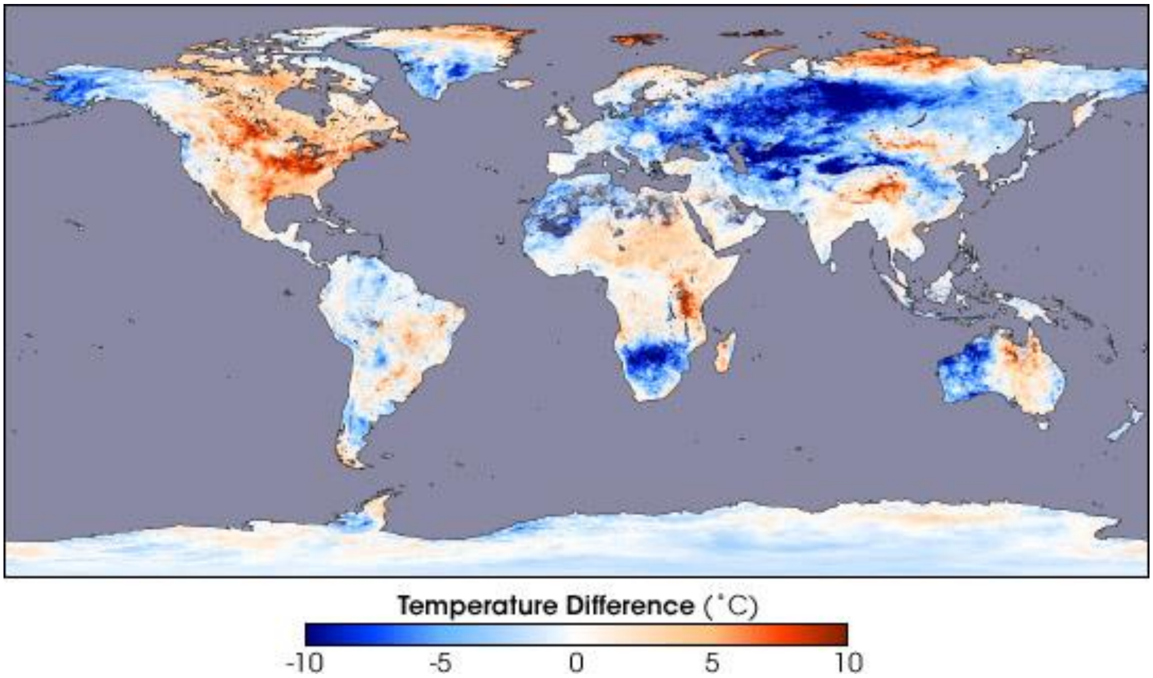
Despite the variety of definitions, key emerging issues are the duration of observation and the role played by both natural variability and human activities. To this extent, several theories have been advanced as to the causes of climate change. The commonly discussed ones include the anthropogenic global warming and solar variability theories of climate change. Others include bio-thermostat, cloud formation and albedo, ocean currents and planetary motion theories (Bast, 2010).

Anthropogenic global warming attributes climate change to human activities, the release of Greenhouse Gas and reduction of carbon sequestration capabilities of earth systems whose arguments go back to the seventeenth century (Hulme, 2009). Solar variability proposes that sunspots and solar flares cause warming of the earth (Bast, 2010), a position also noted by IPCC as a contributing factor. That said, there is evidence by the IPCC, that human activities are playing a conspicuous role in global warming (IPCC, 2007b; Henson, 2011; UN-Habitat, 2011). This has been done through the modelling of both natural and anthropogenic drivers both in isolation and together (IPCC, 2007a; IPCC, 2007c).

At the centre of the climate change debate is also the discourse on whether what we are experiencing is climate change or climate variability. Climate variability is generally defined as variations in the mean state and other statistics such as standard deviation of the extremes of climate on all temporal and spatial scales beyond that of individual weather events (IPCC, 2007b; Ahrens & Henson, 2015). There is also consensus that the climate anomalies are quite varied, and the rates of variability are higher than any ever recorded (National Academy of Sciences, 2014).

Urbanization and climate change are closely interlinked and show interrelations with processes such as economics, land-use change and demographics. However, the manifestations vary in urban areas due to uneven exposure and susceptibility (Krellenberg, 2016). Climate change impacts sectors in the urban areas namely energy, infrastructure, water supply, waste, and communications which in turn affects social, economic, ecological, and cultural aspects of human life (Zimmerman & Faris, 2010; World Bank, 2010). Statistics show that the globe is experiencing compelling climate anomalies (United Nations Environmental Programme [UNEP], 2010). The notable anomalies are in the elements of temperature, precipitation, winds, and sea-level rise (Hegerl, Brönnimann, Schurer, & Cowan, 2018; Mokhov & Semenov, 2016; Henson, 2011).

The first effect of climate change is extreme temperatures (Figure 2.12). The top 10 warmest years on record have occurred between 2005 and 2019 with 2016 being the warmest of them all (World Meteorological Organization [WMO], 2019; WMO, 2016; WMO, 2014) Urban areas have also experienced an increase in extreme heat events (Stone, Hess, & Frumkin, 2010). Most cities in Africa, Asia, and Latin America will experience more instances of heatwaves due to a combination of the UHI effect, the increasing global temperatures and increased air pollution in the larger cities of high density. On the other side is the lowering of temperatures in the normally cold days (Satterthwaite, Huq, Pelling, Reid, & Lankao, 2007; Henson, 2011).



Source: Earth Observatory (2006)

Figure 2.12: Global Extreme Surface Temperatures of January 2006

Extreme temperatures, especially high temperatures, affect human productivity, health, and the air quality of the urban areas by increasing pollution (Roof, Crichton, & Nicol Fergus, 2005; Satterthwaite, Huq, Pelling, Reid, & Lankao, 2007; Henson, 2011; Environmental Protection Agency, 2008a). Noise pollution is expected to increase in previously cold climate cities due to increased outdoor activity because of warmer conditions (Roof, Crichton, & Nicol Fergus, 2005). Extreme heat events also cause morbidity, mortality, higher energy consumption, thermal pollution, pavement damage and wildfires with a higher number of deaths occurring during heat waves (Bell et al., 2016; Horton, Mankin, Lesk, Coffel, & Raymond, 2016; Mitchell et al., 2016).

The second effect is extreme precipitation. In tropical zones, the dominant form of precipitation is rainfall and sometimes hail. In the higher latitudes, precipitation manifests as rain, snow, sleet, and hail (Ahrens, 2015). These precipitation changes manifest as extremes of rainfall or drought. Extremes manifest in the form of intensity or duration (IPCC, 2007b).

When precipitation occurs in urban areas, the resultant water is usually either drained off as runoff, collected for use or infiltrated into the pervious surfaces (Figure 2.13) (Sattethwaite, Huq, Reid, Pelling, & Lankao, 2009). Surface runoff is the component that poses risks to urban areas as surface flooding.

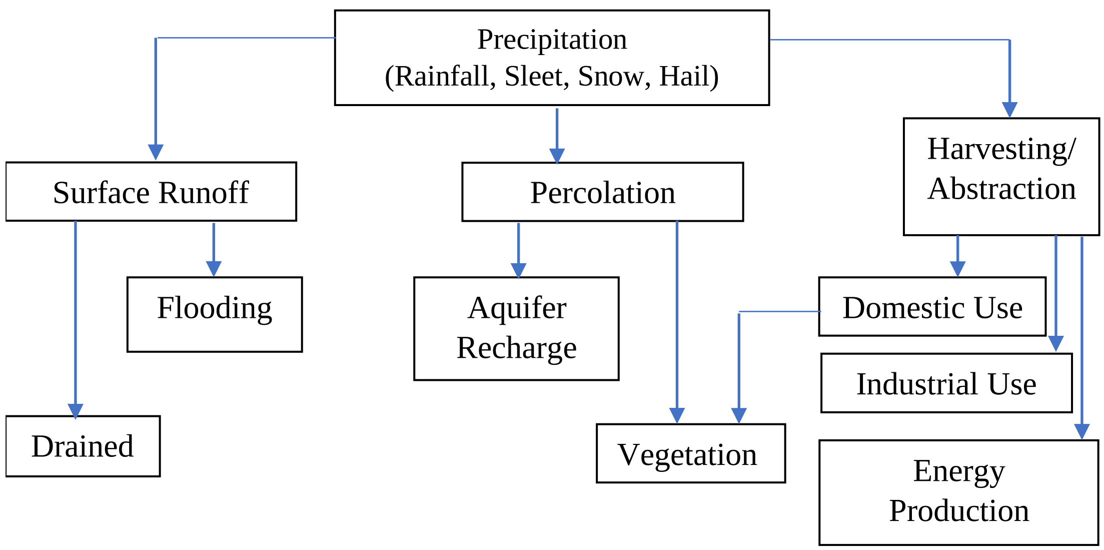


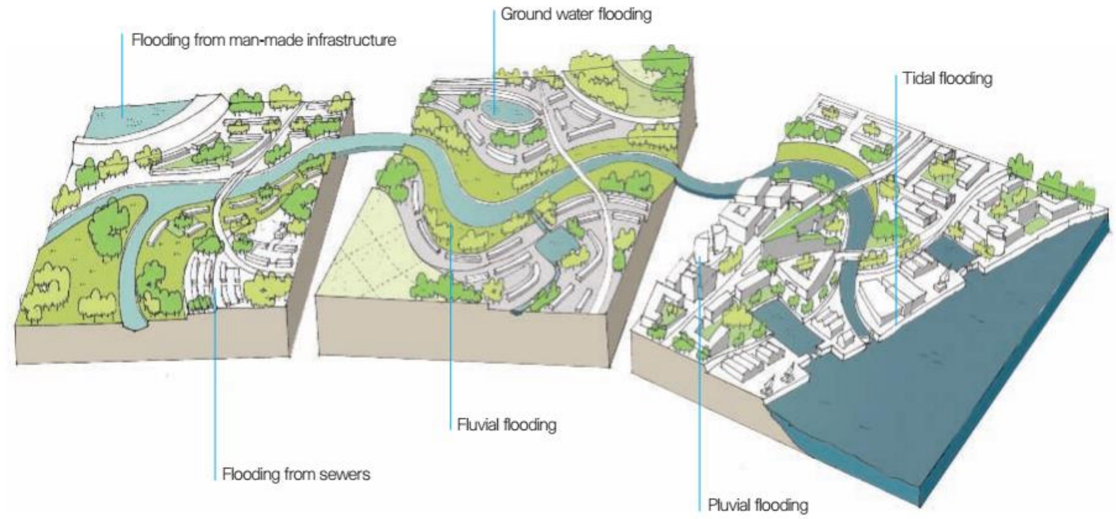
Figure 2.13: Precipitation in Urban Areas

Flooding is a normal natural occurrence and risk in urban areas (Satterthwaite, Huq, Pelling, Reid, & Lankao, 2007). However, the damage from flooding is a purely man instigated occurrence that happens at the confluence of meteorological, hydrological, physical, and anthropogenic activities (Associated Programme on Flood Management, 2012). The physical characteristics manifest as landcover with different runoff coefficients (Table 2.3) which have great potential to impact ecosystem processes, hydrology, biodiversity, climate, and human activities (Alsaaideh, Al-Hanbali, & Tateishi, 2012). Aside from the runoff coefficients, the dysfunctional drainage systems also contribute. They are often either underprovided or poorly maintained thereby blocking and not performing their intended functions. The replacement of natural landcover with paved surfaces increases surface runoff, making urban areas vulnerable to flooding. Flooding experienced in African towns and cities is either pluvial, fluvial, or tidal (Figure 2.14).

Table 2.3: Runoff Coefficients of Urban Landcover Types

By Surface Type (for flat areas)	Runoff Coefficients
Lawns:	
Sandy Soil	0.05 - 0.10
Loamy Soil	0.10 - 0.20
Park Areas	0.10 - 0.25
Asphalt/Concrete Surfaces	0.70 - 0.95
Roof Areas	0.75 - 0.95
By Landuse	**K Values**
Unimproved	0.10 – 0.30
Suburban residential	0.25 – 0.40
Single-Family Units (Urban)	0.30 – 0.50
Apartments	0.50 – 0.70
Business Sector (Central City)	0.70 – 0.95
Industry:	
Light	0.50 – 0.80
Heavy	0.60 – 0.90

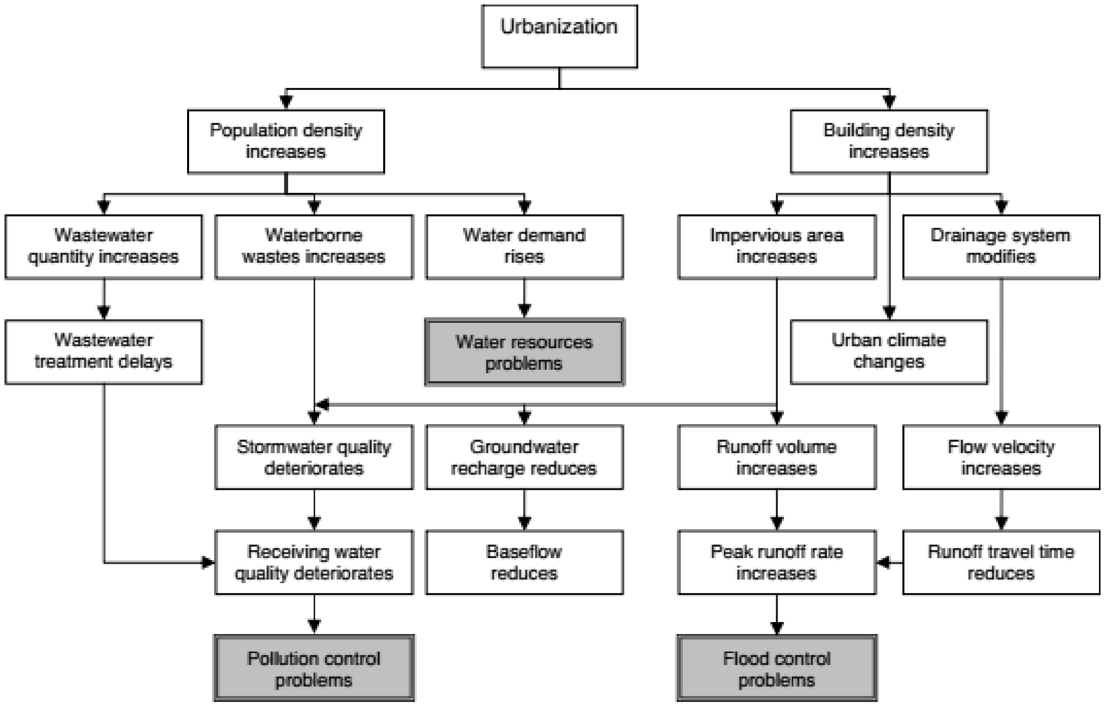
Note: Landsberg (1981)



Source: RIBA (2009)

Figure 2.14: Sources of Flooding

Flooding leads to economic losses, loss of life, livelihoods, and health risks (Cowie, 2013; World Bank, 2010). It also damages urban infrastructure and buildings and compromises on water quality, general water scarcity (Associated Programme on Flood Management, 2012; Roof, Crichton, & Nicol Fergus, 2005). Other than the direct and indirect impacts of flooding, the other aspects of urban services that get affected include waste management challenges due to waste being swept away and increasing the risk of contamination (Roof, Crichton, & Nicol Fergus, 2005). These lead to various inter-related problems directly resulting from urbanization (Hammond, Chen, Djordjević, Butler, & Mark, 2015; Miller & Hutchins, 2017) as shown in Figure 2.15.



Source: Associated Programme on Flood Management (2012)

Figure 2.15: Flood Dynamics in Urban Areas.

Landslides are intricately linked to precipitation. They are influenced by vegetation cover, slope angle, and stability, and precipitation patterns. Spatial distribution data on landslides point to a strong correlation with rapid land-use changes (UN-Habitat, 2011). Nowhere are these changes more evident than in urban areas, particularly those settled by the urban poor which tends to be physically vulnerable such as riverfronts and mountainsides. Due to the confluence of precipitation and physical characteristics of a space, these locales have higher risks of landslide with impacts being loss of life and property, damage to infrastructure, and a general rise in the cost of living (UN-Habitat, 2011).

Droughts are a typical occurrence in the climatic cycles of a region because of the El Niño and La-Nina effects. However, climate change has been noted to cause further changes in these known systems through increased evaporation during the dry periods (Henson, 2011). The effects of drought on urban areas include water stress, high cost of access to water, compromised water quality, groundwater subsidence, interrupted inland water transport, rural-urban migration, urban forestry loss, and hydro-electric energy shortages (UN-Habitat, 2011; IPCC, 2014a). In water-deficient environments, primarily cities in deserts and semi-arid areas, civil unrest, and wars between countries can be expected (Roof, Crichton, & Nicol Fergus, 2005).

The third effect is extreme wind speeds (Figure 2.16). These manifest as either hurricanes, cyclone, or dust storms. Extreme winds are considered to affect coastal areas. However, inland areas are also affected by windstorms and tornadoes (Henson, 2011). These are as well projected to increase in intensity due to climate change. In a general context though, wind has the greatest impact on urban climate as it affects temperature and humidity through evapotranspiration and evaporation (Hough, 2002). It also affects human comfort in different spaces (Ghasemi, Esfahani, & Bisadi, 2015; Hsieh, Jan, & Zhang, 2016; Szucs, 2013).

Source: Thuo, (2019)

Figure 2.16: Dust Storm Experienced in Nairobi in October 2019

The fourth effect is biodiversity loss and changes in plant phenology. Climate change is causing many changes to flora and fauna structures globally (Pecl et al., 2017; Turner, 2018). Such changes include phenology, geographic distribution, flora and fauna community networks, and sometimes total biodiversity loss (Wilby & Perry, 2006; Henson, 2011; Staudinger et al., 2012). They are caused by effects such as extreme precipitation and temperatures that affect the entire ecosystem (IPCC, 2007b).

Of the five transmission mechanisms through which climate change will affect human development, four will be heavily felt in urban areas. Three out of the four will be felt in inland urban areas. They include increased extreme temperatures, extreme precipitation and droughts and landslides (International Institute of Environmental Development [IIED], 2016). The impacts will, however, affect all the sectors of urban life ranging from tourism to natural ecosystems, infrastructure, and housing (MENR, 2014). Impacts manifest in extreme and mean values of the different parameters. These manifestations vary from location to location and affect different groups of people (Table 2.4).

Table 2.4: Summary of Climate-Driven Phenomena, Impacts and Affected Groups

Climate-Driven Phenomena	Evidence of Current Impact	Other Processes/ Stresses	Projected Future impacts	Zones, Groups affected
		Changes in Extremes		
Extreme Rainfall	Erosion, Landslides, flood Casualties, economic losses, and infrastructure damage	Landuse, population density, institutional capacity	Effects in Settlements, health, economy, buildings, and infrastructure	Population in settlements and infrastructure
Heat or Cold Waves	Health, social stability, water, energy, and infrastructure	Building design, Social Contexts, and Institutional Capacity	Health, populations, energy requirements	5<age>65 and poor
Drought	Water, livelihoods, energy generation, water transport	Water systems, water demand, and energy demand	Water resource, migration, and economic activities	Poor areas, Arid and Semi-arid, regions with human-induced water scarcity
		Changes in Means		
Temperature	Energy demand and costs, urban air quality, recreation, livelihoods, retail consumption	Demographic and economic changes, land-use changes, air pollution, innovations, and institutional capacities	Energy demand and costs, urban air quality, recreation, livelihoods, retail consumption	Population vulnerabilities
Precipitation	Agricultural livelihoods, energy supply, and water infrastructure	Competition from other places	Flooding/Drought	Poor regions and populations

Note: Developed from IPCC (2007a)

2.5.2 Climate Change Vulnerability Components

Vulnerability is the degree to which a system is susceptible to and unable to cope with adverse effects of climate change including climate variability and extremes (IPCC, 2007b). It is multidimensional and a function of the city's biophysical, social, and economic characteristics (Birkmann et al., 2014). These make them susceptible to climate variations and include location, timing, slope, population size, density, and inhabitants' economic status (Swart et al., 2012; Fritzsche et al., 2014). Vulnerability classifications have been varied. The three main classifications are shown in Table 2.5.

Table 2.5: Summary of Vulnerability Classifications

Classification	Authors
Biophysical versus Socioeconomic	Klein & Nichols,1999; Krellenberg, 2016; Brooks, 2003; Brooks, 2003; Satapathy et al., 2014
Physical, Economic and Environmental	UN, 2004
Physical-Environment, Social	Moss et. al., 2001

Despite the different classifications, recurrent terminologies in vulnerability discussions remain the same. They are susceptibility, sensitivity, adaptive capacity, exposure, and risk (Birkmann et al., 2015; Krellenberg, Welz, Link, & Barth, 2017). Risk is agued to exists at the confluence of vulnerability, hazard exposure and adaptive capacity (IPCC, 2014a; Madruga et al., 2011). This is evidenced by the Sorsogon and Kampala case studies (UN-Habitat, 2014a; UN-Habitat, 2010). The point of convergence between impacts and risk is driven by the exposure and sensitivity dynamics (Ministry of Environment and Natural Resources [MENR], 2014).

Reduction of vulnerability to its key components (Figure 2.17) of exposure, sensitivity and adaptive capacity remains critical in measuring vulnerability. This is due to the complex relationship between climate and non-climatic factors. This position is supported by Krellenberg (2016), Gilard (2016), Herslund et al., (2015), Satapathy et al., (2014), Fritzsche et al., (2014), Revi et al., (2014), and Romero (2011).

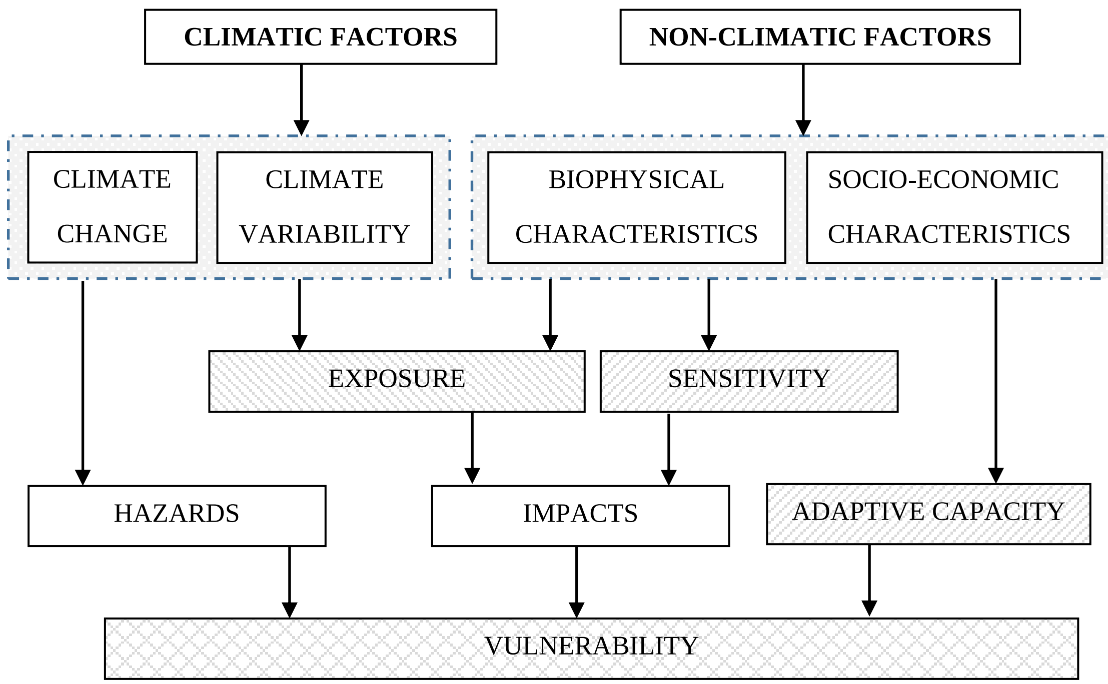


Figure 2.17: Climate Change Vulnerability Components

Exposure is defined as the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected (IPCC, 2012). It is linked to climatic parameters and concerned with the presence of people in setting where they could be adversely affected by climatic elements (Fritzsche et al., 2014; Ramón & Thomas, 2015).

Sensitivity is the degree to which a system is affected directly or indirectly, either adversely or beneficially, by climate-related stimuli (IPCC, 2001). The degree of a system's sensitivity to climatic hazards depends on geographic conditions and socioeconomic factors. Indicators of sensitivity encompass geographical conditions, landuse and socio-demographic factors (Ludena & Yoon, 2015).

Adaptive capacity is defined by IPCC (2007b) as the ability of a system to adjust to climate change and moderate potential impacts through the combination of the strengths, attributes, and resources. These can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities (IPCC, 2012). Indicators of adaptive capacity compose economic capability, physical infrastructure, social capital, institutional capacity, and data availability (Ludena & Yoon, 2015).

The appreciation of vulnerability and the relationship of the components vary among different authors and viewpoints. For instance, Swanson, Hiley, Venema, and Grosshans (2007) ignore the sensitivity aspect in their aggregation of vulnerability as a concept (Equation 2.1). Lee (2017) considers sensitivity (Equation 2.2 and 2.3) while Satapathy et al.,(2014) brings in the aspect of weighting (Equation 2.4). Satapathy et al. (2014) position is the most comprehensive as it does not assume that all vulnerability parameters have an equal influence on the levels of vulnerability. As such, it was used for the study.

$$V = f(E, A) \tag{2.1}$$

Where:
V: Vulnerability
E: Exposure
A: Adaptive Capacity

$$S = \frac{S1 + S2 + S3}{3} \tag{2.2}$$

Where
S1 Exposure
S2 Adaptive Capacity
S3 Sensitivity

$$V = E \times S - A \tag{2.3}$$

Where:
V: Vulnerability
E: Exposure
S: Sensitivity
A: Adaptive Capacity

$$V = \sum_{k=1}^{n} wS + \sum_{k=1}^{n} wE - \sum_{k=1}^{n} wA \qquad (2.4)$$

Where V: Vulnerability index
wA: Weighted indicators for adaptive capacity,
wS: Weighted indicators for climate change sensitivity,
wE: Weighted indicators for climate exposure

The evolution of exposure, sensitivity and adaptive capacity indicators depends on the type of vulnerability being assessed. For instance, flood vulnerability assessment differs from thermal stress vulnerability assessment based on the indicators to be considered. Flood and thermal stress vulnerability assessment indicators from different authors are shown in Table 2.6 and Table 2.7, respectively.

Table 2.6: Summary of Flood Risk Factors

Flood Risk Factors	Indicators	Authors
Drainage frequency	The ratio of stream no to the total area of the watershed	(Elmoustafa & Mohamed, 2013)
Drainage density	The ratio of Stream length to the total watershed area	(Elmoustafa & Mohamed, 2013; Elkhrachy, 2015; Stefanidis & Stathis, 2013)
Surface flow length	Distance travelled by water before reaching a stream	(Elmoustafa & Mohamed, 2013; Gigovich, Pamoderate vulnerabilityyear, Bajic, & Drobnjak, 2017; Bathrellos, Karymbalis, Skilodimou, Gaki-Papanastassiou, & Baltas, 2016; Ouma & Tateishi, 2014; Elkhrachy, 2015; Dou et al., 2017; Skilodimou, Bathrellos, Chousianitis, Youssef, & Pradhan, 2019)
Elevation	Height relative to the lowest point in the area	(Gigovich, Pamucar, Bajic, & Drobnjak, 2017; Bathrellos, Karymbalis, Skilodimou, Gaki-Papanastassiou, & Baltas, 2016; Ouma & Tateishi, 2014; Dou et al., 2017; Chen, Ito, Sawamukai, &

		Tokunaga, 2015; Skilodimou, Bathrellos, Chousianitis, Youssef, & Pradhan, 2019)
Slope	(L/H) *100 L: Horizontal distance H: Vertical change in height	(Gigovich, Pamvear, Bajic, & Drobnjak, 2017; Bathrellos, Karymbalis, Skilodimou, Gaki-Papanastassiou, & Baltas, 2016; Ouma & Tateishi, 2014; Stefanidis & Stathis, 2013; Dou et al., 2017; Doyle, Sullivan, Mahtta, & Pandey, 2017; Skilodimou, Bathrellos, Chousianitis, Youssef, & Pradhan, 2019; Mentzafou, Markgianni, & Dimitriou, 2017)
Landcover/Use	The type (permeability and roughness of landcover)	(Gigovich, Pamucar, Bajic, & Drobnjak, 2017; Bathrellos, Karymbalis, Skilodimou, Gaki-Papanastassiou, & Baltas, 2016; Ouma & Tateishi, 2014; Elkhrachy, 2015; Stefanidis & Stathis, 2013; Dou et al., 2017; Skilodimou, Bathrellos, Chousianitis, Youssef, & Pradhan, 2019; Mentzafou, Markgianni, & Dimitriou, 2017)
Hydro-lithology (Soil and Geology)	Geological permeability (Classified as permeable; semi-permeable and impermeable)	(Bathrellos, Karymbalis, Skilodimou, Gaki-Papanastassiou, & Baltas, 2016; Ouma & Tateishi, 2014; Elkhrachy, 2015; Stefanidis & Stathis, 2013; Dou et al., 2017; Chen, Ito, Sawamukai, & Tokunaga, 2015; Skilodimou, Bathrellos, Chousianitis, Youssef, & Pradhan, 2019; Mentzafou, Markgianni, & Dimitriou, 2017)
Rainfall Intensity	Rainfall (mm) Duration (Hour)	(Dou et al., 2017; Chen, Ito, Sawamukai, & Tokunaga, 2015; Mentzafou, Markgianni, & Dimitriou, 2017)
Flow Accumulation	Topography	(Dou et al., 2017; Mentzafou, Markgianni, & Dimitriou, 2017)

Table 2.7: Thermal Stress Risk Factors

Thermal stress risk Factors	Indicators	Authors
Temperature	Land Surface Temperature, Air Temperature, No. of Hot Days (above a certain value), Daily Maximum, Daily Minimum	(Inostroza, Palme, & de la Barrera, 2016; Bao, Li, & Yu, 2015; Romero-Lankao, Qin, & Dickinson, 2012; Weber, Sadoff, Zell, & de Sherbinin, 2015; Wolf & McGregor, 2013; Swart et al., 2012; Mendez-Lazaro, Muller-Karger, Otis, McCarthy, & Rodriguez, 2017; Janicke et al., 2018; Macintyre et al., 2018; Apreda, D'Ambrosio, & Di Martino, 2019)
Age Group	Elderly and the young (+65 and below 5)	(Inostroza, Palme, & de la Barrera, 2016; Pincetl, Chester, & Eisenman, 2016; Wilhelmi & Hayden, 2010; Bao, Li, & Yu, 2015; Romero-Lankao, Qin, & Dickinson, 2012; Nayak et al., 2018; Wolf & McGregor, 2013; Swart et al., 2012; Sánchez, Peiró, & Gonzales, 2017; Gamble et al., 2018; Mendez-Lazaro, Muller-Karger, Otis, McCarthy, & Rodriguez, 2017; Macintyre et al., 2018)
Housing Quality	Buildings Materials (Roof and walls)	(Inostroza, Palme, & de la Barrera, 2016; Bao, Li, & Yu, 2015; Romero-Lankao, Qin, & Dickinson, 2012; Nayak et al., 2018; Wolf & McGregor, 2013; Stangl, 2018; Macintyre et al., 2018)
Normalized Difference Vegetation Index	Plantings/Vegetation, Parks, Street Trees	(Inostroza, Palme, & de la Barrera, 2016; Pincetl, Chester, & Eisenman, 2016; Weber, Sadoff, Zell, & de Sherbinin, 2015; Swart et al., 2012; Barron, Ruggieri, & Branas, 2018; Stangl, 2018; Apreda, D'Ambrosio, & Di Martino, 2019)
Income Levels	% Population below the poverty line	(Pincetl, Chester, & Eisenman, 2016; Inostroza, Palme, & de la Barrera, 2016; Wilhelmi & Hayden, 2010; Romero-Lankao, Qin, & Dickinson, 2012; Weber, Sadoff, Zell, & de Sherbinin, 2015; Nayak et al., 2018; Swart et al., 2012; Sánchez, Peiró, & Gonzales, 2017; Sánchez, Peiró, & Gonzales, 2017; Gamble et

		al., 2018; Apreda, D'Ambrosio, & Di Martino, 2019)
Albedo	Surface Albedo character	(Pincetl, Chester, & Eisenman, 2016; Wolf & McGregor, 2013; Apreda, D'Ambrosio, & Di Martino, 2019)
Urban Form/ landcover	% of landcover	Pincetl, Chester, & Eisenman, 2016; Wilhelmi & Hayden, 2010; Romero-Lankao, Qin, & Dickinson, 2012; Nayak et al., 2018; Wolf & McGregor, 2013; Wolf & McGregor, 2013; Mendez-Lazaro, Muller-Karger, (Otis, McCarthy, & Rodriguez, 2017; Stangl, 2018; Savic et al., 2018.)
Population Density	% Population per Km2	(Bao, Li, & Yu, 2015; Romero-Lankao, Qin, & Dickinson, 2012; Nayak et al., 2018; Wolf & McGregor, 2013; Swart et al., 2012; Gamble et al., 2018)

Vulnerability assessment also lacks a unified system of indicators or framework for assessment (Mehrotra et al., 2009). As such, different studies have developed different indicators and frameworks of approach with the most developed theme indicators being those for socioeconomic parameters (Table 2.8).

Table 2.8: Cumulative Vulnerability Assessment Indicators

Sub-variables	Indicators	Units	Authors
Precipitation	Very wet days (90th Percentile)	mm	(Linkd, 2012; Ludera & Yoon, 2015; Marigi, 2017; Centre for e Research and Digital Innovation [CeRDI], 2014; Kumar, Geneletti, & Nagendra, 2016; Revi et al., 2014; Ozkan & Tarhan, 2016)
	Very Dry days (10th Percentile)	mm	
	Mean Annual Rainfall	mm	
	Mean Annual Decadal Rainfall	mm	
	Rainfall Intensity	mm/hr	
Temperature	Mean Annual Maximum Temperature	℃	(CeRDI, 2014; Kumar, Geneletti, & Nagendra, 2016; Revi et al., 2014; Ozkan & Tarhan, 2016; Inostroza, Palme, & de la Barrera, 2016; Wilhelmi & Hayden, 2010; Chuanglin, Yan.Wang, & Jiawen, 2016; Manik & Syaukat, 2015)
	Mean Annual Minimum Temperature	℃	
	Higher Extreme (90th Percentile)	℃	
	Lower Extreme (10th Percentile)	℃	
	Land Surface Temperature, Sky View Factor, Albedo and Solar Exposure		
Population Density, Gender Status and Age	No of People per Km2	Ratio	(Marigi, 2017; Moss, Brenkert, & Malone, 2001; Chuanglin, Yan.Wang, & Jiawen, 2016; Linkd, 2012; Lee, 2014; Ludera & Yoon, 2015; Krellenberg, 2016; Kumar, Geneletti, & Nagendra, 2016; Revi et al., 2014; Adger, Brooks, Bentham, Agnew, & Eriksen, 2005; Rana & Routray,
	% of females in the population	%	
	% of female household heads	%	
		%	

	% Population under 5 years % Population above 65 years	%	2017; Inostroza, Palme, & de la Barrera, 2016; Wilhelmi & Hayden, 2010; Gosain, Ravindranath, Garg, & Rao, 2014; Tapia et al., 2017)
Slope, Landcover, Soil types and, Drainage Density, Elevation, Geology, and Flow Accumulation	% Slope of the area of interest % of different landcover types to the overall area % Permeability Relative height to the lowest point Permeability	% % % % %	(UNEP, 1998; Satapathy et al., 2014; Fussel, 2007; Ludera & Yoon, 2015; Krellenberg, 2016; Chuanglin, Yan.Wang, & Jiawen, 2016; Ozkan & Tarhan, 2016; Ozkan & Tarhan, 2016; Adger, Brooks, Bentham, Agnew, & Erikson, 2004; Krellenberg & Welz, 2016)
Density and Materials	% of the floor area to plot % of type to the total dwelling stock The orientation of Building (E-W) Proximity to UHI Hotspot (CBD) Proximity to UHI Cool spots (Parks) % Ventilation	% % Degree Km Km %	(Lee, 2014; Chuanglin, Yan.Wang, & Jiawen, 2016; Rana & Routray, 2017; Krellenberg & Welz, 2016; Inostroza, Palme, & de la Barrera, 2016; Wilhelmi & Hayden, 2010; Gosain, Ravindranath, Garg, & Rao, 2014; Tapia et al., 2017)
Access to water, energy, waste collection, road infrastructure, drainage infrastructure and to	% of people with access to clean water % of households with electricity	% % %	(Linkd, 2012; Moss, Brenkert, & Malone, 2001; Ludera & Yoon, 2015; Kumar, Geneletti, & Nagendra, 2016; Lee, 2014; Marigi, 2017; Adger, Brooks, Bentham, Agnew, & Erikson, 2004; Rana & Routray, 2017;

healthcare services	% of people with access to waste collection services % Population with paved roads % Coverage of drainage % Population with access to healthcare services	% % %	Inostroza, Palme, & de la Barrera, 2016; Wilhelmi & Hayden, 2010; Manik & Syaukat, 2015; Gosain, Ravindranath, Garg, & Rao, 2014)
Household income	% of people above the poverty level	%	(Linkd, 2012; Lee, 2014; Kumar, Geneletti, & Nagendra, 2016; Satapathy et al., 2014; Fussel, 2007; Adger, Brooks, Bentham, Agnew, & Erikson, 2004; Rana & Routray, 2017; Inostroza, Palme, & de la Barrera, 2016; Wilhelmi & Hayden, 2010; Manik & Syaukat, 2015; Gosain, Ravindranath, Garg, & Rao, 2014; Tapia et al., 2017)
Policy Frameworks Disaster Preparedness	Existence of adequate policy frameworks Adequacy of disaster preparedness	-	(Ludera & Yoon, 2015; Satapathy et al., 2014; Swanson, Hiley, Venema, & Grosshans, 2007; Inostroza, Palme, & de la Barrera, 2016; Gosain, Ravindranath, Garg, & Rao, 2014)
Level of Education	% Population over 25 years without Form 4 education	%	(Marigi, 2017; Ludera & Yoon, 2015; Swanson, Hiley, Venema, & Grosshans, 2007; Fussel, 2007b; Adger, Brooks, Bentham, Agnew, & Erikson, 2004; Inostroza, Palme, & de la Barrera, 2016; Manik & Syaukat, 2015; Gosain, Ravindranath, Garg, & Rao, 2014)

Mobile phone network coverage	% Population with mobile phone	%	(Ludera & Yoon, 2015; Swanson, Hiley, Venema, & Grosshans, 2007; Inostroza, Palme, & de la Barrera, 2016; Gosain, Ravindranath, Garg, & Rao, 2014)
Green Spaces	%Green Space Area	%	(Kumar, Geneletti, & Nagendra, 2016; Satapathy et al., 2014; Inostroza, Palme, & de la Barrera, 2016)

2.5.3 Climate Change Vulnerability Assessment Framework and Method

Proposed approaches to vulnerability assessment vary based on a scale (Ludena & Yoon, 2015). Different approaches have been applied by different studies depending on the location (rural or urban), scope (regional or local) and the elements of interest (biophysical or social). The emerging frameworks are grouped either deductive or inductive; top-down or bottom-up. The inductive is data-driven while the deductive is theory-driven (Ge, Dou, & Dai, 2017). The top-down approach considers climatic parameters as the starting point while the bottom-up approach considers the adaptive capacity of the people as the starting point (Satapathy et al., 2014).

Despite the different approaches in the method of vulnerability assessment, aspects such as spatial and temporal considerations are common. Other critical aspects include attributes of time and exposure (Madruga et al., 2011). Vulnerability assessment also requires mapping (Fussel, 2007). Because of the nature of the climate-related vulnerability, historical data are significant (Sherbinin, 2014). Twigg (2015) advocates for the combination of both quantitative and qualitative aspects.

The selected method combines components from Satapathy et al. (2014), Linkd (2012) and Feenstra et. al., (1998). It favours an integrated approach that combined both qualitative and quantitative elements of the urban environment and climate. This is because the parameters under consideration are biophysical and socioeconomic. The combination is based on the multi-dimensional nature of vulnerability which requires comprehensive considerations (Birkmann et al., 2014).

The aspects that guided the assessment included:

1. Purpose of the Assessment.
2. Planning the Assessment. The planning includes:
    a) Setting the geographic boundary of the study area
    b) Determining the System of interest: Whether biophysical or socioeconomic.
    c) Unit of Measurement: Determining the unit of measurement. Scales can be city-wide, landuse types, elective units, or administrative locations.
    d) Approach: Either Top-Down or Bottom-Up. A Top-Down approach recommended when dealing with biophysical elements.
3. Assessment using quantifiable indicators. This follows the components of vulnerability: sensitivity, exposure, and adaptive capacity.
    a) Assess the Profile of Current System
    b) Assess the observed data.
    c) Assess the effects of climate stimuli on the system.
    d) Assess the tools of response to climate variability and extremes.
4. Combining all the above to determine current vulnerability. The vulnerability can then be classified into low, medium, high, and extreme.

Since the measured values in item three above are of different units, normalization as expressed in equation 2.5 is often used (Swanson, 2012; Inostroza, Palme, & de la Barrera, 2016).

$$N_v = \frac{V_u - V_{min}}{V_{max} - V_{min}} \quad (2.5)$$

Where N_v is the Normalized Value of the parameter of interest; V_u: Value of the parameter of interest; V_{min}: Minimum value of the parameter in the complete study area and V_{max}: Maximum value of the parameter in the complete study area.

In the combination in part 4, weighting of the scores in each of the cases is key (Linkd, 2012; Ozkan & Tarhan, 2016). This approach was favoured as it uses a pairwise approach and relies on expert opinions to determine the rankings in the weighting (Getahun & Gebre 2015; Dou et al., 2017; Chen, Ito, Sawamukai, & Tokunaga, 2015; Gigovich, Pamucar, Bajic, & Drobnjak, 2017 and Ouma & Tateishi, 2014).

Vulnerability is often represented spatially by various authors using colour codes which have been green, yellow, orange and red. Green for low, yellow for medium, orange for high and red for extreme (Petersen et al., 2014). Notable is that these have variations of shades depending on the minor classifications which could either be Low to Extreme or Low-Low to High-High (Figure 2.18).

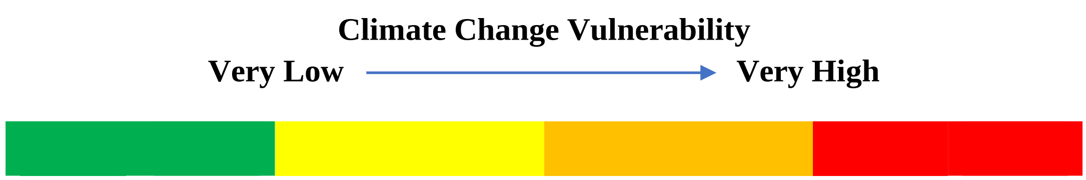


Figure 2.18: Climate Vulnerability Colour Codes

One limitation of this methodology is subjective nature of the classification into the various groups (Gosain, Ravindranath, Garg, & Rao, 2014). This aspect is best managed through the consideration of the types of vulnerability namely flood and heat vulnerability separately.

Vulnerability and risk assessment are critical precursors to climate change adaptation. They determine the need for adaptation and how to conduct it since climate change is dynamic and affects different components of human life in unique ways (UNFCCC, 2011). The uniqueness is determined by factors of exposure, sensitivity, and adaptive capacity and how they interact with external drivers (Figure 2.19).

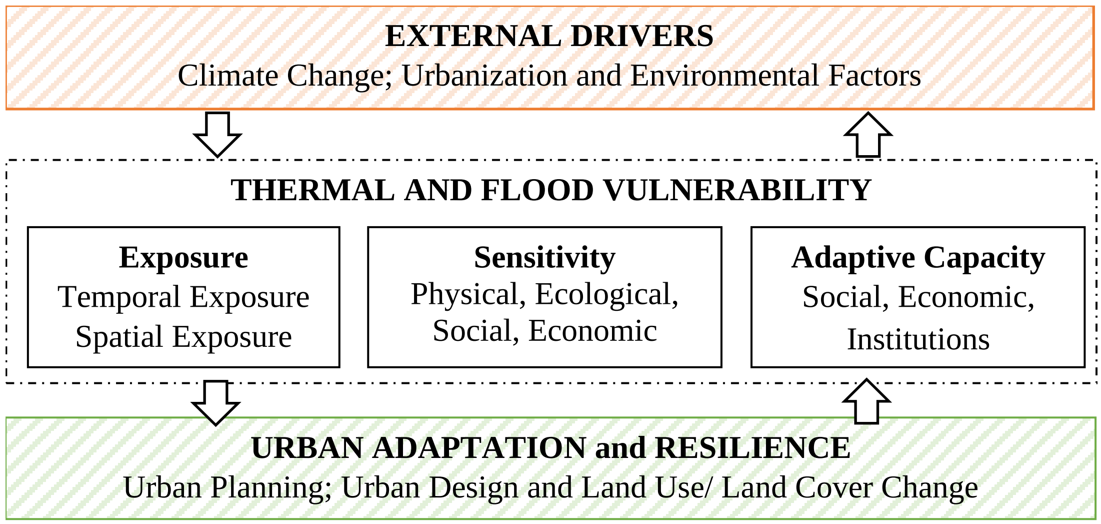


Figure 2.19: Thermal and Flood Vulnerability Analysis Framework

2.6 Climate Change Adaptation and Resilience Approaches in Urban Areas

Management of urban vulnerability to climate requires climate action. Climate action, at all the scales, falls into the two categories of mitigation or adaptation (Fussel & Klein, 2006). Climate mitigation is concerned with reducing the levels of greenhouse gas emissions in the atmosphere. Adaptation focuses on coping with impacts through adjustments in human and/or natural systems to reduce adverse impacts or take advantage of opportunities (UNFCCC, 2007; IIED, 2016).

Climate action bestows economic benefits, aids in the achievement of national development goals and reduces climate-related disasters that cause loss of life and livelihood (Ashley, Kenton, & Milligan, 2009; World Bank, 2010; UN-Habitat, 2011). As such, it should inform the renewal, regeneration, and development of old and new urban locations (Shaw, Colley, & Connell, 2007; Pattacini, 2012).

On the global scale, mitigation efforts are more established than adaptation measures (Sattethwaite, Huq, Reid, Pelling, & Lankao, 2009). Nonetheless, adaptation measures are already taking place globally albeit in a limited way and with extensive variations across societies due to varying capacities (IPCC, 2007b). The principal characteristics of adaptation are that it benefits most of the urban systems, affects both local and regional scales, fully benefits the payer and has an immediate lead time (Fussel & Klein, 2006).

They often benefit the location where they have been conducted or have a knock-on effect on other areas (IPCC, 2014a).

Climate change adaptation is a complex, dynamic process that cuts across scales, sectors, and levels of intervention. The scales of implementation are citywide to neighbourhood, site, and building (Lindfield & Steinber, 2012). They can also make use of both natural elements such as water and trees, or materials of construction (Hough, 2002). The interventions can target specific weather elements, or a combination of different weather elements such as precipitation, temperature, and wind, even though Wilbanks (2011) advocates for consideration of other development-related stresses. Nonetheless, aspects of institutional and governance frameworks also play a compelling role (IPCC, 2014a). However, the effectiveness and efficiency of the natural elements depend on the climate of the region, the slope of the site and the nature of the built-up area (Hough, 2002).

Cumulatively, four elements are critical for successful adaptation. First is an understanding of current physical and socioeconomic changes. Second is the design and implementation of adaptation measures. Third is the need for coordinated action by all stakeholders. Fourth is the availability of reliable information on actions (IIED,2016).

Adaptation approaches have schemes such as cooling services and designs, energy and water supply security, flood protection, relocation and zoning, blue and green infrastructure, building codes for extreme weather, early warning systems, and behaviour-based services (Broto & Bulkeley, 2013). These measures can be classified into built environment initiatives, water sensitive urban design approaches, landuse planning and biodiversity conservation.

2.6.1. Built Environment Adaptation Measures

The built environment in urban areas occurs at different scales. It can exist at a holistic mesoscale of the entire urban area and catchment or the individual buildings' microscale. Several authors have outlined the scales as either catchment scale, neighbourhood scale or the building scale on one hand or regional, city and neighbourhood on the other (Shaw, Colley, & Connell, 2007). The scales determine the appropriate types of adaptation measures.

Built environment adaptation measures encompass avoidance, improvement, and replacement (Rattanachot, Wang, Chong, & Suwansawas, 2015). Replacement is concerned with the substitution of built environment elements that make it prone to climate hazards such as changing from non-porous to porous paving. Improvement includes upgrading the status of existing elements such as the addition of street trees. Avoidance is concerned with totally avoiding risky elements such as paving of green spaces.

Hough (2002) opines that infrastructure systems such as roads, waterfronts, and railway lines have idle land that can green the urban areas as a green infrastructure improvement approach. Green and blue infrastructure systems can assist in adaptation through thermal regulation, runoff regulation and biodiversity conservation for evaporative cooling. Additional approaches include the provision of shade, water interception, storage, and infiltration to minimize flooding risk and enhance aquifer recharge (Demuzere et al., 2014; Gill, Handley, Ennos, & Pauliet, 2007). These functions are based on the ecosystem services of urban natural systems (Table 2.9).

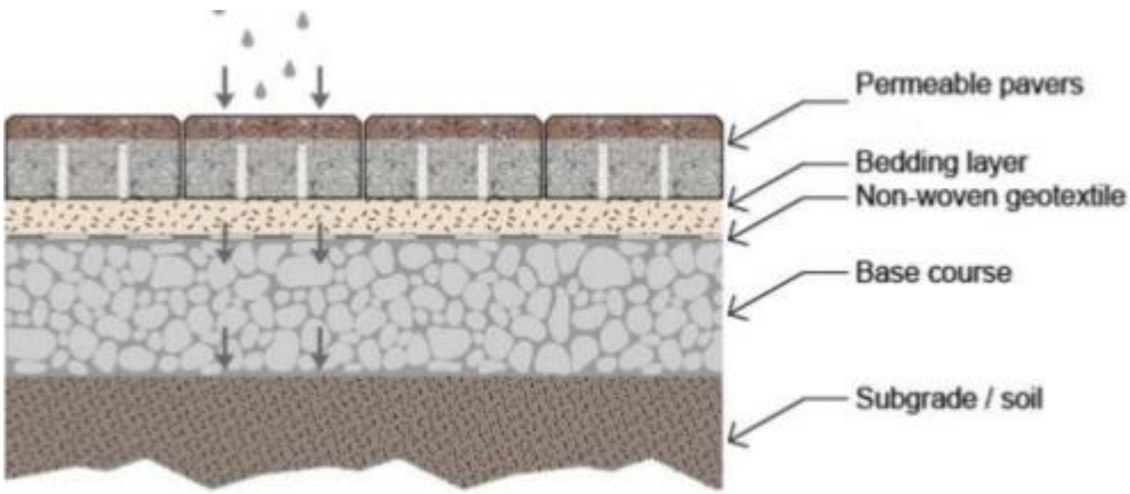
Table 2.9: Ecosystem Services of Different Urban Natural SystemsEcosystem Services of Different Urban Natural Systems

Ecosystem Services	Street Vegetation	Lawn and Parks	Urban Forests	Wetlands	Streams	Eco-roofs and Walls
Air Filtration	X	X	X	X	-	X
Micro-climate Regulation	X	X	X	X	X	X
Noise Reduction	X	X	X	X	-	X
Rainwater Drainage	X	X	X	X	X	X
Recreation/ Cultural	X	X	X	X	X	X
Sewage Treatment	-	-	-	X	X	-

Effectiveness of green infrastructural systems is dependent on the quantity, quality, connectivity of the green spaces, and the level of integration between the different green and blue systems in urban areas (Zinia & McShane, 2018). The larger the quantity, the better the quality and connectivity, and the more integrated green infrastructure, the more effective they are in climate change adaptation.

Specific approaches used at the built environment scale come at the building level, street level and green open space levels. Building level interventions are at the roof and facades as eco-roofs and walls. Street interventions exist as cool and permeable paving and street vegetation. Green open space interventions come as green parks at different scales. (Shaw, Colley, & Connell, 2007; Foster, Lowe, & Winkelman, 2011; Hoverter, 2012; EPA, 2008c; Brown, Vanos, Kenny, & Lenzholzer, 2015; Bolund & Hunhammar, 1999).

The first green infrastructural element is cool and/ porous pavements. They are pavements that have reflective and emittance properties (Environmental Protection Agency [EPA], 2008c). They either reflect or emit low amounts of received thermal component and conserve aquatic biodiversity by reducing the temperature of runoff water that ends up in the natural water systems (Hoverter, 2012). They also have voids that trap water and air (Figure 2.20), allowing for evaporative cooling in warm weather conditions and reduced runoff volumes (Battista & Pastore, 2017; Mohegh et al., 2017; Qin, 2015b, 2015a). To enhance their effectiveness in ameliorating UHI during the dry seasons, watering is recommended (Hendel, Gutierrez, Colombert, Diab, & Royon, 2016).



Source Vanam, (2017)

Figure 2.20: Porous Paving for Storm Water Management

The second element is Eco-roofs and walls (Figure 2.21). They are either planted, cool or blue roofs and walls (Foster, Lowe, & Winkelman, 2011). The most researched and published ones include cool and green roofs and green walls. Green roofs and walls are vegetative layers grown on a rooftop while cool roofs are roofs made of highly reflective and emissive materials (EPA, 2008a; EPA, 2008b). According to Price, Jones, and Jefferson (2015), eco-walls are likely to be even more effective in urban cooling than eco-roofs as they can cover a larger area.

Eco-roofs and walls reduce the rate of flow of stormwater and heat loading, increase storage in the substrate and purify the suspended particles in water (Alcazar, Olivieri, & Neila, 2016; Francis & Jensen, 2017; Mayrand & Clergeau, 2018). They also reduce water acidity (Zhang et al., 2015; Berland et al., 2017). Additional benefits key to climate change mitigation include reduction in air pollution, a reduction in carbon dioxide emissions and carbon sequestration in cases of intensive green roofs (Lee, Kim, & Lee, 2013).

Source: Garden Design Academy, (2020)

Figure 2.21: Ecoroofs and Walls

Factors that determine the effectiveness of eco-roofs and walls include the plant species, type of substrates, size of plants and the elevation at which they are (Jim, 2015). They also perform better when they are on shorter buildings and upwind of taller buildings since the cool air is then deflected to the lower areas (Myint, Recktenwald, & Sailor, 2015). Their functionality also depends on the green roof typology which can either be extensive or intensive; extensive having mainly stonecrop species while intensive having normal garden plants including trees (Poórová & Vranayová, 2020; Lee, Kim, & Lee, 2013; EPA, 2008a).

The third element is greenways, parks, and street vegetation (Figure 2.22). Park and street vegetation provide ecosystem services such as cooling, biodiversity habitat, and surface runoff regulation through shading and evapotranspiration cooling (Stone, Hess, &

Frumkin, 2010; Duarte, Brown, Vanos, Kenny, & Lenzholzer, 2015). In the management of thermal stress, park and street vegetation are most effective, followed by water, grass, green roofs, and street orientation (Chatzidimitrious & Yannas, 2015; Andersson-Sköld et al., 2015).

Source Kalvapalle, (2016)

Figure 2.22: Greenways and Street Vegetation.

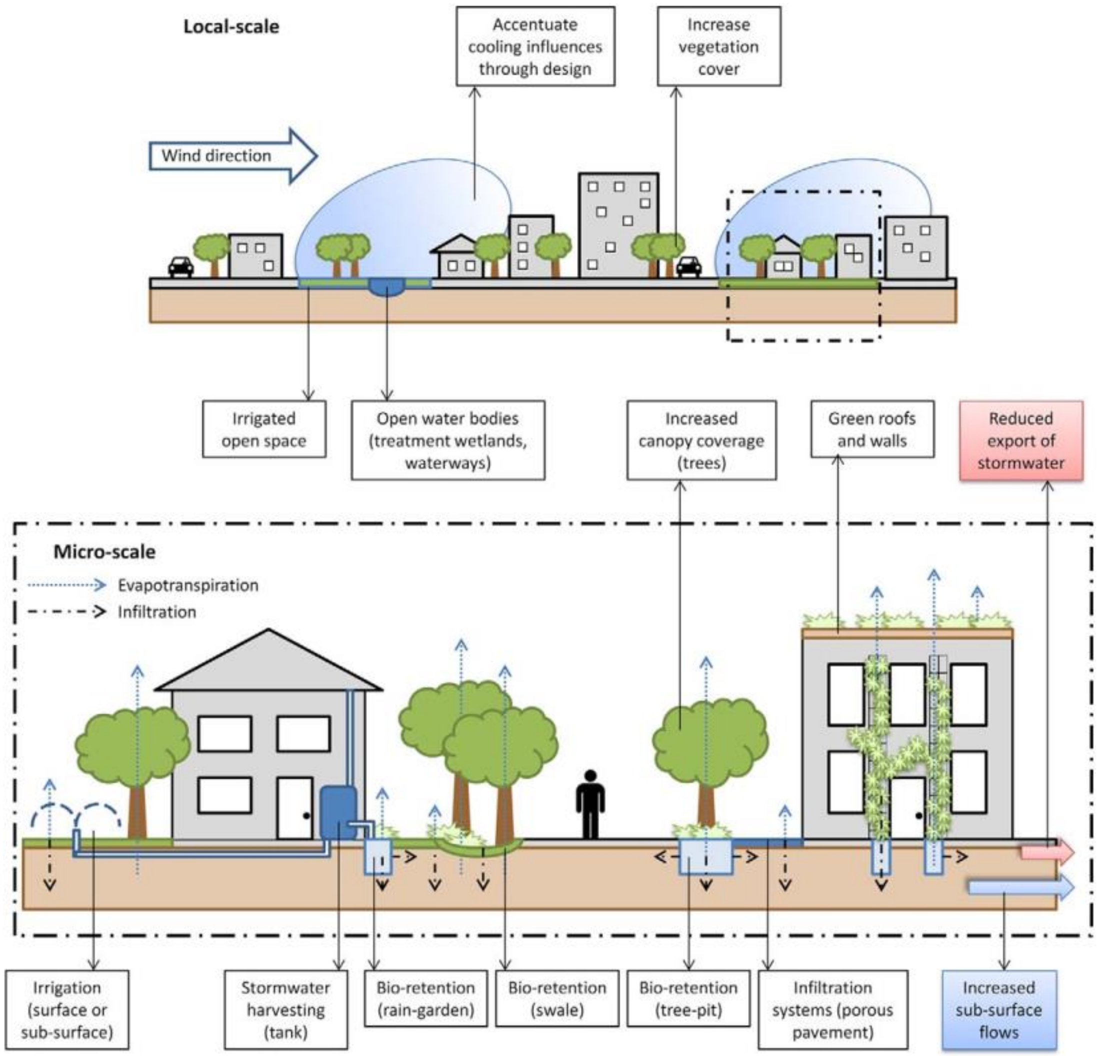
Effectiveness of trees/vegetation in climate amelioration is determined by the species, planting design, distribution, and orientation (Brown R., 2010; Wenting, Yi, & Hengyu, 2014; Morakinyo & Lam, 2016). On species, a mix of evergreen and broadleaved deciduous trees have the highest temperature regulation ability followed by deciduous broadleaved then coniferous trees (Wenting, Yi, & Hengyu, 2014). Deciduous trees offer cooling benefits in summer while evergreen ones offer shading all year round (Brown, 2010). The effectiveness of shading is dependent on height and canopy coverage (Hough, 2002). The greater the closed canopy of a city's trees, the bigger its impact on moderating surface temperatures (Hough, 2002). Smaller well-distributed parks also perform better than larger central parks in temperature regulation (Morakinyo & Lam, 2016). Zhao, Fu, Liu, & Fu (2011) supports and notes that denser gardens and tree cover is predisposed to perform better.

2.6.2 Water Sensitive Urban Design

Water plays a considerable role in the challenges posed by climate change in urban areas. It exposes urban areas to flooding risk. However, it also assists in thermal regulation. As such, the management of water either through water sensitive design or sustainable urban drainage can play a momentous role in the adaptation of urban areas to multiple impacts of climate change (Shaw, Colley, & Connell, 2007).

The concept of water management in urban areas is referred to by different names: Low Water Impact Development in the U.S.A., Sustainable Urban Drainage Systems in the United Kingdom and Water Sensitive Urban Design in Australia. Nonetheless, they involve the percolation, collection, treatment, and storage of stormwater (Gogate, Kalbar, & Raval, 2017). Alongside adaptation, these initiatives can help in meeting the growing global water demand (Chang, Lu, Chui, & Hartshorn, 2018). The interventions can be applied in the city or local scales (Figure 2.23).

The elements used include vegetated bio-retention systems, porous pavements, wetlands, bio-swales rainwater tanks, rain gardens, and stormwater ponds. Other mechanisms include rain barrels and cisterns, stormwater planters, infiltration ponds, vegetated buffers, and green rooftop systems (Fletcher et al., 2008; Zölch, Henz, Keilholz, & Pauleit, 2017). The effectiveness of some of the systems is enhanced by having vegetation in them. Hough (2002) recommends the preservation of natural drainage systems either as swales, retention or detention ponds which should be protected as easements with undisturbed undergrowth. This approach encourages percolation of water into the ground thereby reducing surface runoff. It also provides for incorporation of nature in the otherwise highly paved urban systems. However, they often require higher maintenance compared to the paved drainage systems.



Source: Coutts, Tapper, Beringer, Loughnan, & Demuzere, (2012)

Figure 2.23: Water Sensitive Urban Design Interventions at the Citywide and Local Scales

Urban planning is a societal tool charged applied to bringing order and minimizing or eliminating conflict between the different components of the urban system (Matthews, 2011). The spatial configuration of cities and towns, and how land is used and developed, have some compelling implications for adaptation (Stead, 2013). Aside from adaptation, certain urban patterns also ensure sustainable development initiatives such as the green economy (Robinson et al., 2012).

Landcover planning acts through preventive and curative approaches. They can be used in either ensuring developments are kept away from climate risk-prone areas, or infusion of ameliorative land uses where needed. For instance, green open spaces can function as flood plains and wetlands to control flooding or the relocation of informal settlements from vulnerable locations prone to floods and landslides (Hamin & Gurran, 2009).

2.6.4 Biodiversity Conservation

Adaptation approaches should consider biodiversity conservation measures such as the designation of reserves, increased habitat connectivity and countering the UHI effect (Wilby & Perry, 2006). Landscape Architecture interventions can be applied as they consider both the social and natural benefits of urban biodiversity (Pickett et al., 2001). This should be done at a more regional scale to ensure better success in meeting ecological services (Robinson et al., 2012). The success is dictated by ecological concepts such as connectivity, contiguousness, and networks.

2.6.5 Challenges Facing Adaptation

Urbanization in low- and middle-income countries occurs in the unplanned urban fringes of urban areas with massive urban sprawl (Sattethwaite, Huq, Reid, Pelling, & Lankao, 2009; UN-Habitat, 2014b). This happens in either the high vulnerability zones of informal settlements or sub and peri-urban areas that were not originally within the planned boundaries of the city. As a result, deficiencies in infrastructure, low economic standards, and lack of technology pose challenges to adaptation in these areas (Sattethwaite, Huq, Reid, Pelling, & Lankao, 2009; UNFCCC, 2011).

Inadequate knowledge or data in certain locations and the inability to predict certain climate-related scenarios with a high degree of precision is another challenge facing adaptation (IPCC, 2007b; IPCC, 2014a). The uncertainty involving the future impacts of climate change and the possibility of changes occurring or stabilizing is affecting adaptation and planning for adaptation (Associated Programme on Flood Management, 2012).

Human, financial and institutional capacities remain a major challenge for climate change action in the developing world (UNFCCC, 2011; Leal Filho & Nalau, 2018). Adaptation is likely to be a challenge since the most vulnerable populations are usually the urban poor who are often overlooked in planning, funds allocation and enforcement of adaptation initiatives (Ashley, Kenton, & Milligan, 2009). This is shown by Douglas et al., (2008) who point out that in Africa, climate change adaptation has been individually driven. Where it has been institutionalized, the focus has been on adaptation in rural areas at the expense of urban areas and in a fragmented manner (Bulkeley & Tuts, 2013). Some adaptation approaches require intense investment which may not be a major budgetary priority for the developing countries (World Bank, 2010; IPCC, 2007b).

Most climate change adaptation approaches have been a top-down approach with notable challenges of lack of appreciation of challenges unique to specific communities (Ashley, Kenton, & Milligan, 2009). Social and cultural barriers also pose a challenge to climate change adaptation. They affect the way societies experience, interpret, and respond to climate change (IPCC, 2007b). For example, in African societies within the urban areas, using recycled greywater may be a challenge for most urban dwellers.

There is conflict between adaptation and mitigation in planning. For example, as Stone, Hess, and Frumkin (2010) argue in favour of a compact city form as an adaptation to dealing with the effects of extreme heat events, Hamin and Gurran (2009) point out that a sprawling urban area with established green fingers may be a better approach in adapting to flood risks. This discourse is carried further to whether planning as a tool should be used for adaptation or mitigation (Stead, 2013). To counter these challenges, Hamin and Gurran (2009) suggest an integrated approach where green spaces are fused into settlements but as ribbons along transportation corridors and drainage systems as opposed to the large expanse and having them designed for multiple uses like urban agriculture, parks, and flood plains.

2.7 Theoretical Framework

The theoretical framework considers three theories namely the theory of good city form, ecosystems theory, and the Integrated Urban Ecosystems Theory (IUET). The choice is based on the interlinked and sometimes cyclic relationship between urban land uses, urban forms and natural systems as pointed out by Moughtin and Shirley (2005). Environmental and social processes influence land use and urban forms. The ecological processes influence the functionality of urban areas in certain cadres (Breuste, Haase, & Elmqvist, 2010).

2.7.1 Theory of Good City Form

The theory of good city form, as proposed by Lynch (1981), highlights three concepts (Figure 2.24). First is the appreciation of urban areas as ecosystems made up of interdependent sub-systems. As such changes to one sub-system are likely to influence the performance of the other subsystems. Second is the relationship between the human and natural environment in determining the performance and sustenance dimension of good urban forms. The third is the consideration of flow versus adapted systems when observing urban areas. Lynch defines flow systems as the circulatory aspects and adapted as the usable non-circulatory systems.

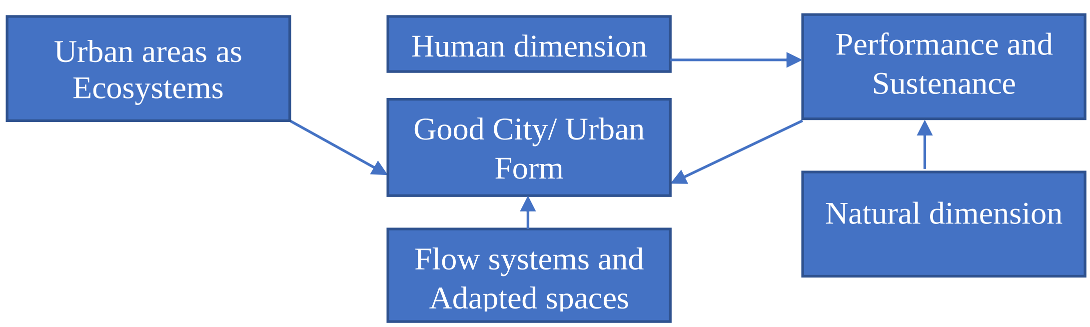


Figure 2.24: Concepts of Good City Form Theory Relevant to the Study

2.7.2 Ecological Systems Theory

The ecological systems theory is derived from the general systems theory and traces its origins to the transcending relationships between physics and ecology from the 1960s.

The general systems theory has been observed to exist in fields like earth sciences, geo-form, meteorology, ecology, biology, and general popular thinking (Bertalanffy, 1968; Pickett, Kolasa, & Jones, 2007). Ecosystem theory comprises many integrated concepts such as, the network and hierarchical concepts (Jørgensen, 1997), all of which call for expanded knowledge in the fields of meteorology, geology, and hydrology (McIntosh, 1985). Three of Jørgensen's (2007) proposed eight laws of the ecosystems' theory are relevant in the interaction between the natural and man-made elements in urban areas.

Firstly, all ecosystems are open and embedded in an environment from which they receive energy-matter input and discharge energy-matter as output. This points to the interactive nature of the relationship between natural systems and man-made features. Secondly, ecosystems have levels of organization and work hierarchically. Within an urban context and based on the first law, this means that an impact at the bottom of the system is likely to exponentially affect other systems. Thirdly, non-ecological entities exist in isolation but are linked to other entities. This draws the link between the ecological biophysical parameters and non-ecological socioeconomic parameters of vulnerability in urban areas.

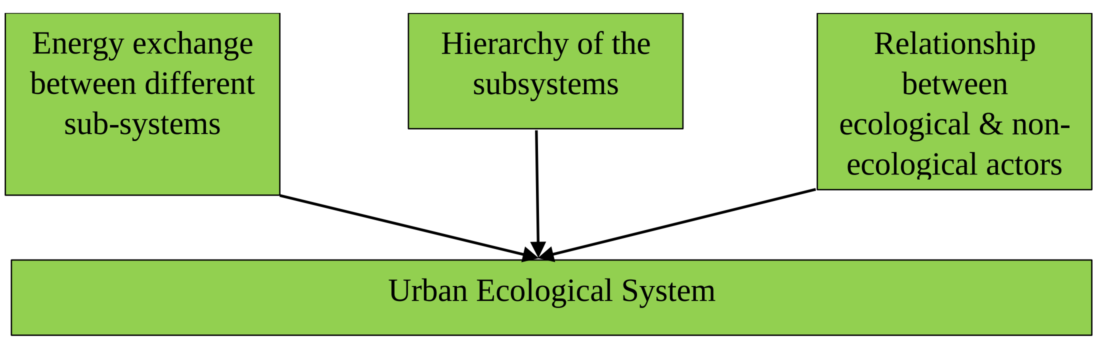
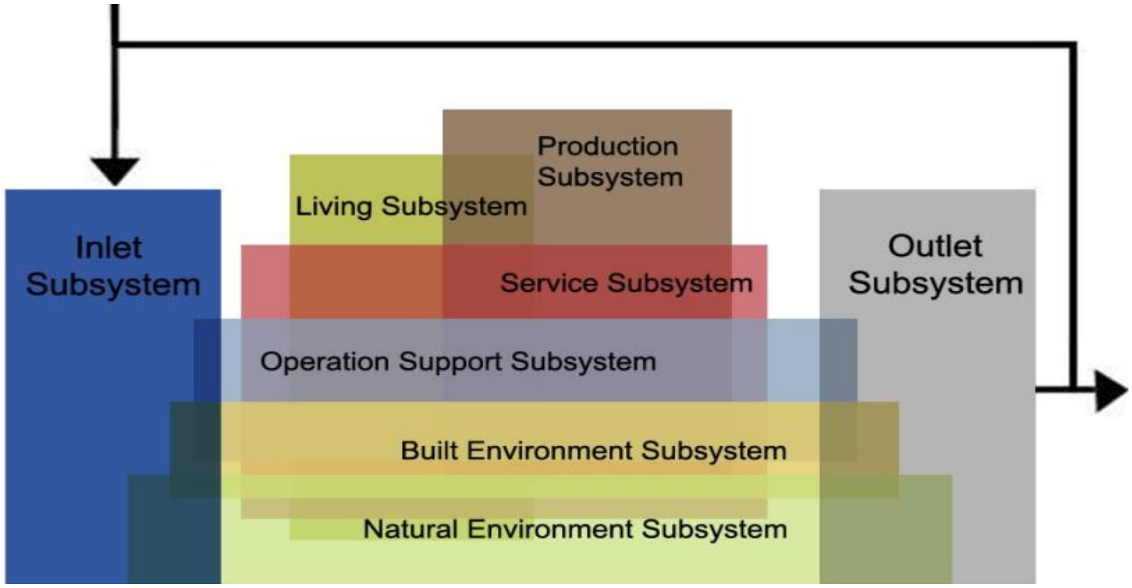


Figure 2.25: Aspects of Ecological Systems Theory Relevant to the Study

2.7.3 Integrated Urban Ecosystems Theory

The Integrated Urban Ecosystems Theory (IUET) is a continuation of what Mugerauer (2010) argues is the progression towards developing urban ecological theory. The theory as put forward by Steward, Pickett, Burch Jr, Dalton, and Foresman (1997) and supported by Huang and Du (2010), denotes the relationship between the sub-systems in urban areas (Figure 2.26).



Source: Huang & Du (2010)

Figure 2.26: Integrated Urban Ecosystems Theory Model

It outlines the momentous role played by the natural system in the survival of urban areas. This argument is further lent credence by the various authors on ecosystem services in urban areas as summarized in Table 2.10 (Bolund, 1999; Elmqvist et al., 2015).

Table 2.10: Ecological Services and their Quality-of-Life Indicators in Urban Areas

Sustainability Dimension	Urban Ecosystem Service	Quality of Life Indicator
Ecology	Air Filtration; Climate Regulation; Noise Reduction; Rainwater drainage; Water Supply; Wastewater Management and Food Production	Health (clean air, protection against cold and heat death); Safety; and Drinking water.
Social Sphere	Landscape; Recreation; Cultural Values; Sense of Identify	The beauty of the environment; Recreation and Stress reduction; Intellectual endowment; Communication and Place to live

Urban ecosystems offer various services to urban areas which can be classified as either provisioning, cultural, regulating, habitat and supporting services (Breuste, Haase, & Elmqvist, 2010). Even though they have been discussed in a different context, the ecosystem services as enumerated in Table 2.8 are like climate change adaptation, and those considered by authors such as Oke (1995) and Erell, Pearlmutter, and Williamson (2011) in urban climate amelioration.

In the conceptualization of urban systems, Breuste, Haase, and Elmqvist (2010) considers the goal of urban systems the well-being of human beings. This aim's achievement relies on the provision of basic human needs, access to goods and livelihood opportunities, security, health, social relations, and freedom, which are derived from natural resources and services provided by ecosystems. That said, Huang and Du (2010) denote the significance of the natural environment in supporting all the other seven subsystems. A position supported by Pickett et al., (2001) who further points out the significance of considering physical and socioeconomic systems when viewing ecological systems.

2.8 Conceptual Framework

The interaction between urban areas and climatic parameters occurs at the scale of urban surfaces, which manifest as either land uses or landcover. As such, urban areas have unique climates different from the regional climate in which they are. Due to this, they are affected by both the global or regional climate and their unique urban climate. Global climate change influences regional precipitation, temperature, and wind patterns.

The unique urban climate exhibits certain characteristics that differ from the regional climate. This difference is caused by the confluence of urban physical characteristics and regional climates. The physical characteristics include density, landcover, surface roughness, and construction materials. The resulting unique phenomena include UHI, unique wind patterns, and unique precipitation dynamics. Impacts caused by the unique urban climate include flood risk and thermal stress risk. Risks translate to hazards when exposed to vulnerability components of exposure, sensitivity, and adaptive capacity.

Climate action exists as either mitigation or adaptation. Adaptation is a more urgent climate action need in the developing world compared to mitigation. The adaptation approaches proposed in literature lean towards the modification of the urban physical environment. Existing theories on urban systems like the IUET Theory and Theory of Good Urban Form support this approach and stress the significance of both human and non-human, ecological and non-ecological, physical, social, and biological factors in the development of resilient and cohesive urban environments. They echo the interlinked nature of urban systems and further note that the natural system is the most critical in urban areas as it bears all the other systems and has direct contact with each of them. For a fully functional, harmonious, and resilient urban environment, the natural subsystem needs protection from the negative impacts of other subsystems. The natural subsystems within the urban planning and design context include elements like parks, lakes, rivers, wetlands, waterfronts, forests, and other green open spaces. It also encompasses urban vegetation in its various forms namely trees, shrubs, and groundcovers.

Deductively, action on the natural subsystem would achieve exponential success in the other subsystems. This is effective alongside the other urban physical elements viz. materials of buildings, the orientation of streets and extent of green spaces. The largest part focuses on using ecosystem-based approaches such as green infrastructure systems in the management of the thermal and stormwater component. The interventions include eco-roofs and walls, distribution of green open spaces, planning, and zoning to avoid intensive development vulnerable locations and sustainable management of stormwater.

These adaptation measures will not only contribute to climate resilience at the local scale, but they have the potential of mitigating climate change alongside the amelioration of urban climate challenges even if climate change and variability is eliminated from the equation. For instance, the distribution of green open spaces can manage air quality. Street vegetation can perform carbon sequestration. Bioswales can filter and percolate stormwater, thus recharging urban water aquifers.

The conceptual model (Figure 2.28) shows the relationship between the different variables discussed above. These are grouped under four main classes: urban dynamics, climate, vulnerability assessment, and urban resilience/ adaptation. Urban dynamics encompass urban form and socioeconomics, which influence and are also influenced by climate. The climate component has 2 facets: unique urban climate and global climate change. These influence each other but also interact with urban form to dictate different vulnerability levels. These vulnerabilities are either thermal stress or flood related. The management of climate vulnerability is through climate change adaptation. This aids in improving urban resilience. The relationship between urban resilience/ adaptation and the other three variables is multidirectional. For instance, urban form determines the type of urban adaptation initiatives, while adaptation initiatives modify urban form elements for them to reduce vulnerability and increase resilience.

As such, the null hypothesis (H_o [Equation 2.6]) portends that urban form does not influence climate change in the City County of Nairobi. The alternate hypothesis (H_a

[Equation 2.7]) signifies that urban form influences climate change vulnerability in the City County of Nairobi.

$$H_o: \beta = 0 \; for\ all\ regression\ coefficients\ of\ urban\ form \quad (2.6)$$

$$H_a: \beta \neq 0 \; for\ at\ least\ one\ regression\ coefficient\ of\ urban\ form \quad (2.7)$$

2.9 Operational definition of terms

The operationally defined terms in the hypothesis are urban form, climate change, and vulnerability (Table 2.11). Urban form was measured as landcover (Km^2), Normalized Difference Vegetation Index (NDVI) and Population Density (People/ Km^2). Climate was measured from the climatic elements of average annual minimum temperature (℃), average annual maximum temperature (℃), highest annual temperature (℃), lowest annual temperature (℃), and annual rainfall (mm). Vulnerability was an expert ranking based aggregate of urban form, climate, and socioeconomic parameters. The socioeconomic parameters were poverty (%), age (%), gender (%) and access to services (%).

Table 2.11: Operationalization of Variables

Variable	Parameters	Sub-parameters	Units
Urban Form	Landcover	Built-up area	Km^2
		Forest	Km^2
		Open Space Network	Km^2
		Normalized Difference Vegetation Index	Unit
	Elevation	Elevation	m ASL
	Slope	Slope	%
		Flow accumulation	Unit
	Soil	Soil drainage properties	%
	Density	Population density	People/ Km^2
Climate	Temperature	Average annual maximum temperature	℃
		Average annual minimum temperature	℃
		Highest annual temperature	℃
		Lowest annual temperature	℃
	Rainfall	Annual rainfall	mm

Urban resilience in a changing climate depends on the development of adaptation mechanisms. The prescription of adaptation approaches requires a clear determination of different vulnerabilities. Climate oriented vulnerability assessment relies on the evaluation of biophysical and socioeconomic characteristics. These characteristics have been found in certain circumstances to be intricately linked with and manifested as urban form.

Urban form influences the interaction between climatic elements and urban areas. This influence is based on the different landcover typologies. For instance, built-up areas worsen the UHI effect and increase surface runoff through thermal loading and surface sealing, respectively. These expose urban areas to heat and flooding risks. The vulnerability of urban areas to climate is therefore two-tier. Firstly, through unique urban climates because of urbanization. Secondly, through the globally changing climate that exposes urban areas to impacts such as flooding and thermal stress at the regional level.

Management of urban vulnerability to climate change is through adaptation. Climate change adaptation is through response to an individual or a collection of climatic parameters. Common approaches appear to be ecosystem-based, for instance, the green and blue infrastructure and water sensitive design. As such, an ecosystem-based approach is ideal in enhancing urban resilience to based climate change vulnerability as it responds to the intricate relationships between urban form, urban climate, climate change and vulnerability as shown in Figure 2.27 and Figure 2.28.

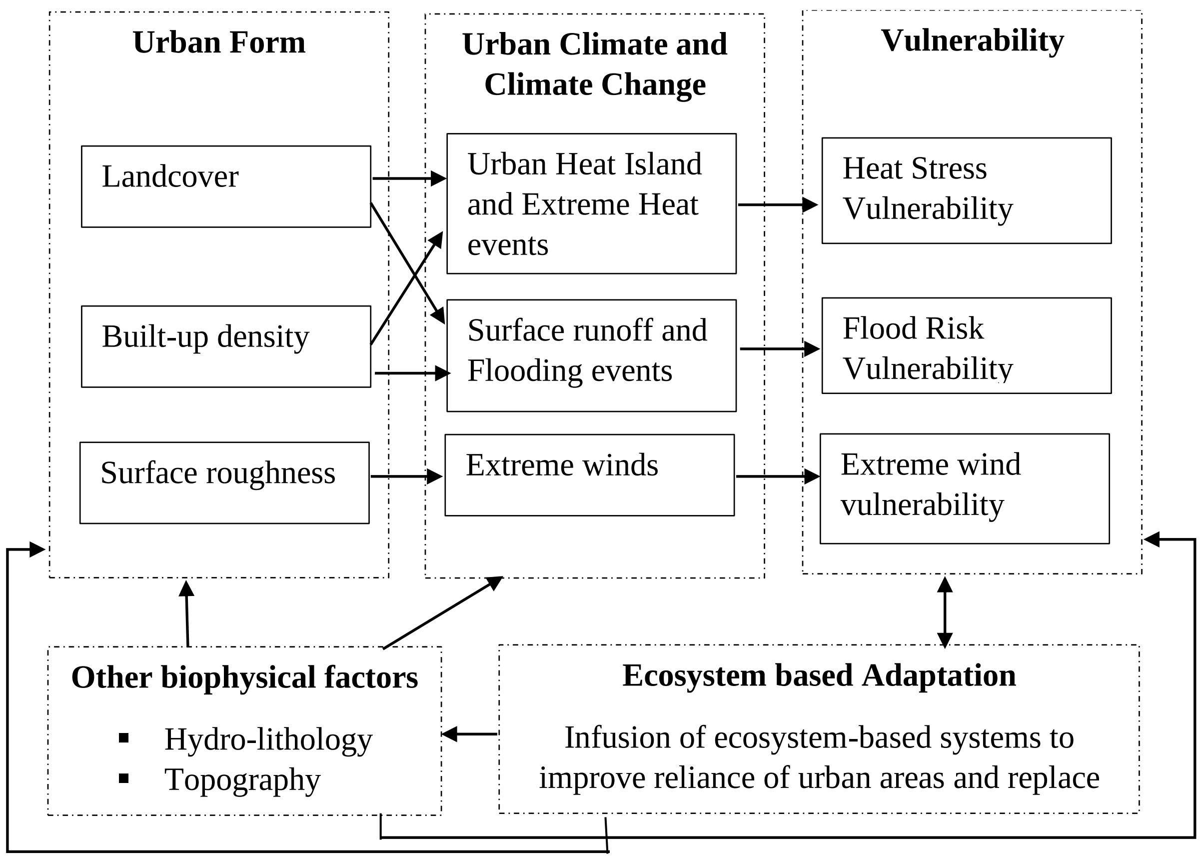


Figure 2.27: Relationship Between Climate Change, Urban Form, Vulnerability, and Adaptation Approaches

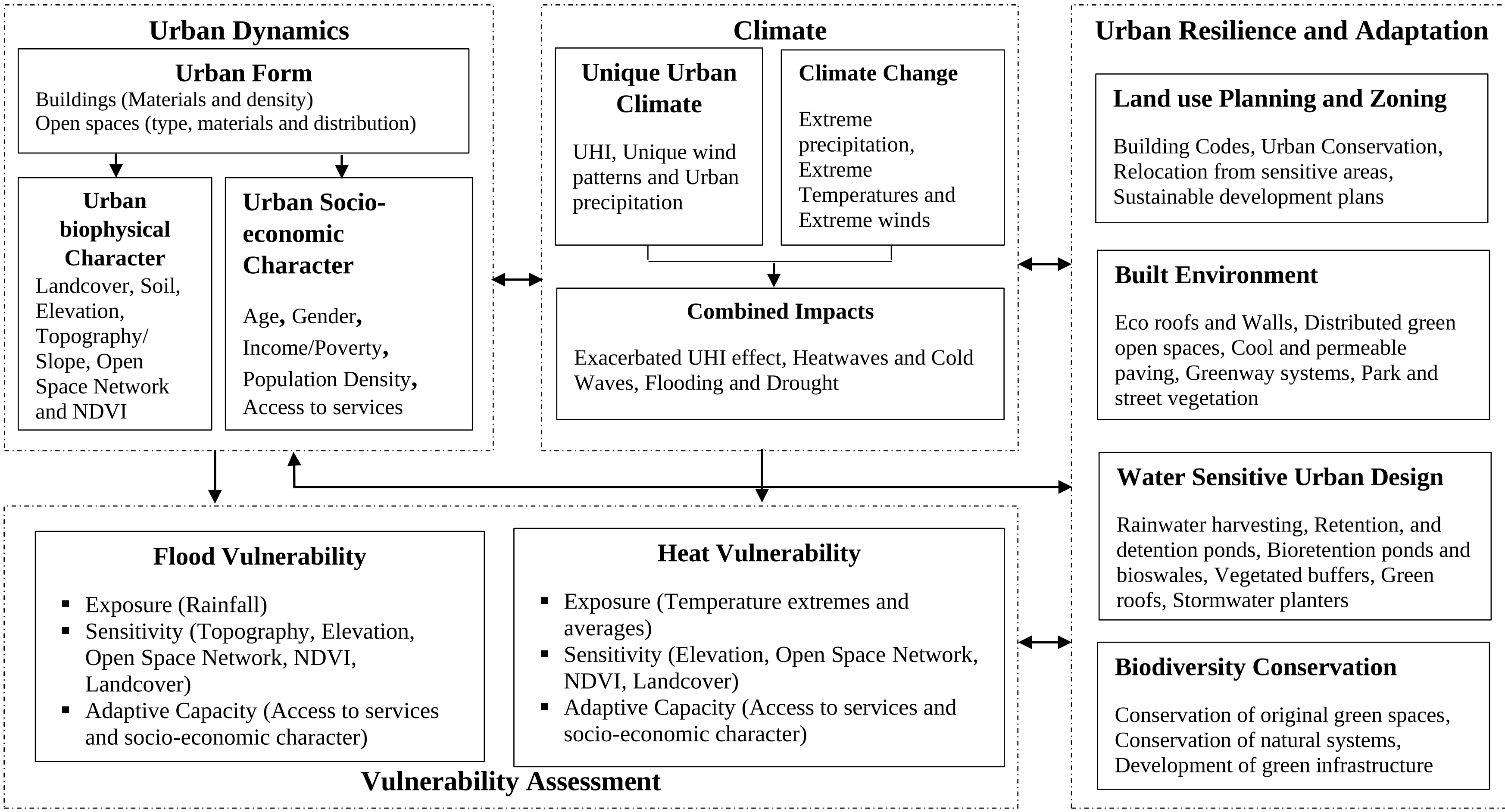


Figure 2.28: Conceptual Model for Urban Climate Vulnerability Assessment, Resilience and Adaptation

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses key aspects of the City County of Nairobi County. It outlines the history of Nairobi's urban planning from 1898 plan to the Integrated Urban Plan of 2014, key physical characteristics, and the legal and institutional frameworks for climate action in Kenya. This chapter also articulates the overall research design. It details the sources of data, sampling design, data selection, and processing methods, data analysis and presentation, data reliability, validity, and research ethics. In data choice, collection and processing it details the methods, and tools used while in data analysis it explains the methods of analysis, and the justification for their selection.

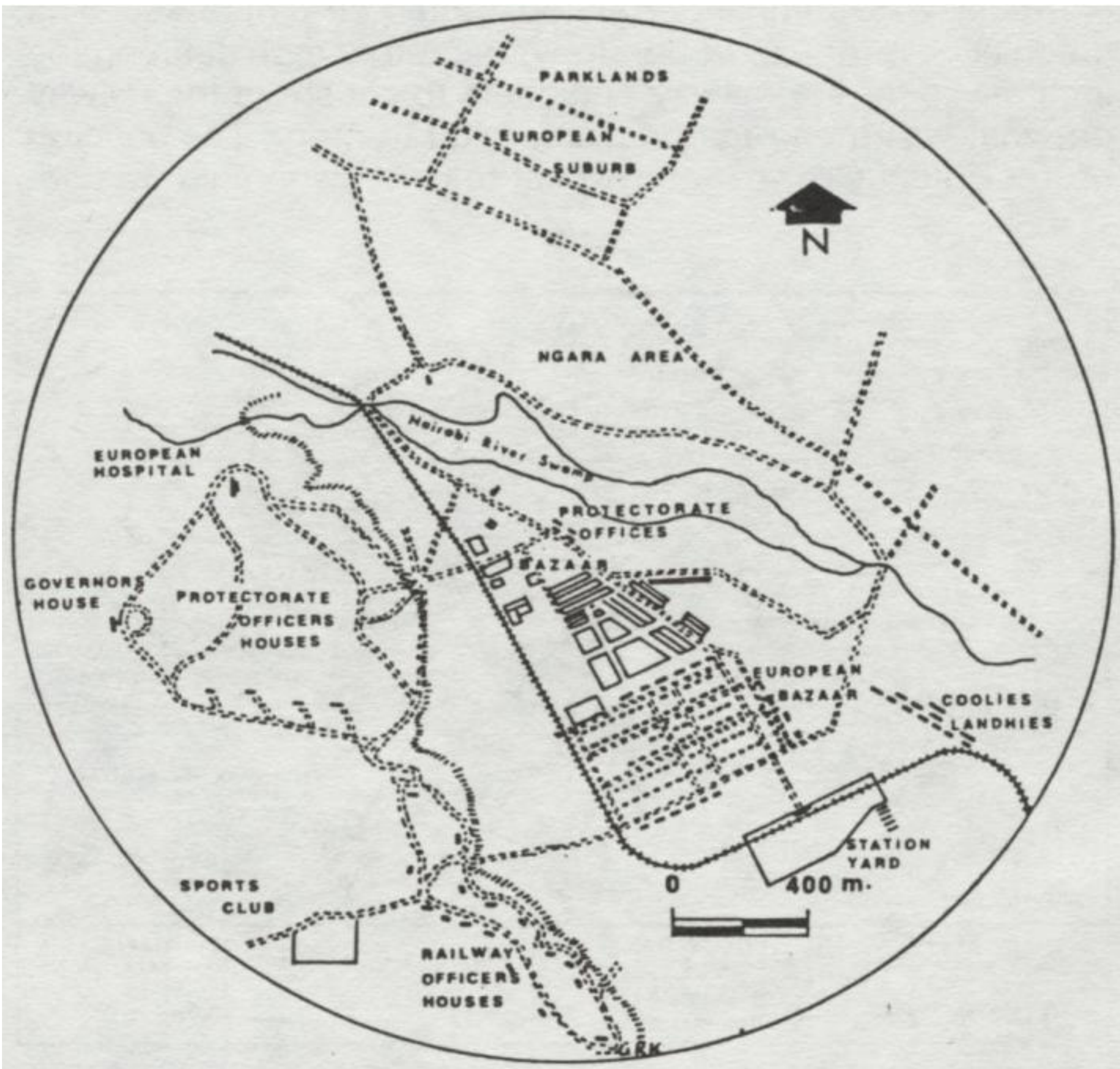
3.2 Study Area

3.2.1 Nairobi's Urban Form History

The origin of the city is not linked to the existence of an African village but precolonial urbanism which can be traced to 1889 town (Anyamba, 2011). This was driven by barter trade among the African communities. It was followed by the railway town and eventually the development of an urban area when both the provincial headquarters and the protectorate headquarters were transferred from Machakos and Mombasa respectively to Nairobi (Owuor & Mbatia, 2012). Urban plans developed for the city were in 1898, 1927, 1948, 1973 and 2014.

The first plan for Nairobi was a railway town depot plan in 1898. The key features of the plan included the damming of Nairobi River to create an impounding pond, the location of senior staff housing at the current Upper Hill area, commercial plots along the current Moi Avenue and a parallel street (currently Tom Mboya Street) as the main town street (Japan International Cooperation Agency [JICA] and Japan Science and Technology Agency [JST], 2014a). The choice of location for the railway town was guided by the slope suitable for construction of shunting areas, workshops and commercial zones, adequate water supply from Nairobi and Mbagathi rivers, and a deserted land offering space for expansion (Owuor & Mbatia, 2008; Vorgel, 2008).

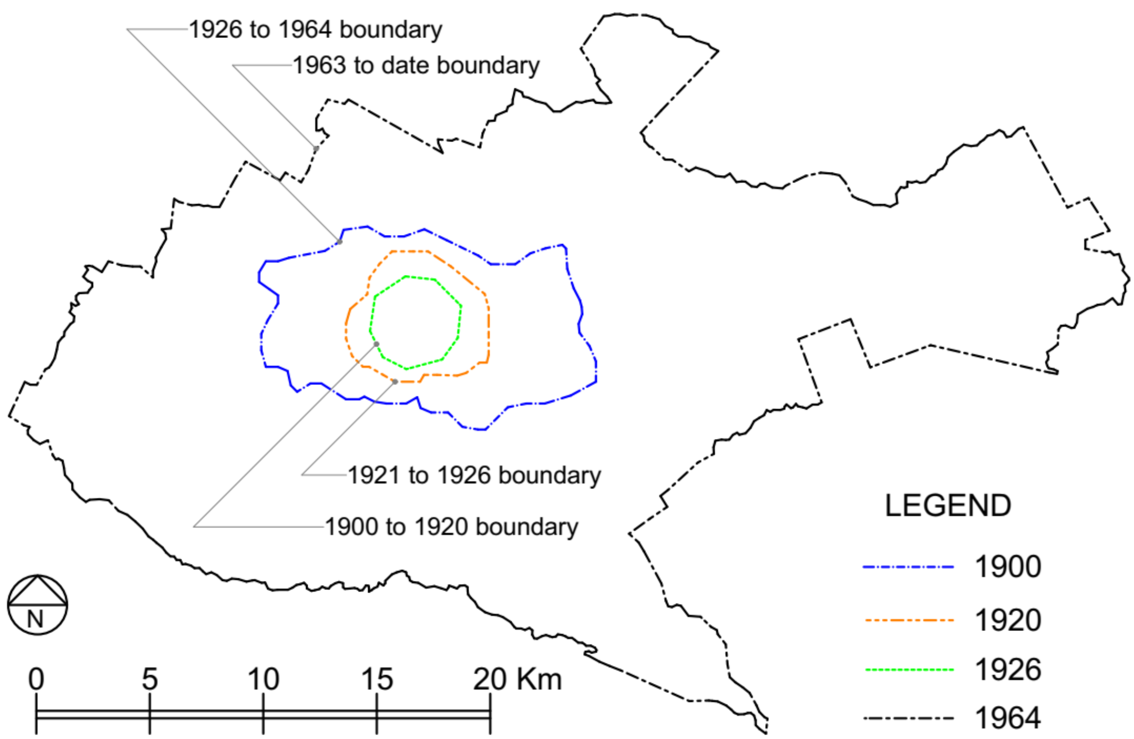
By 1905, the town (Figure 3.1) had grown into definite landuses hosting a population of over 11,000 inhabitants but without a clear spatial plan and, therefore, a very incoherent urban form (Owuor & Mbatia, 2008).



Source: Morgan (1967)

Figure 3.1: Nairobi Township and Central Business District in 1905

The town extent was originally 18 km^2 which expanded to 25 km^2. (Mwaniki, Wamuchiru, Mwau, & Opiyo, 2015). No form of development control or planning other than the gridiron street pattern layout seen within the Central Business District ([CBD] Figure 3.2) existed at the time (White, Silberman, & Anderson, 1948; Vorgel, 2008).



Source: Adapted from Adebayo (2012)

Figure 3.2: The City County of Nairobi Boundary Extensions

The second plan was the 1927 plan which saw the extension of the boundary to 77 Km^2 (Mundia, 2017). It proposed the regularization of circulation routes, the drainage and clearance of the swamps and the regulation of buildings and density (Vorgel, 2008; JICA and JST, 2014). The other extensions of the boundary happened in 1963 (Adebayo, 2012).

The third and final formal plan was the 1948 plan for the City of Nairobi (Vorgel, 2008; White, Silberman, & Anderson, 1948). The plan expanded the city to 83 Km^2 (Mwaniki, Wamuchiru, Mwau, & Opiyo, 2015). This was to be achieved by segregating landuses and income classes into well-defined areas. Industry was to the south of the CBD, high-income neighbourhoods to the west, middle-income residential to the north, and low income to the east (Morrison, 1974). The recognition of emerging challenges posed by race, caste, and religion prompted the inclusion of sociologists in the planning team (White, Silberman, & Anderson, 1948). This led to the development of zones like the open spaces and parks, the railway, residential and commercial areas (Vorgel, 2008).

Hallmarks of the historical plans were segregation on racial grounds. The housing typologies also followed this system. The Europeans inhabited the western zone, the Asians to the northern and Africans to the eastern zones of the town. Housing typologies also followed this segregation with notable changes between the 1920s and the 1940s (Vorgel, 2008; Owuor & Mbatia, 2008; JICA and JST, 2014; Martin & Bezemer, 2019). The Asian and African neighbourhoods, which were in the lower areas of the city, had black cotton soil and this exposed them to flooding challenges compared to the European neighbourhoods that were in elevated areas and had well-drained volcanic soils (Owuor & Mbatia, 2008).

The 1974-78 and 1979-1983 plans are known as the 3rd and 4th Plans (Richardson, 1980). They are the plans currently used by the city. Nonetheless, development outpaced them since they were planned for the period ending in the year 2000 (UN-Habitat, 2006; JICA and JST, 2014). The 3rd plan had two strategies: the city strategy and the regional strategy. The city strategy was the decentralization of urban development through the establishment of new self-contained centres to reduce the density in the city centre. The regional strategy involved the expansion of the city and linkage with the neighbouring urban areas of Thika town, Athi River and Machakos along an East and North-West Corridor (Vorgel, 2008). However, the plans were never fully implemented due to lack of funds, skilled personnel, and short-term plans (JICA and JST, 2014).

Other notable efforts at planning included the 1984-1988 the City County of Nairobi Commission Development Plan and the 1993 the City County of Nairobi Convention (Mundia, 2017; Owuor & Mbatia, 2008). They sought to manage the deteriorating urban physical environment and social services (Mundia, 2017). These subsequent plans were also never implemented.

The Integrated Urban Development Master Plan for the City of Nairobi commonly referred to as the Nairobi, Integrated Urban Plan was developed between 2012 and 2014 to succeed the 1973 Metropolitan Growth Strategy. The plan was handed over to the County Government on 5th March 2015 but had not been gazette for implementation (JICA, 2015a; JICA, 2015b). Of key interest to this study are priority programmes II and IV which are urban transport and environment improvement, respectively. These point to the development of new urban sub-centres alongside the CBD and the improvement of water, solid waste management and air quality (JICA and JST, 2014).

Nairobi's growth is intricately connected to its colonial past, defined by racial segregation. This was maintained at independence and changed from racial to social class segregation. High income Africans replaced the Europeans. Middle income Africans joined the Asians. The low-income Africans settled in informal settlements (Anyamba, 2011).

Even though the city boundary did not change after 1964, urbanization and urban sprawl has continued unabated. This sprawl is best captured by Mundia (2017) and Oyugi, Karanja, & Odenyo,(2017). Between 1988 and 2015, changes included built-up areas increase of 73.08 Km^2 in the year 1988 to 228.65 Km^2 in the year 2015. The major losses were in green cover which encompassed forest and agricultural land.

A pictorial review of Nairobi's transformation between the 1900s and 1990s revealed a notable land cover change from an expansive grassland to built-up urban area (Figure 3.3). The informal growth of the city can be traced to the end of the first world war in 1918. This period marked the development of 8 informal settlements to the west, south, western and northwest of the administrative district. Due to this informal growth, Nairobi's urbanization story is dominated by informal settlements (Amnesty International, 2009; Mwaniki, Wamuchiru, Mwau, Opiyo, & Mwaniki, 2015; urbaNext, 2020).

The unplanned growth beyond independence was supported by the inadequacies of the legal frameworks such as the Local Government Act (repealed upon the advent of the Constitution of Kenya, 2010) and the Physical Planning Act (Adebayo, 2012). The provisions of these frameworks were inadequate in robust development control especially in the context of urban planning. The lack of urban plans after 1948 masterplan and the failure to implement the 1973-1978 plans aided the sprawl. To remedy this, the National Urban Development Policy was formulated; the Physical and Landuse Planning Act (PLPA) was also revised.

Source: 1900s (The Agora, 2020); 1930s (Vintage East Africa, 2020); 1960s (Paul, 2013) and 1990s (Doug Scott, 1998)

Figure 3.3: The City County of Nairobi Transformations Between 1900s and 1990s

The emerging provisions anticipated to assist in proper planning include provision for conservation of green spaces, development of adaptive housing, green urban landscapes, incorporation of climate in design and the promotion of innovative technology on climate change adaptation (Government of Kenya, 2015). Enacted in 2019, the Physical and Landuse Planning Act provides for the planning, use, regulation, and development of land and any connected purposes. It noted climate change as one of the outstanding elements to be included in situational analysis during the preparation of development plans. Other than the direct provision, the Act also advocates for environmental conservation, protection, and improvement alongside the utilization of environmental management tools captured in the EMCA (Government of Kenya, 2019).

Environmental degradation and the need to consolidate over 78 regulations managing environmental issues led to the development of the National Environment Policy (NEP) and Environmental Management and Coordination Act (EMCA) 1999 (Government of Kenya, 2010; Government of Kenya, 2012). EMCA created institutions such as the National Environmental Management Authority (NEMA). It also outlined environmental management tools such as Environmental Action Plans, Environmental Impact Assessment, Environmental Auditing and Monitoring, Environmental Quality Standards, Environmental Restoration Orders, Environmental Conservation Orders and Environmental Easements (Government of Kenya, 2000). The Act was also identified by the Climate Change Act to monitor climate change response duties conferred on individuals.

Recognition of climate change as an emerging development challenge led to the development of National Climate Change Response Strategy, National Climate Change Action Plan and National Adaptation Plan (Government of Kenya 2010b; Government of Kenya 2016c & Government of Kenya, 2018). These led to the development of the Climate Change Act, the regulatory framework for climate change action (Government of Kenya, 2016a). The Act further advocates for mainstreaming sustainable development principles into planning and decision making alongside providing for climate action funding through the climate fund.

Climate challenges have also resulted in other disasters such as floods, droughts, storms, and landslides. A compelling number of these hazards are caused or exacerbated by climatic elements such as rainfall and temperature. Ongugo et al., (2014) argue that climate change parameters result in over 70% of the national disasters experienced in the country. The National Policy for Disaster Management was developed to address emerging disasters (Government of Kenya, 2009a). Even though the policy underscores the role of climate change action in sustainable development, it acknowledges the lack of capacity in dealing with climate change adaptation. The policy enumerated pillars of disaster management to offer an opportunity for climate change adaptation. Ongugo et al. (2014) cautions that the policy nevertheless does not give a strategy on how to manage disasters.

Other legislations enacted to both streamline urbanization and realign legislations to the Constitution of Kenya 2010 include the Urban Areas and Cities Act. In the management of cities and municipalities, the Act creates a board that shall develop Integrated Urban Development plans, control landuse, land development, and zoning and promote a safe and healthy environment. The components of integrated development plans, landuse control, and zoning, offers a great opportunity in climate change action. (Government of Kenya, 2010a; Government of Kenya, 2011).

Other Acts of Parliament deal with sectoral issues such water the (Water Act, 2002), forests (the Forest Conservation and Management Act, 2016) and wildlife conservation (Government of Kenya, 2002; Government of Kenya, 2016b; Government of Kenya, 2009b). These have also established various institutions such as the Water Resources Management Authority, Kenya Forestry Service, and the Kenya Wildlife Service. These connected laws create frameworks that allow for climate action both at the national and local levels.

3.2.2 Nairobi's Climatic and Physical Characteristics

The City County of Nairobi County (NCC) is Kenya's capital city. It is one of the 47 counties and the only City County in Kenya (Figure 3.4) It is situated at the southern end of Kenya's agricultural heartland and is the second-largest city in Eastern Africa (UN-Habitat, 2014a).

NCC's current area measures about 693 Km^2 after various expansions. These expansions occurred in 1910, 1921, 1926 and 1964 (Owuor & Mbatia, 2008). The city is at the junction of the Athi River plateau and the Rift Valley (Kikuyu) escarpment (Medard, 2010). It is at a mean altitude of 1700 m above sea level and longitude 36 48'E and 1 17'S (Makokha & Sishanya, 2010). Soils vary from red volcanic soils to alluvium, clay, and volcanic tuffs (Onyancha, Mathu, Mwea, & Ngecu, 2011). These display various porosity, water retention, and plasticity capacities. The red volcanic soil resulted from weathering of volcanic rock. This led to red soils of up to 15 m depth in selected locations (Saggerson, 1991).

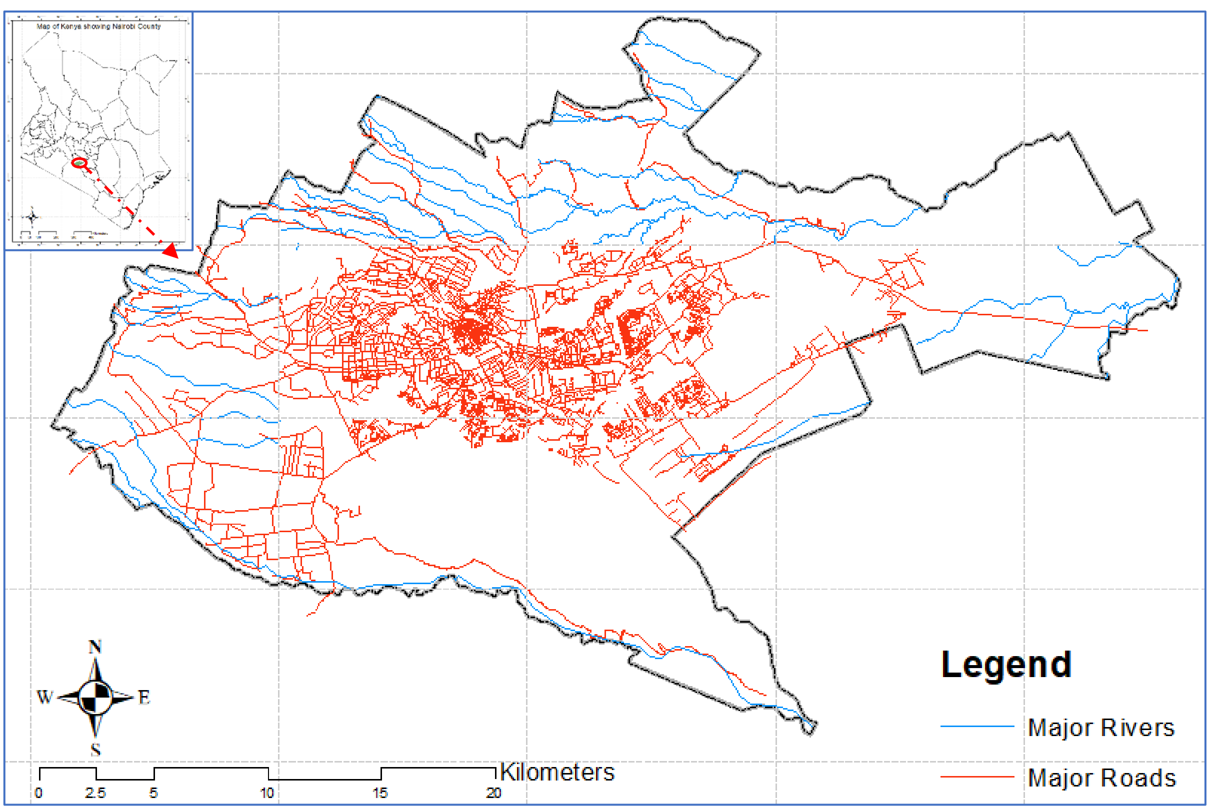
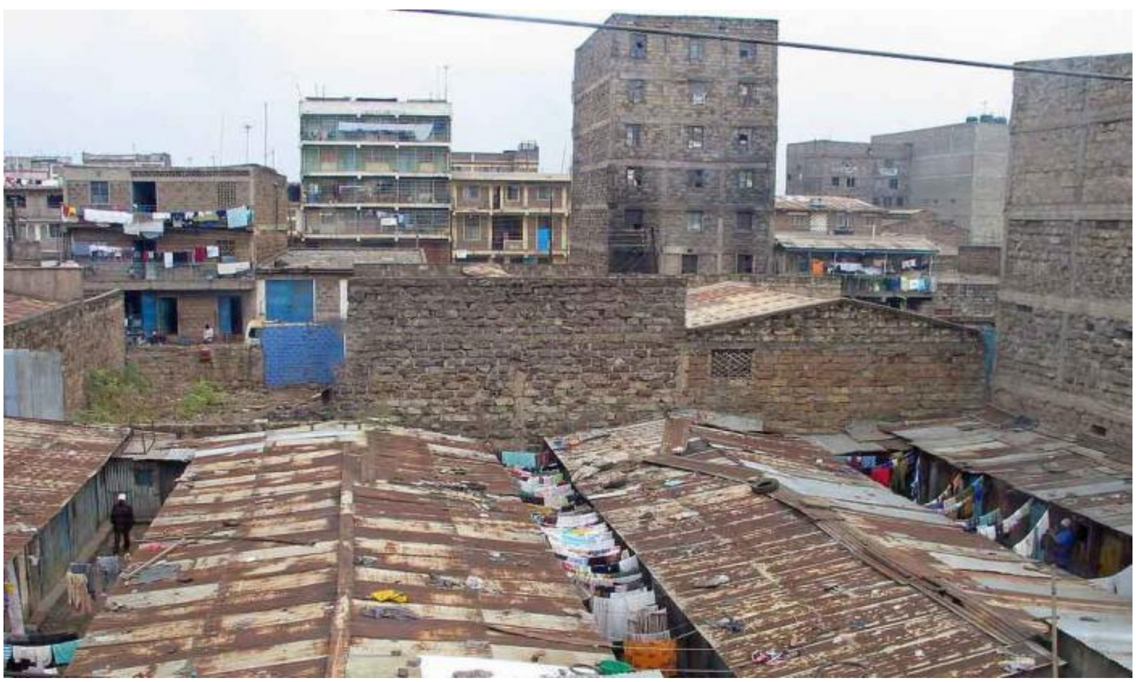


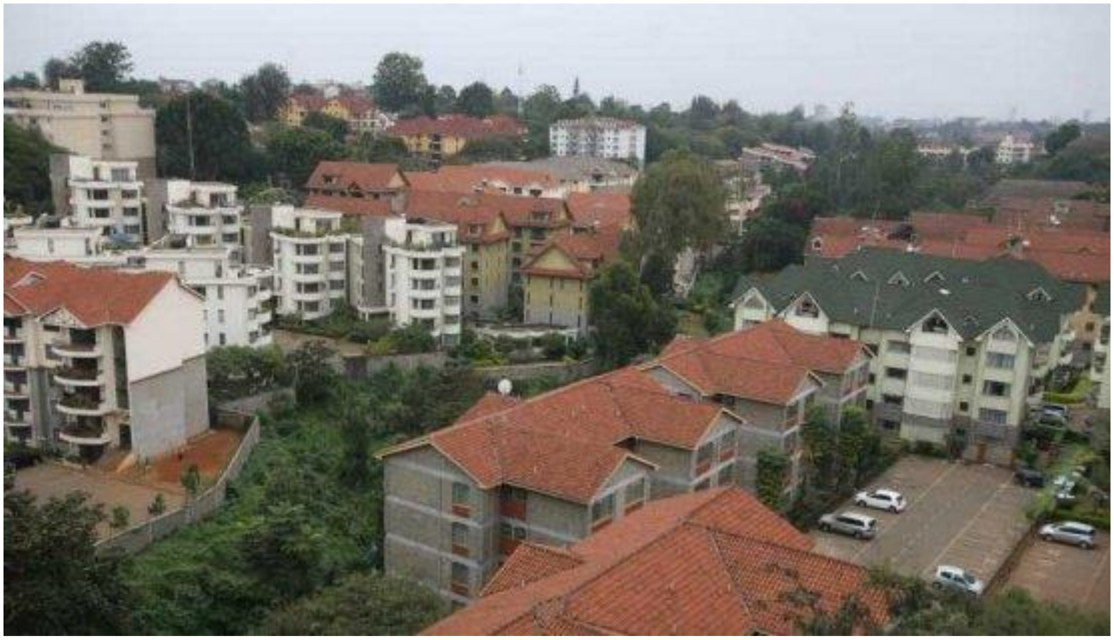
Figure 3.4: Map of Nairobi City County showing its location in Kenya

The city showed a compartmentalized structure inherited from the colonial town (Medard, 2010). The physical, socioeconomic characteristics, and government policy, played a momentous role in determining the structure of the city (Kingoria, 1983). The physical aspects that influenced the expansion of the city include soils, slope, and gazetted parks. For instance, the eastern side has gentle terrain but clay soil which makes it a challenge for construction while the western side has favourable soils but steeper slopes (Mundia, 2017). Racial segregation of settlements also followed the soil typologies. For instance, the higher altitudes north and west of the railway line were mostly red volcanic soils and inhabited by the Europeans. The Africans resided in the lower plains East and South of the railway line; areas comprising non-porous black cotton soils (Owuor & Mbatia, 2008; Anyamba, 2011). These patterns led to distinct settlement characters (Figure 3.5 and Figure 3.6).



Source: Okwiri (2017)

Figure 3.5: Dominant Character in the Eastern Part of the City



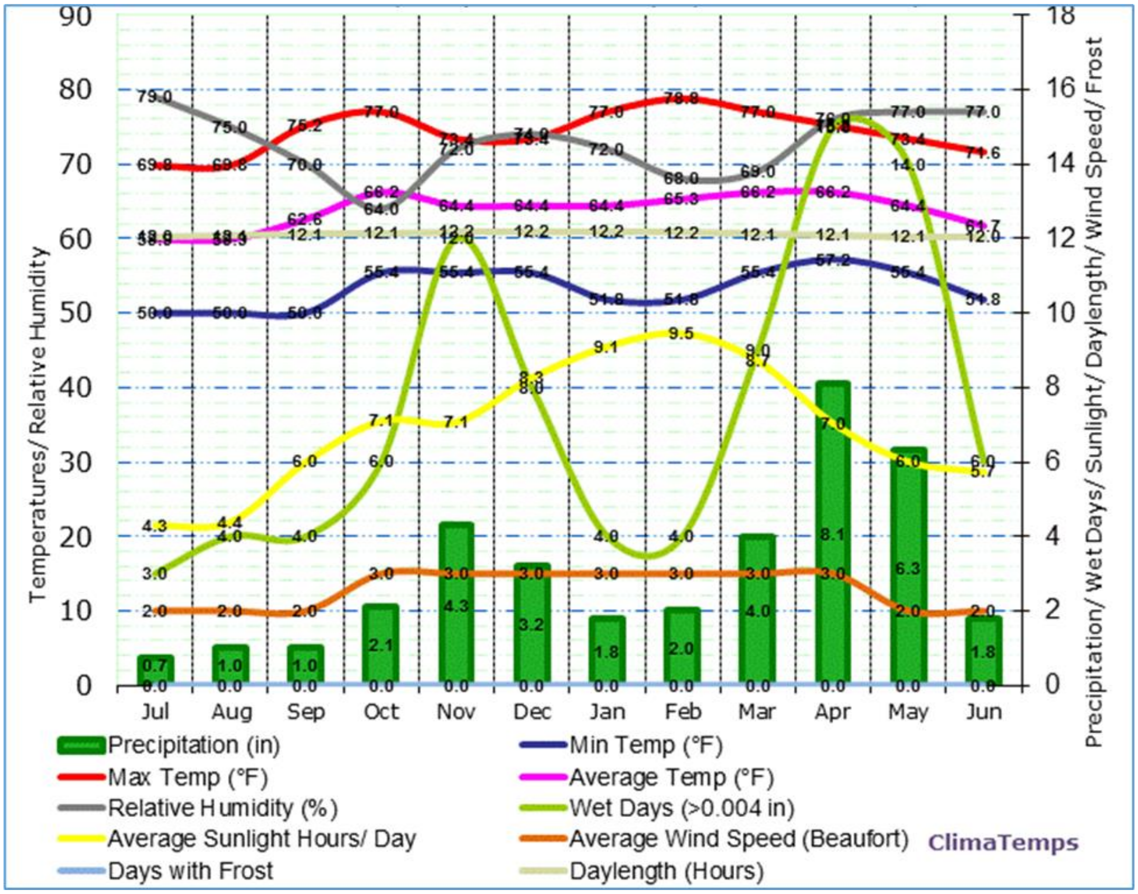
Source: Yaruman, (2005)

Figure 3.6: Dominant Character in the Western Part of the City

Nairobi has a temperate tropical climate with rainfall peaks in April and November (JICA and JST, 2014). The short rains are experienced in November and December while the long rains fall between March and April (UNEP, UN-Habitat, Nairobi City Council, 2008). The average amount of annual rainfall is about 600 mm and mean daily temperatures between 12 ^{o}C and 26 ^{o}C as shown in Figure 3.7 (University of Capetown, 2017; Central Bureau of Statistics, 2003).

Climate projections, both Global Climatic Models and downscaled models point to a changing climate. For instance, the Average annual maximum temperature and Average annual minimum temperature are projected to increase by between 0.5 ^{o}C and 2 ^{o}C by the year 2040. Similar trends, though minimal, are expected in rainfall (University of Capetown, 2017).

The initial planning models such as the sector model, multiple nuclei model and garden city concepts have not enhanced environmental sustainability either. The situation worsened in the year 2000 after the expiry of the 1973-1978 plans. The urbanization challenges that prompted the initial plans have therefore continued unabated. They manifest as urban physical decay, environmental degradation, urban sprawl, and segregation of settlements.



Source: http://www.nairobi.climatemps.com/graph

Figure 3.7: Nairobi's Climate Profile

Nairobi has experienced uncontrolled urbanization and unplanned sprawl since the 1948 masterplan. There has been consistent conversion of farmland and open grassland into sprawling built-up area. The racially segregated planning and the succeeding social class systems have acted in conjunction with the uncontrolled urbanization to make the city into a biophysically vulnerable zone. For instance, high-density low-income neighbourhoods are domiciled in the poorly drained areas, and this exacerbates flooding risk. Informal settlements and low-income neighbourhoods still have mud-walled housing typologies.

The low-income neighbourhoods that succeeded the racially segregated African settlements in the eastern zone of the city still experience flooding just as they did during colonization.

Aside from the growth and expansion of the city, there are marked changes in climate affecting temperature. These changes can be traced to the 1960s with a marked increase in temperatures. The crossroads between Nairobi’s urban form evolution and climate change has predisposed it to climate related challenges such as flooding. The biophysical elements that prompted its selection and settlement are emerging as the vulnerability elements.

Even though urban planning and management has been deficient, the legal and institutional frameworks have evolved to meet the emerging challenges. As such, there is an adequate legal, institutional and policy framework for action. The notably mentioned deficiency is in capacity.

3.3 Research Design

This research design was a descriptive case study research. The study investigated the trends in biophysical and socioeconomic characteristics as they relate to variations in climatic parameters within the City County of Nairobi using the framework illustrated in Figure 3.8.

The biophysical and socioeconomic characteristics included landcover, elevation, soil drainage properties, Open Space Networks (OSN), Normalized Difference Vegetation Index (NDVI), and slope. The socioeconomic characteristics included poverty levels, population density, age, percentage of female-headed households and access to services. The climatic parameters were temperature and rainfall. Temperature was further divided into average annual minimum, average annual maximum, highest annual and lowest annual parameters.

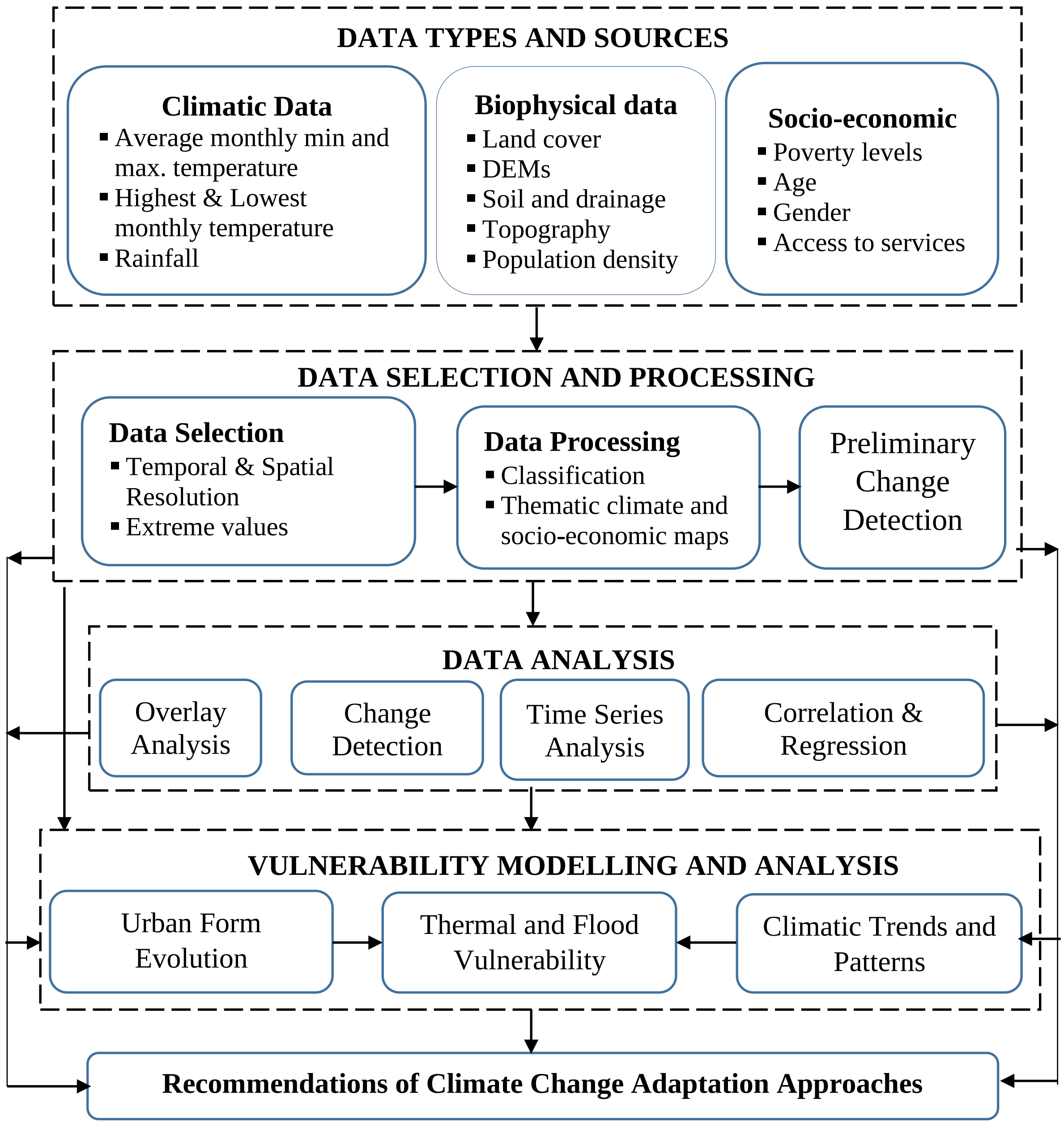


Figure 3.8: Research Methodology Framework

Data were collected through primary and secondary methods. The primary data sources were observation and self-administered questionnaires (Appendix 1). Secondary data sources entailed archival Geographic Information Systems and analogue maps, census statistics, and climate data. Maps and climatic data time frames were 30 years (between 1988 and 2018) in 10-year epochs. Both the urban form and climatic data were selected from corresponding periods. These were the years 1988, 1998, 2008 and 2018 except for special circumstances where data gaps existed such as the years 1998 and 2008. In those cases, 5-year epochs of 1988, 1993, 1998, 2003, 2008, 2013 and 2018 were used to investigate any trends that would be lost due to data gaps in the earlier epoch selection method.

Biophysical parameters were either directly derived or modelled from Landsat images (Appendix 5) or Digital Elevation Models (DEM). Landcover data were obtained through classification in ArcGIS and measured in square kilometres (Km^2). The city's elevation, measured in meters above sea level (m ASL), was modelled using ArcMap 10.6 to extract the different elevations from the DEMs. The slope percentages were derived from the digital elevation model using spatial analyst tool in ArcMap 10.6. The slope data were classified using the ranges proposed by Nassif and Wilson (1975) and Huang, Kang, Yang, and Jin (2017). Flow accumulation was generated by deriving the flow direction followed by flow accumulation. The Normalized Difference Vegetation Index (NDVI) was modelled in ArcMap from the Landsat images using the formula (Equation 3.1). Landsat images. Flow accumulation and NDVI were indices and therefore had no units. The results standardized as percentages for comparison across the years.

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}} \quad (3.1)$$

Where NDVI is Normalized Differential Vegetation Index, NIR is Near Infra-Red.

Climatic data were sampled from five weather stations. These were Jomo Kenyatta International Airport (JKIA), Wilson Airport, Eastleigh Moi Air Base (MAB), Dagoretti Corner and Kabete Agrovet Station (Table 3.1, Figure 3.9).

Table 3.1: Weather Station Identifiers

Weather Station	Station ID
Jomo Kenyatta International Airport	9136168
Wilson Airport	9136130
Dagoretti Corner	9136164
Eastleigh Moi Air Base	9136087
Kabete Agrovet Station	9136208

Note: Developed from Kenya Meteorological Department data

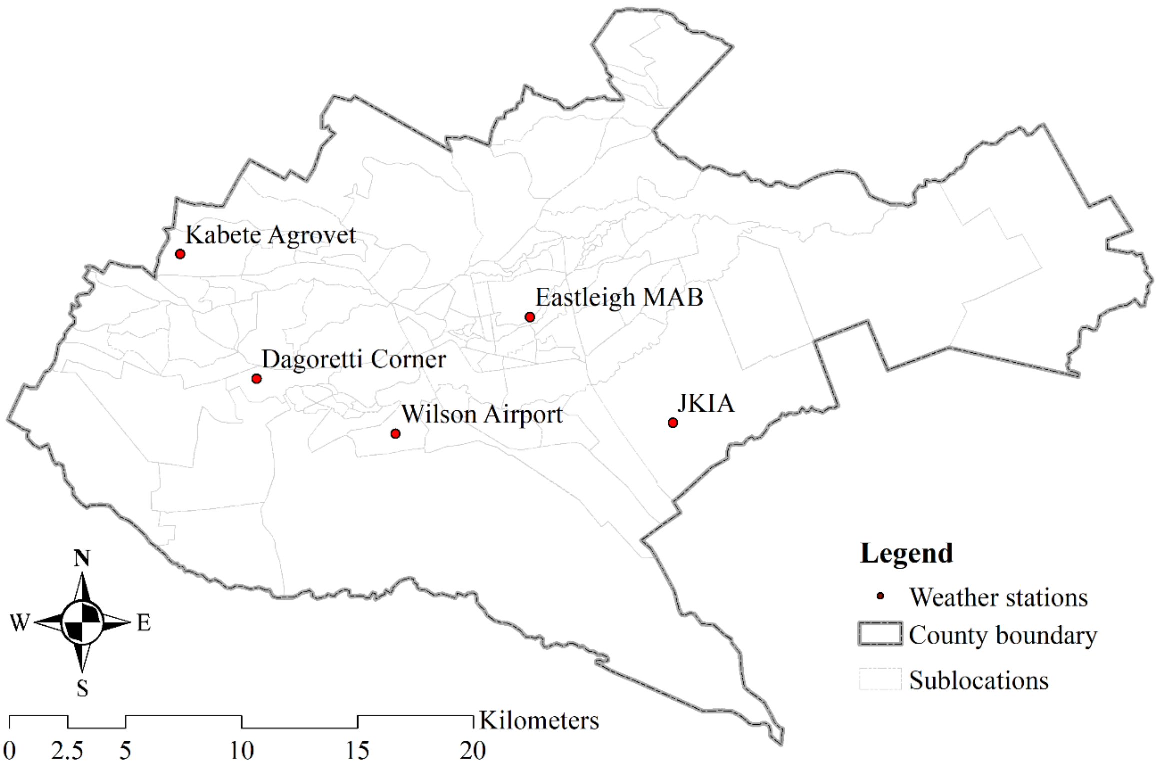


Figure 3.9: Distribution of Weather Stations in Relation to the Sublocations

Rainfall was measured in millimetres (mm). Temperature was measured in Degree Celsius (°C). The station-to-station data were converted to ArcMap 10.6 attribute table data and interpolated using the spline interpolation method to achieve data for the entire city. The interpolated data were then classified into 10 ranges using Equation 3.2.

$$\text{Range} = \frac{z - a}{10} \tag{3.2}$$

Where z is the highest recorded value of the climatic parameter; and a is the lowest recoded value of the climatic parameter.

Where there were data gaps, the scaling factor recommended by Fong et al. (2014) was used (Equation 3.3). This used existing reliable information, for example, population data from the 2009 Population and Housing Census to project the missing information. However, this process assumes that there are no compelling changes in social dynamics between the years 2009 and 2018.

$$\mathrm{ID} = \left(\frac{\mathrm{F_{IV}}}{\mathrm{F_{AD}}}\right) \times \mathrm{AD} \tag{3.3}$$

Where ID is Inventory Data (Data of Interest); F_{IV}: Factor Inventory Data (Estimation factor for the year of missing information); F_{AD}: Factor Available Data (Estimation factor for the year with complete information) and AD: Available Data of the group of interest for F_{AD}.

Table 3.2: Summary of Parameters, Data Set and Data Sources

Data Class	Data	Data source	Parameters
Secondary data	Statistical abstracts	KNBS	Poverty levels
	Housing and Population census reports	KNBS	Population, age, female headed households, access to water, water sources, access to sanitation, access to energy
	Climatic data	KMD	Average annual maximum temperature, average annual minimum temperature, highest annual temperature, lowest annual temperature, rainfall
	Soil map	KALRO	Soil drainage properties
	GIS Maps	UN-Habitat	Open space networks
		KNBS	Sublocation boundaries
	Landsat images	RCMRD and USGS	Landcover, flow accumulation, normalized Difference vegetation index
	DEM		Slope, elevation
Primary data	Expert Ranking	Sampled experts	Landcover, flow accumulation, soil drainage properties, normalized Difference vegetation index, temperature, rainfall, poverty, age, gender, access to services
	Soil type	Sampled Coordinates	Soil drainage properties
	Altitude		Elevation
	Landcover		Bare land, Built-up area, Forest, Waterbody and Grassland

Note: RCMRD is Regional Centre for Mapping of Resources for Development, KMD is Kenya Meteorological Department, KNBS is Kenya National Bureau of Statistics, KALRO is Kenya Agricultural and Livestock Research Organization and USGS is United States Geological Survey

A triangulation approach combining qualitative and quantitative approaches was used. It aids in counteracting the weaknesses of each approach (Dawson, 2009). The quantitative approach focused on normalization and weighting of different data sets and vulnerability indicators, respectively. The qualitative approach was used to rank expert opinions and determine vulnerability ranks for the sublocations. Data analysis employed four methods: change detection (Appendix 8) analysis, time series analysis, correlation, and regression analysis.

Scatter plots and trendlines were used in trend detection. In cases with outliers, the study sought theoretical explanations and checked for data entry errors. The criteria for retention of outlier data were guided by three parameters: theoretical explanation, data entry errors and consistency with other data sets (Anscombe, 1960). Trendline plotting was based on the linear trendline. This was guided by the theoretical associations discussed in Chapter Two.

For purposes of vulnerability assessment, socioeconomic data were also collected. They were extracted from the 2008 housing and population census obtained from the Kenya National Bureau of Statistics (KNBS). The parameters included population density, age composition, gender of household head, poverty levels and levels of access to services. This data were based on the 2008 sub locations boundaries.

Vulnerability assessment of the different counties required the aggregation of the different biophysical, socioeconomic, and climatic parameters. Of the two widely used methods, the study selected the weighting based on the expert opinion ranking method. This method required the collection of data on how experts ranked the contributions of the different parameters to the overall vulnerability of the sublocations. This was achieved through a questionnaire (Appendix 1) with a seven-level Likert type scale that ranged from most unlikely to contribute to most likely to contribute (Table 3.3).

Table 3.3: The Urban Form and Climatic Parameters Ranking Scale

1	2	3	4	5	6	7
Most unlikely to contribute	Very unlikely to contribute	Unlikely to contribute	Neutral	Likely to contribute	Very likely to contribute	Most likely to contribute

The questionnaire was administered to twelve respondents in the field of Urban Planning, Sociology, Landscape Architecture, Landscape Planning, and Architecture were used. The number 12 was selected due to the concept of theoretical saturation, domiciled in grounded theory, where any data collected above 12 expert opinions was argued to be akin to the opinions gathered. The experts ranked (Appendix 3 and 4) the parameters of urban form and climate (Table 3.4).

Table 3.4: Sample Expert Ranking on Urban Form Contributions to Flood Vulnerability

Parameters	Expert opinions												Mean	Standard Deviation
	A	B	C	D	E	F	G	H	I	J	K	L		
Elevation	5	6	6	5	7	6	6	7	5	7	7	6	6.08	0.76
Slope	5	5	5	5	5	6	7	5	5	6	6	7	5.58	0.76
Landcover	6	7	7	4	6	6	7	6	4	7	7	7	6.17	1.07
Rainfall	7	6	6	6	7	6	7	7	6	7	7	7	6.58	0.49
Flow Accumulation	7	6	7	5	7	5	7	7	5	6	6	6	6.17	0.80
Soil drainage Properties	5	4	6	5	4	6	7	4	5	6	6	6	5.33	0.94

Note: A to L represents the different experts

3.4 Research Methods

The study used three research methods: archival, interview and observation. Interview and observation methods yielded primary data. The archival method yielded secondary data. The combination of the three methods was to increase construct validity and plug the shortcomings of each of the methods in case they were to be used in isolation (Gillham, 2000; Yin, 2003).

3.4.1 Archival Method

The archival method included the review of housing and population census data, climatic data, boundary delimitation maps, soil property maps, Landsat, and Digital Elevation Models (DEM). The data from housing and population census generated socio-economic data. Climatic data generated the climatic parameters. Landsat, soil properties maps, and DEM datum was used to model urban form such as landcover, elevation, slope, soil drainage properties and flow accumulation. Climatic data generated the average annual minimum, average annual maximum, highest annual and lowest annual temperatures, and rainfall data.

3.4.2 Interview Method

The interview method was used to collect primary data from experts. These data helped the study determine the magnitude of the contribution that urban form, climate, and socio-economic parameters had on climate change vulnerability.

3.4.3 Observation Method

The observation method generated information for ground truthing of urban form models and classifications. The questions raised by MacDonald and Headlam (2008) on the reliability of observation were solved using a standardized observation checklist as suggested by Mouton and Marais (1996) and Kothari (2004). The standardization process included preliminary use of the observation checklists (Appendix 2) by all research assistants on the same space and a full explanation of the method of translation. Nonetheless, since the items under observation were inanimate, the reliability and validity were guaranteed using other tools such as photographs.

3.5 Data Collection Techniques, Tools and Sources

3.5.1 Techniques, Tools and Data Sources for the Archival Method

Archival data were collected using the note taking and data transfer techniques. The digital data were transferred and stored in portable hard disk. The printed and published hardcopy data were printed and photocopied, respectively. Analogue maps were scanned using a portable scanner and digitized using ArchiCAD and ArcGIS software. To ensure all the required archival data were collected, the study developed an archival checklist (Table 3.5).

Table 3.5: Archival Review Checklist

Variable	Parameters	Specific data sets	Source	Remarks
Urban form	Landcover, Slope, Open Space Network and NDVI	Landsat images (1988, 1993, 1998, 2003, 2008, 2013 and 2018)	RCMRD and USGS	✓
	Elevation, Slope and Flow Accumulation	DEM	RCMRD and USGS	✓
	Soil drainage properties	Nairobi soil maps	KALRO	✓
Climate	Average annual maximum, average annual minimum, highest annual and lowest annual temperatures	Temperature	KMD	✓
	Annual Rainfall	Rainfall	KMD	✓
Socio economics	Poverty levels, Age, Gender, Access to services, and Population Density	Housing and Population census Data	KNBS	✓

Note: RCMRD is Regional Centre for Mapping of Resources for Development, KMD is Kenya Meteorological Department, DEM is Digital Elevation Model, NDVI is Normalized Difference Vegetation Index, USGS is United States Geological Survey and KNBS is Kenya national Bureau of Statistics

Housing and population census data were obtained from the Kenya National Bureau of Statistics (KNBS). Climatic data were sourced from Kenya Meteorological Department (KMD), and World Climate (https://www.worldclim.org/). Boundary delimitation maps were obtained from Nairobi County office, Kenya National Bureau of Statistics (KNBS) and Independent Electoral and Boundaries Commission (IEBC). Soil property maps were obtained from Kenya Agricultural and Livestock Research Organization (KALRO [https://files.isric.org/public/sotwis/SOTWIS_KEN.zip]). Landsat and Digital Elevation Models (DEM) were obtained from Regional Centre for Mapping of Resources for Development (RCMRD) and United States Geological Survey (USGS [https://earthexplorer.usgs.gov]).

3.5.2 Techniques, Tools and Data Source for the Interview Method

The questionnaire technique was used to collect primary data from the experts. The tools used were questionnaires (Appendix 1). These were self-administered to the 12 selected experts in the fields of landscape architecture, urban and regional planning, urban design, sociology, and hydrology (Table 3.6).

Table 3.6: Number of Respondents per Profession

Profession	Number of respondents
Urban and Regional Planning	3
Urban Design	3
Sociology	1
Hydrology	2
Landscape Architecture	3
Total	12*

3.5.3 Techniques, Tools, and Data Source for the Observation Method

The technique used for the observation method was observation. The data collection tools were observation checklists (Table 3.7), handheld Global Positioning Systems (GPS) devices and digital cameras. The data were recorded using notebooks and photographs.

The data were collected from 17 locations spread around the city. The locations were sampled from the 17 sub counties (Figure 3.10 and Table 3.8) using the maximum variability sampling approach.

Table 3.7: Checklist with Sample Data Collected for Ground Truthing

Urban form		Observation locations			
		Point 1 (36.882, -1.223)	Point 2 (36.992, -1.256)	Point 3 (36.929, -1.2557)	Point 10 (36.842, -1.276)
Soil	Poorly drained	-	-	-	X
	Well drained	X	X	-	-
	Very well drained	-	-	-	-
Altitude*(m ASL)		1642	1495	1561	1652
Land-cover	Forest/ Woodlot	X	-	X	-
	Grassland	-	-	-	-
	Water	-	-	-	-
	Built-Up	-	X	-	-
	Bare ground	-	-	-	X

Note: *Altitude was measured in meters above sea level using GPS at a ground level.

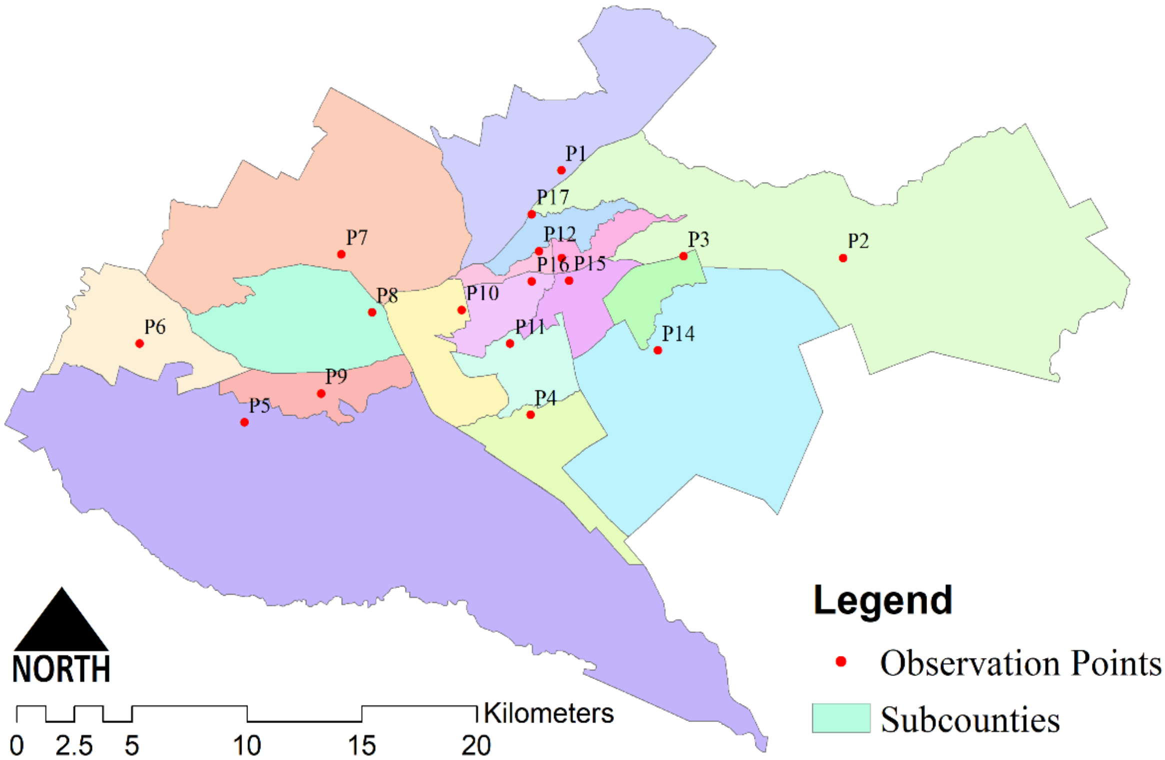


Figure 3.10: Ground Truthing Locations in the 17 Sub counties

Table 3.8: Observation Point Coordinates in the Sub counties

Point	Subcounty	Coordinates (Decimal Degrees)	
		X - Coordinate	Y - Coordinate
P1	Roysambu	36.882	-1.223
P2	Kasarani	36.992	-1.256
P3	Embakasi Central	36.929	-1.2557
P4	Embakasi South	36.869	-1.316
P5	Langata	36.758	-1.319
P6	Dagoretti South	36.717	-1.289
P7	Westlands	36.796	-1.255
P8	Dagoretti North	36.807	-1.277
P9	Kibra	36.788	-1.308
P10	Starehe	36.842	-1.276
P11	Makadara	36.862	-1.289
P12	Mathare	36.873	-1.253
P13	Embakasi North	36.882	-1.256
P14	Embakasi East	36.924	-1.283
P15	Embakasi West	36.885	-1.265
P16	Kamukunji	36.871	-1.264
P17	Ruaraka	36.870	-1.239

The resultant data were compared with secondary data on landcover, and soil drainage properties obtained from Regional Centre for Mapping of Resource for Development (RCMRD) and Kenya Agricultural and Livestock Research Organization, respectively (KALRO).

3.6 Sampling Design

According to (Kothari, 2004), a sampling design is a definite plan for getting a sample from a population. The sampling design considered three aspects: sampling approach, sampling unit and sampling procedures.

3.6.1 Sampling Approach.

The study sampling approach considered four elements: the universe, the sampling unit, sample size and parameters of interest. The universe was considered as the City County of Nairobi since this was a case study research design. The urban form, and climatic data collected covered the entire city either directly or through interpolation.

3.6.1.1 Sampling unit

There were three sampling units. The sampling unit for climatic data were the weather stations. However, the climatic data were interpolated to cover the entire city and finally analysed at the sublocation level. Sampling unit for vulnerability assessment was the sublocation. This was based on the unit of analysis of the population and housing census data. Expert's sampling unit was the individual person. Other authors such as Linkd (2012) who have conducted similar studies in other places used the ward as the unit of analysis which is comparable to sublocation. The third sampling units was the sublocations (Figure 3.11, Table 3.9, Appendix 6 &7). This was used to compute the interpolated climatic parameters and the urban form parameters.

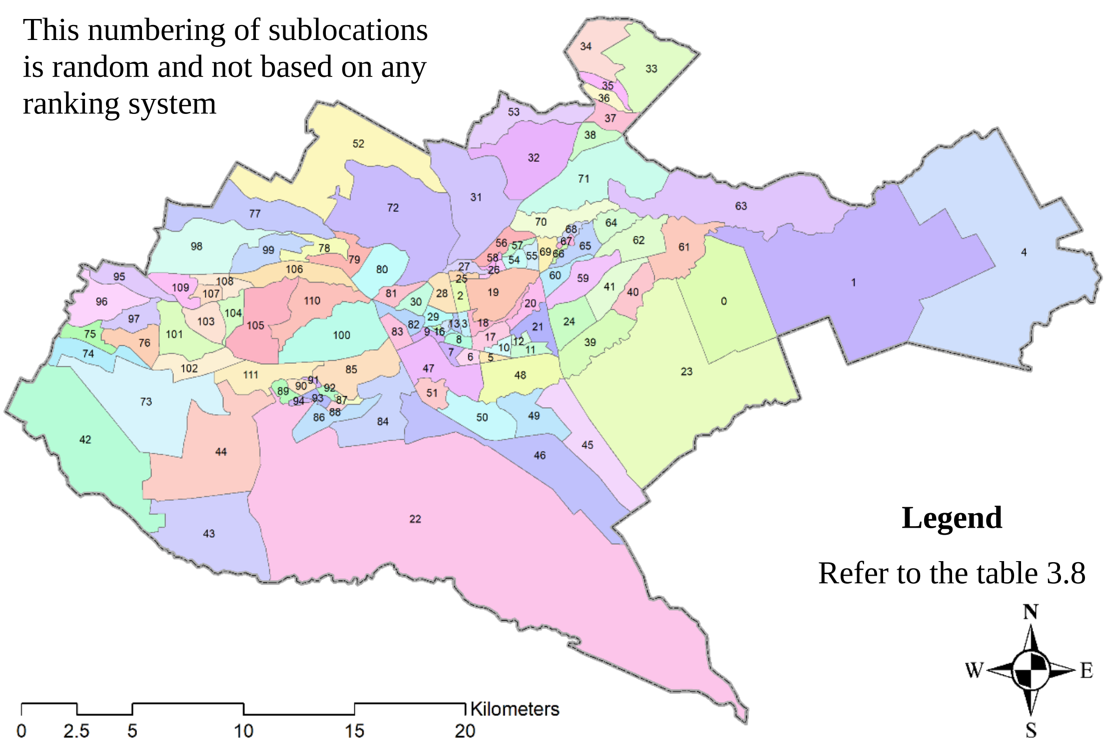


Figure 3.11: Map of Nairobi County Showing Sublocation Numbers

Table 3.9: Legend for the Map of Nairobi County Showing Sublocation Numbers

No.	Sublocation
0	Mihango
1	Ruai
2	Eastleigh north
3	California
4	Ngandu
5	Mbotela
6	Makongeni
7	Kaloleni
8	Shauri moyo
9	Muthurwa
10	Ofafa Maringo
11	Hamza
12	Lumumba
13	Majengo
14	Bondeni
15	Gikomba
16	Kamukunji
17	Kimathi
18	Eastleigh south
19	Air base
21	Uhuru
22	Harambee
23	Bomas
24	Embakasi
25	Umoja
26	Mlango Kubwa
27	Mabatini
28	Mathare
29	Pangani
30	Ziwani/Kariokor
31	Ngara east
32	Garden
33	Roysambu
34	Kiwanja
35	Kahawa west
36	Kongo Soweto
37	Kamuthi
38	Githurai
39	Zimmerman
40	Savannah
41	Kayole
42	Komarock
43	Karen
44	Hardy
45	Langata
46	Mukuru kwa Njenga
47	South c
48	Land Mawe
49	Viwandani
50	Imara Daima
51	Hazina
52	Nairobi south
53	Karura
54	Njathaini
55	Huruma
56	Kiamaiko
57	Utalii
58	Mathare north
59	Mathare 4a
60	Mowlem
61	Kariobangi south
62	Njiru
63	Saika
64	Mwiki
65	Dandora b
66	Dandora a
67	Korogocho
68	Nyayo
69	Gitathuru
70	Kariobangi north
71	Ruaraka
72	Kasarani
73	Muthaiga
74	Lenana
75	Mutuini
76	Kirigu
77	Kabiria
78	Kitisuru
79	Spring valley
80	Upper parklands
81	Highridge
82	Ngara west
83	City centre
84	City square
85	Nairobi west
86	Kenyatta/ Golf C
87	Mugumoini
88	Laini Saba
89	Silanga
90	Olympic
91	Makina
92	Kibera
93	Soweto
94	Lindi
95	Gatwikira
96	Uthiru
97	Ruthimitu
98	Waithaka
99	Loresho
100	Kyuna
101	Kilimani
102	Riruta
103	Ngando
104	Kawangware
105	Gatina
106	Maziwa
107	Muthangari
108	Gichagi
109	Kangemi
110	Mountain view
111	Kileleshwa
112	Woodley

3.6.1.2 Sample size

The study sample sizes were computed at different levels. For the administration of questionnaires (Appendix 1), a sample size of 12 respondents was settled on based on the concept of theoretical saturation. For observation and computation of evolution trends and patterns for both urban form and climate, multiple sample sizes were used. To develop the urban form and climate relationship models, all the 112 sublocations were used. For comparative analysis, the five sublocations with weather stations and an additional 25 were sampled.

3.6.3 Sampling Procedure.

3.6.3.1 Purposive Sampling

Purposive sampling was used in the selection of the case to study. It is a non-probability sampling procedure that does not provide the guarantee that each item might be included in the sample (Kothari, 2004). In the study, it was employed in selecting Nairobi for the study. The justification is that Nairobi is the fastest-growing urban area with the largest population in Kenya. It also has the most varied landcover characteristics and the highest concentration of weather stations among the urban areas in the country. The varied landcover characteristics allow the study to cover all urban form variations possible within the same urban and regional climate.

Experts used for ranking were also purposively sampled. They were selected from the fields of urban and regional planning, landscape architecture, hydrology, and sociology. They had at least 15 years of experience in their respective fields. The number of experts sampled was 12. This was guided by theoretical saturation concept in grounded theory for qualitative data collection as the respondents were considered experts in their respective fields (Bloor & Wood, 2006).

3.6.3.2 Maximum Variability Sampling

The maximum variation sampling was used to ensure maximum coverage of the urban form and climate scenarios as proposed by Benaquisto and Given (2008). It was also used in determining the ground truthing points by dividing the city into the 17 sub-counties. Global Positioning System (GPS) data points within each sub-county were then purposively selected for ground-truthing resulting in 17 locations for ground-truthing.

For comparative analysis, 30 sublocations (Table 3.10 and Figure 3.12) were sampled using the maximum variation sampling method. The criteria included six parameters namely widest spread around the city, sublocations hosting weather stations, sublocations with informal settlements, those with lowest and highest poverty levels and those with highest and least urban form changes between 1988 and 2018.

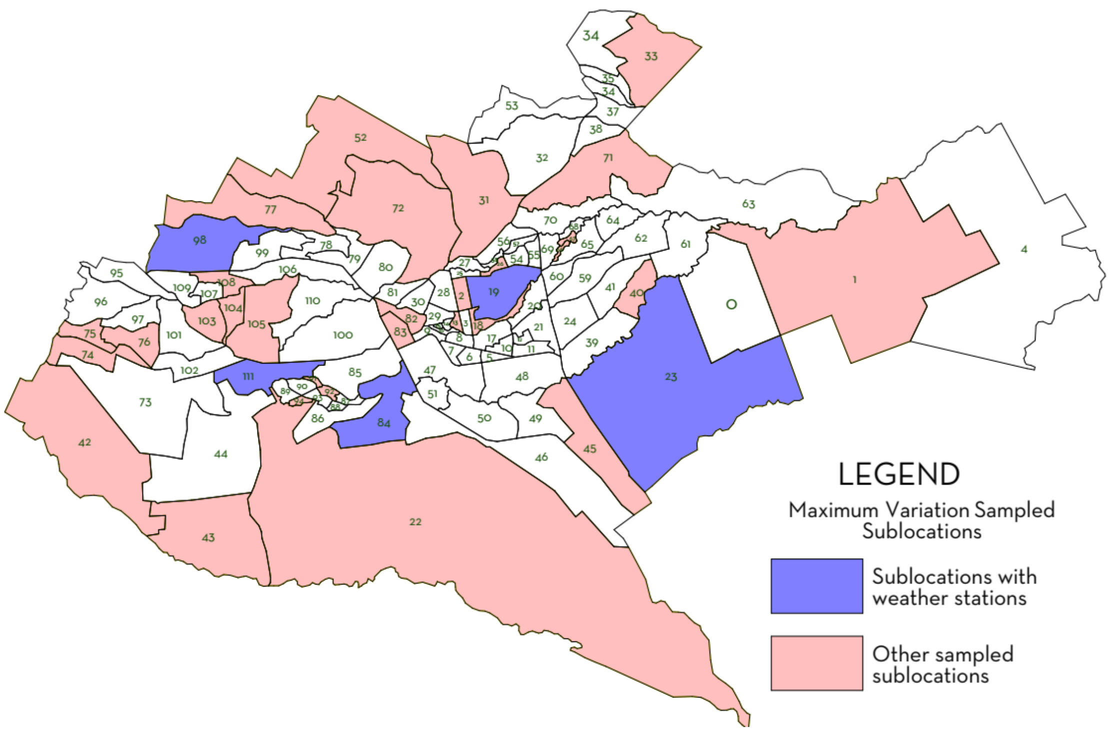


Figure 3.12: Maximum Variation Sampled Sublocations

Table 3.10: Maximum Variation Sampled Sublocations

SN	Sublocation	SN	Sublocation	SN	Sublocation
1	Ruai	43	Hardy	82	City Centre
2	Eastleigh North	45	Mukuru Kwa	83	City Square
13	Majengo		Njenga	84	Nairobi West
18	Eastleigh South	52	Karura	91	Kibera
19	Air base	66	Korogocho	92	Soweto
22	Bomas	67	Nyayo	94	Gatwikira
23	Embakasi	71	Kasarani	98	Loresho
26	Mabatini	72	Muthaiga	103	Kawangware
31	Garden	74	Mutuini	104	Gatina
33	Kiwanja	75	Kirigu	105	Maziwa
40	Kayole	76	Kabiria	108	Kangemi
42	Karen	77	Kitisuru	111	Woodley

Note

SN is the Serial Number given to the sublocations during GIS Analysis.

3.7 Data Selection and Processing

This section explains the rationale for selecting the spatial and temporal resolutions. It also explains how the Landsat and Digital Elevation Models were geometrically and radiometrically corrected for errors.

3.7.1 Rationale for Temporal and Spatial Selection.

The study relied on spatial and urban geometry data supported by other statistical and imagery information for biophysical and climatic data. The criterion for spatial static data selection included spatial and temporal resolutions, the month of interest and the years of focus. Using spatial and temporal resolutions as a guide for selection is supported by Hoa's (2013) argument on the principles of urban morphological analysis of time, resolution, and form.

Temporal resolutions were 5 and 10 years for the 30 years between 1988 and 2018. This resulted in the selection of 1988, 1998, 2008, and 2018 data sets. The 30 years is based on the WMO definition of a timescale boundary between weather and climate (Mudelsee, 2009). The combination of 5- and 10-year epochs was necessitated by data gaps in climatic information. These gaps had the potential of disguising climatic trends. Spatial resolution was based on the available resolutions of the Geographic Information Systems data. This translated to 30 meters for the landcover and two meters for the DEMs. The Landsat images used were from path 168 and row 061. This covered the Nairobi County area for all the epochs

The months of interest were January-February and June-August for the landcover and NDVI data. This period selected months are among the hottest and driest in Nairobi. As such, the vegetation would be under stress, exposing the challenges they would face in the provision of ecosystem services such as temperature amelioration. The land surface temperature would also be unmasked due to a lack of seasonal vegetation covers. The selected period is succeeded by the long rains and short rains, respectively. Considering the role played by vegetation in controlling runoff, they would be at their weakest, exposing the flood risks further.

3.7.2 Processing and Classification of Form and Climatic Data

Landcover features were derived using a hybrid classification system, combining both supervised and unsupervised classification methods. Di Gregorio (2016) argues that this approach eliminates the shortcomings of each of the classification systems if used in isolation and allows for comparative analysis. The selection of classification groups for the landcover data were guided by, among others, the classifications used by Zope, Eldho, and Jothiprakash (2017) who propose the built-up area, waterbody, vegetation, open land, forests, and grassland. As such, the study settled on built-up area, grassland, forest, bare ground, and waterbody. This was guided by the relationship between landcover types and climate.

The landcover images were loaded into ArcMap one epoch at a time. The data were then geometrically and radiometrically corrected. A set of training areas were created using built-up areas, vegetation, and water surfaces. The adoption of training areas was based on prior knowledge of the city. The resultant signature file was then used to classify the different representations using the landcover classification framework (Figure 3.13).

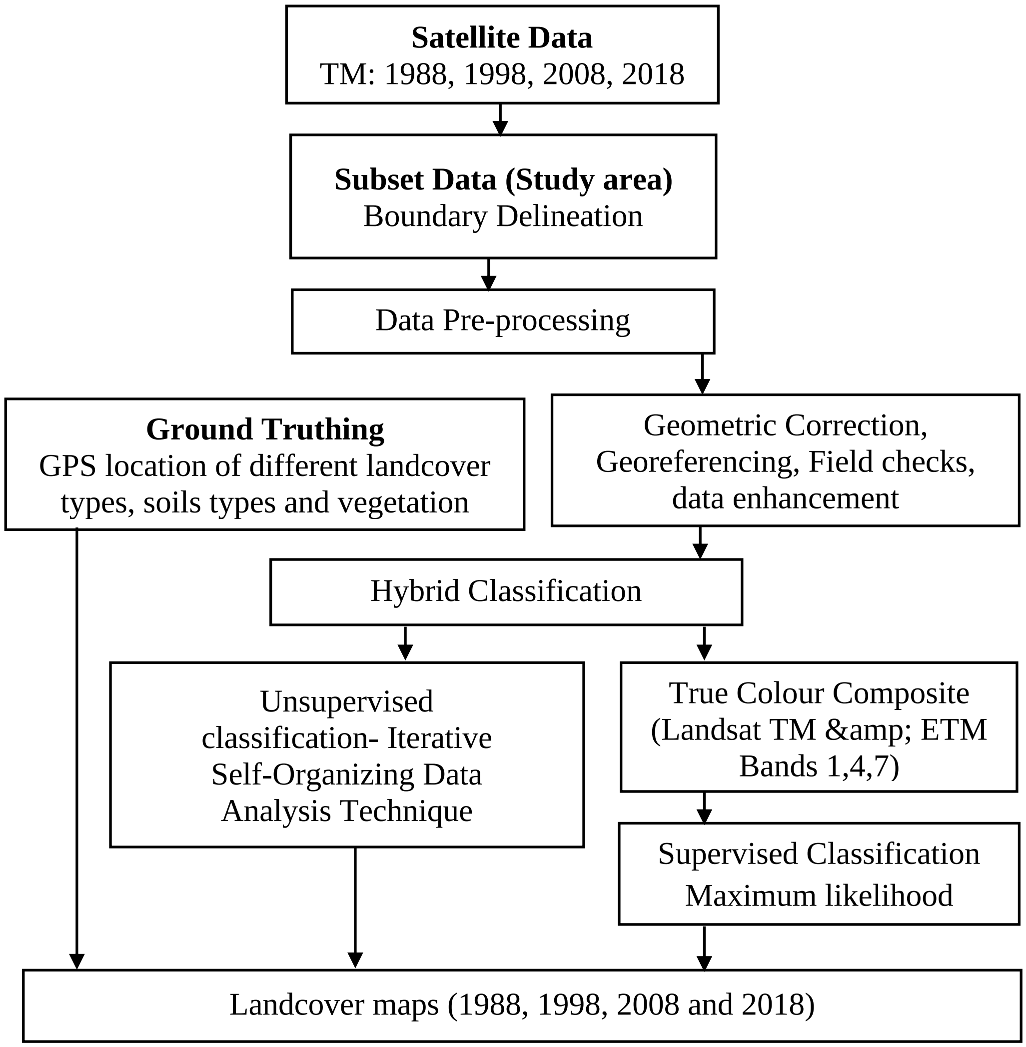


Figure 3.13: Landcover Classification Framework

The accuracy of the supervised classification is heavily dependent on prior knowledge, the skill of the individual processing the image and the distinctness of the classes (Gillian, 2012). For this reason, unsupervised classification was also considered by generating clusters by defining the number of classes and assigning classes. Finally, to generate the map outputs, the classified image was processed using the reclassify tool to merge the various classes. The landcover classes were namely: built-up areas, forest, bare lands, grasslands, water bodies (Table 3.11).

Table 3.11: Landcover Types, Descriptions and Colour Codes

Landcover	Description	Colour code
Built-up	Temporary and permanent structures, artificial infrastructure	Red
Forest	Areas with dense trees cover	Green
Bare lands	Exposed soils, landfill sites, and areas of active excavation	Brown
Grasslands	Shrublands,	Yellow
Waterbody	River, permanent open water, lakes, reservoirs, ponds	Blue

Classification inaccuracies and mixed pixels problems were minimized through post-classification refinement as recommended by Alsaaideh, Al-Hanbali, and Tateishi, (2012). Visual interpretation through ground-truthing and Global Positioning System tagging was used to confirm accuracy for the 2018 data sets. The accuracy of the 1988 to 2013 epochs was corroborated using analogue aerial photographs and historical google earth images (https://earth.google.com/web/search/Nairobi/) of the city.

The NDVI, Flow Accumulation and slope were modelled in ArcMap 10.6. The resultant maps were overlaid on the different epochs. The year 2018 was overlaid with the sublocation map to reveal the relationships between the different parameters and the sublocations. Even though soil, and elevation data were not modelled for all the epochs, the maps were also overlaid with the sublocation maps.

Climatic data was cleaned and enhanced using the procedure proposed by Boissonnade, Heitkemper and Whitehead (2002). They advocate for the use of official climatic data records which have usually undergone cleaning by the national meteorological services. This procedure was implemented by using multiple data sets from the Kenya Meteorological Department from different collection points. For instance, data was purchased in the years 2019 and 2020. These were then compared with each other to check for any inconsistencies. The emerging gaps filled by comparing raw data from the five weather stations with the collated data from the Kenya Meteorological Department at Dagoretti Corner. For instance, the monthly data was collected from the JKIA weather station, the annual means were then computed and compared with the collated data from the KMD headquarters at Dagoretti Corner for the same station. In instances where there were gaps and disparities, corroborative sources such as WorldClim (2019), National Oceanic and Atmospheric Administration (2019) and United States Geological Survey (2016). These sources were used for homogeneity testing to check the consistency of the weather station data with the surrounding areas as they primarily relied on satellite data and were therefore not point data. Climate thematic maps were classified into temperature and rainfall to correspond to thermal stress and flood risk vulnerability assessment. Thermal stress maps relied on the Average annual maximum temperature, Average annual minimum temperature, highest annual temperature, and lowest annual temperature. Rainfall used annual rainfall volume in millimetres. Thematic climate maps were modelled using the spline interpolation method. The interpolation method relies on the existing data to generate information for the zones without data using the algorithm expressed in Equation 3.4 and 3.5. The selected interpolation method was restricted to the county barrier in ArcMap 10.6. (ESRI, 2020). The data points were based on the five weather stations around the city.

$$S(x,y) = T(x,y) + \sum_{j-1}^{N} \lambda_j R(r_j) \qquad (3.4)$$

Where:

- S (x, y) is the interpolated point.
- T (x, y) is a coefficient found by the solution of a system of linear equation.
- R(r) is expressed as Equation 3.5 for a regularized interpolation.
- J = 1, 2, ..., N.
- N is the number of points.
- λ_j are coefficients found by the solution of a system of linear equations.
- r_j is the distance from the point (x,y) to the jth point.

$$\mathrm{R(r)} = \frac{1}{2\pi}\{\frac{r^2}{4}\left[1n\left(\frac{r}{2\tau}\right) + c - 1\right] + \tau^2\left[K_o\left(\frac{r}{\tau}\right) + c + 1n\left(\frac{r}{2\pi}\right)\right]\} \qquad (3.5)$$

Where:

- r is the distance between the point and the sample.
- τ is the Weight parameter.

- K_o is the modified Bessel function.
- c is a constant equal to 0.577215.

The temperature ranges were standardized into 10 classes for comparison across the years (Equation 3.6).

$$D_r = \frac{D_{max} - D_{min}}{10} \tag{3.6}$$

Where D_r represent the range used in modelling; D_{max} represents the highest recorded value of the climatic parameter for all the epochs and D_{min} represents the lowest recorded value of the climatic parameter for all the epochs.

The resultant maps were overlaid based on the thermal stress thresholds as defined by Abdel-Ghany, Al-Helal, and Shady (2013), Matzarakis and Amelung (2008), Matzarakis and Mayer (1996). The thresholds are ≤ 13℃ for cold stress and ≥ 23℃ for heat stress.

3.7.3 Vulnerability Ranking

Vulnerability ranking of the different sublocations was based on the three elements of exposure, sensitivity, and adaptive capacity. Climatic parameters dictated exposure; urban form determined sensitivity while socioeconomic aspects determined the adaptive capacity. The relationships between the parameters and vulnerability aspects were based on the theoretical associations established in the literature review.

For instance, the denser the built-up area, the higher the risk of flooding and higher thermal stress. The lower the urban elevation, the higher the risks of flooding and thermal stress. The steeper the slopes, the lower the risk of flooding. A summary of the vulnerability ranks (Table 3.12) outlining the rationale for vulnerability ranking was developed based on arguments by Oke (1987), Nassif and Wilson (1975) and Huang, Kang, Yang, and Jin (2017), Abdel-Ghany, Al-Helal, and Shady (2013), Matzarakis and Amelung (2008), Matzarakis and Mayer (1996), Stangl, (2018) and Ludena & Yoon, (2015).

Table 3.12: Summary of Vulnerability Ranking Rationale

Variable	Parameters	Vulnerability			
		Very High Vulnerability	High Vulnerability	Moderate Vulnerability	Low Vulnerability
Urban Form	Built-Up Area	<25%	25-50%	50-75%	>75%
	Forest Cover	<25%	25-50%	50-75%	>75%
	Elevation	1452-1566 m ASAL	1566-1676 m ASAL	1676-1784 m ASAL	1784-1951 m ASAL
	Flow Accumulation	<25%	25-50%	50-75%	>75%
	Slope	<4%	4-8%	8-16%	>16%
	Soil drainage Properties	Paved & Very Poorly Drained	Poorly Drained	Imperfectly Drained	Well Drained
	NDVI	<25%	25-50%	50-75%	>75%
Climate	Avg. Monthly Maximum Temp	>33℃	33-29.6℃	26.3-23℃	<23℃
	Avg. Monthly Minimum Temp	<7℃	7-10℃	10-13℃	>13℃
	Highest annual Temp	>33℃	33-29.6℃	26.3-23℃	<23℃
	Lowest annual Temp	<7℃	7-10℃	10-13℃	>13℃
	Rainfall	>1300 mm	1300-1150 mm	1150-950 mm	<780 mm
Socioeconomics	Population Density	<25%	25-50%	50-75%	>75%
	Age (above 64 years)	<25%	25-50%	50-75%	>75%
	Gender	<25%	25-50%	50-75%	>75%
	Poverty	<25%	25-50%	50-75%	>75%
	Access to Services	<25%	25-50%	50-75%	>75%

Note:

M ASL is meters Above Sea Level

3.8 Data Analysis and Interpretation

3.8.1 Post Classification Change Detection Analysis

Of the three popular methods of change detection, the study considered post classification method. It was selected as it minimizes sensor, atmospheric and environmental differences. This eliminated normalization errors between the two epochs of change detection (Mishra, Shrivastava, & Dhurvey, 2017).

According to Butt, Shabbir, Ahmad, and Azizi (2015) post-classification change detection is ideal for urban research as it shows the location, nature, and rate of change. It also derives summary statistics (Pradhan & Abdullahi, 2017). This was significant for the study as it showed whether the change was positive or negative and the landcover types that either lost or gained from the changes.

The comparisons were of independently classified images such as 1988 and 1998 to detect the change between the two. The classified data sets were rectified independently, and thematic maps generated. This was followed by comparison of corresponding sections to identify the areas of change. Further analysis involved two operations: area extraction and crosstabulation. Area extraction was conducted in ArcMap and the resulting area entered in excel where charts and trendlines were generated (Figure 3.14 and 3.15). The same data were used to generate line graphs for trend determination.

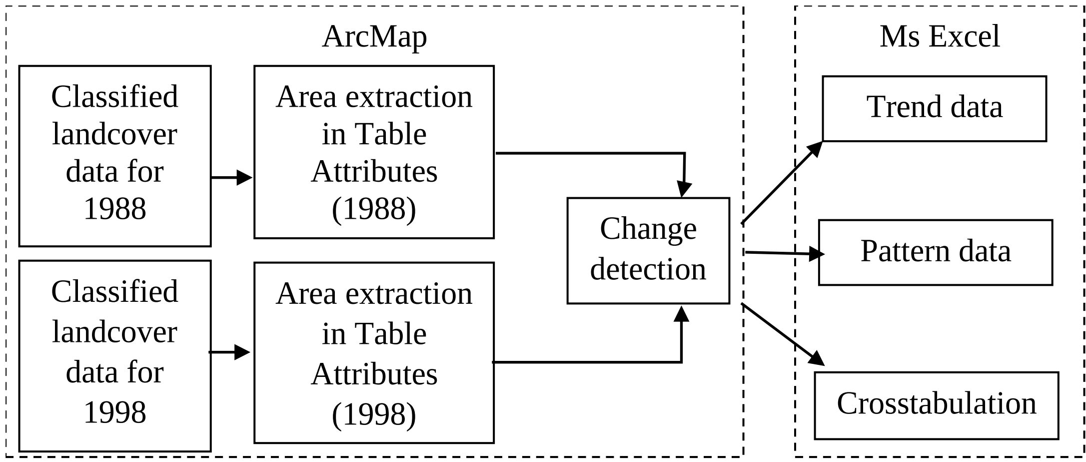


Figure 3.14: Framework for Trend and Pattern Analysis

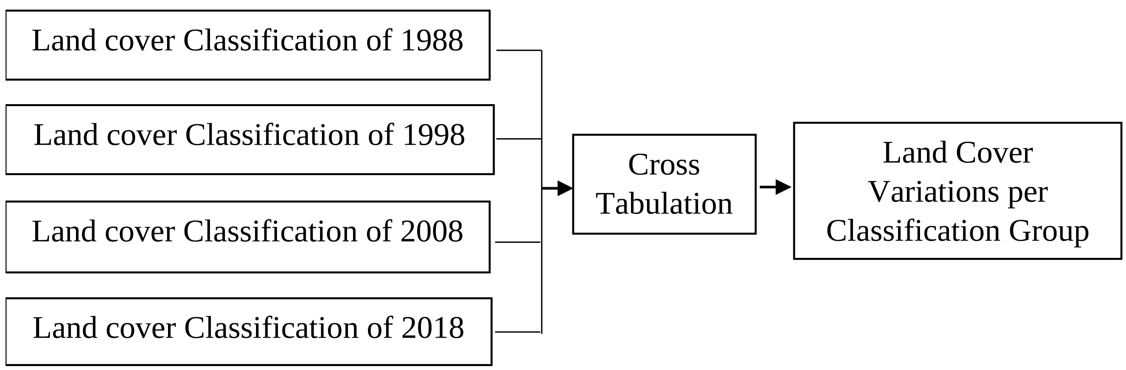


Figure 3.15: Summary of the Cross Tabulation Analysis of Landcover Types

The input process was for two landcover maps at a time, for instance, 1988 and 1998. The outputs used were the cross-classification image and the cross-tabulation table. The statistical data were then exported to Microsoft Excel. It was cross tabulated to determine the nature of change and the changes in and between landcover types. The change analysis included which landcover types changed, by what area, and to what other landcovers between the different years. Change detection was also conducted using percentage change formula (Equation 3.7).

$$Percentage\ change = \left\{\frac{E_2 - E_1}{E_1}\right\} * 100 \tag{3.7}$$

Where E_2 is the succeeding year and E_1 is the preceding year.

This detected percentage change in urban form and climate between epochs and the overall change between the 1988 and 2018 epoch (Appendix 18 & 19). The change was expressed as percentage. Negative values denoted reduction while positive values denoted increase in the parameter being measured.

3.8.2 Time Series Analysis

Even though time series analysis was primarily developed for economic forecasting and projections (Kirchgässner & Wolters, 2007), it can be used for other forms of forecasting and/ projections based on its concept of using underlying past trends in making projections. Yin (2003) and Gillham (2000) advance Time Series Analysis as an appropriate method of analysing quantitative data in a case study research approach as it can generate longitudinal view and projections. This was ideal in making a non-spatially oriented projection for climatic and landcover characteristics for the city using Statistical Package for Social Sciences (SPSS). The other urban form elements such as elevation and soil drainage properties were not projected as they showed no discernible trends or cycles.

The study relied on the Autoregressive Integrated Moving Averages (ARIMA) and seasonally adjusted trends to estimate percentages of different landcover types and climatic parameters in 10-year epochs between 2018 and 2048 ([Equation 3.8] Al-Chalabi, Al-Douri, & Lundberg, 2018). ARIMA was selected as it takes care of trends, seasonality, cycles, errors, and non-stationary aspects of a data set when making forecasts (Bista, 2016).

$$y_t = \mu + \sum_{i=1}^{p}(\sigma y_{t-1}) + \sum_{i-1}^{q}(\theta_i \varepsilon_{t-1} + \varepsilon_t \qquad (3.8)$$

- y_t is the actual data over time.
- μ is the mean value of the time series data.
- p is the number of autoregressive cut-off lags.
- q is the number of cut-off lags of the moving average process.
- σ is autoregressive coefficients (AR)
- θ is moving average coefficients (MA)
- t is time {1, . . ., k}.

To fulfil the requirements of time series analysis, the data were of equal time scales, arranged in chronological order with the projections limited to the same time scales. For instance, the 5-year epochs of past data were used to project 5-year epochs of future trends up to the 30-year mark of 2048. The models incorporated four elements: the projected values, the lower confidence level, the higher confidence level, the fit line, and the projected value (Figure 3.16). The fit line, mean value, was used to determine the projected values of urban form and climate parameters.

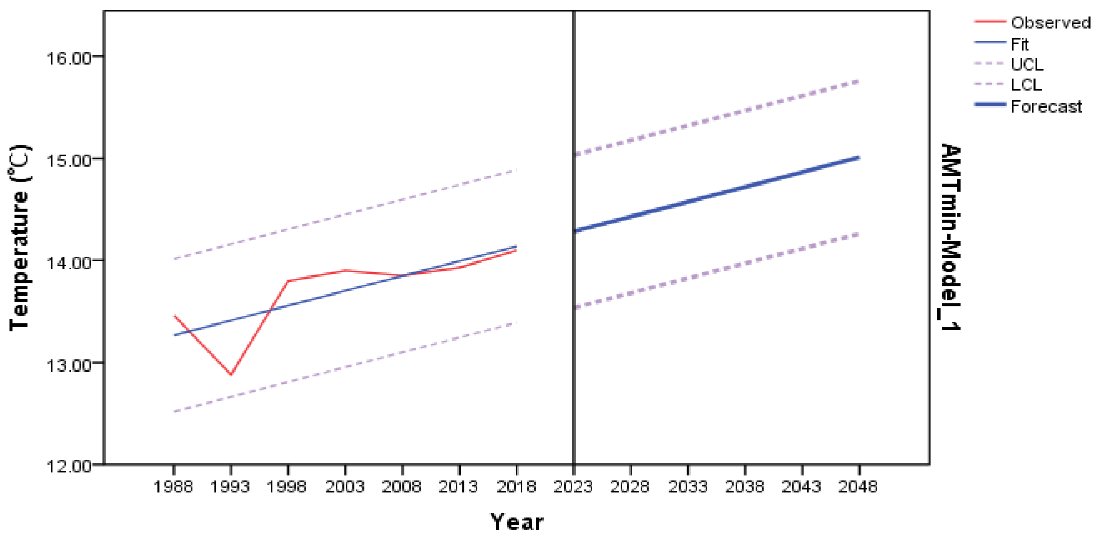


Figure 3.16: Sample Forecasting Graphic Output from SPSS

3.8.3 Overlay and Trend Analysis

To reveal spatial trends of urban form and climate parameters, the classification and interpolation raster were subjected to overlay analysis. This entailed changing the classes to estimated solid fills of different colours per epoch. The fills were systematically overlaid (Figure 3.17).

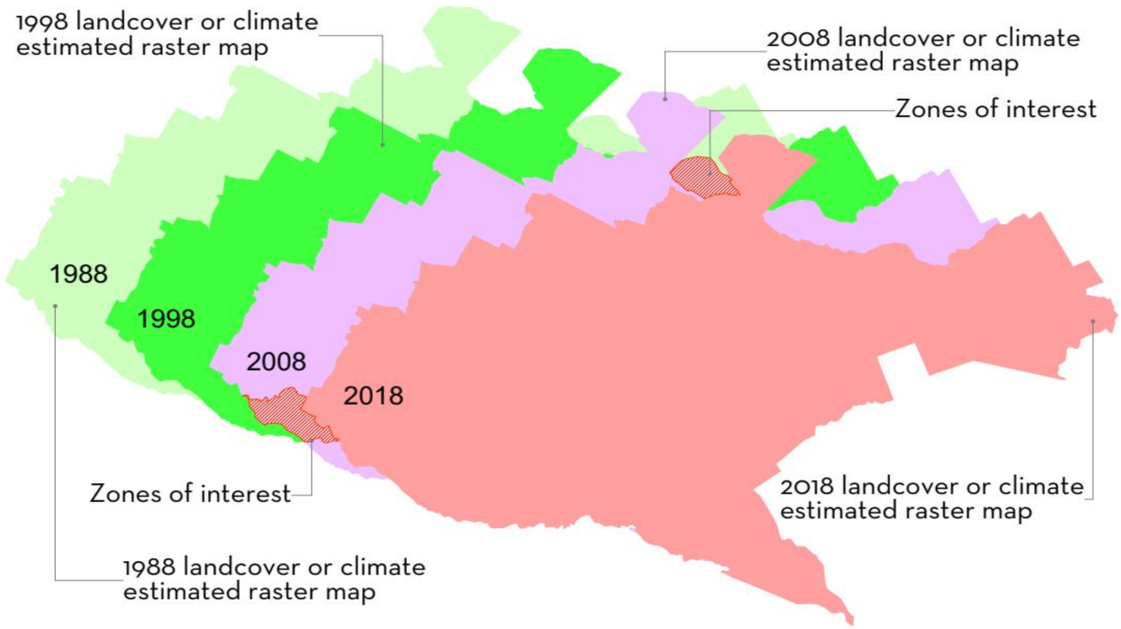


Figure 3.17: Overlay Analysis Method for Landcover and Climate

Two resultant maps were produced; one covered all the epochs to show the spatial trends and the other covered the years 1988 and 2018 epoch to reveal the overall spatial change. The spatial zones of growth or reduction were then highlighted for vulnerability assessment.

The resultants maps in the overlay analysis were then used to reveal trend line statistics. This was conducted by tabulating the urban form and climate parameter values. These were then plotted in two ways: firstly, against time and secondly against the other variable. For instance, average annual maximum temperature was plotted against the Normalized Difference Vegetation Index (Figure 3.18). The scatter plots were also used to extract the rate of change using the resultant trendline equation.

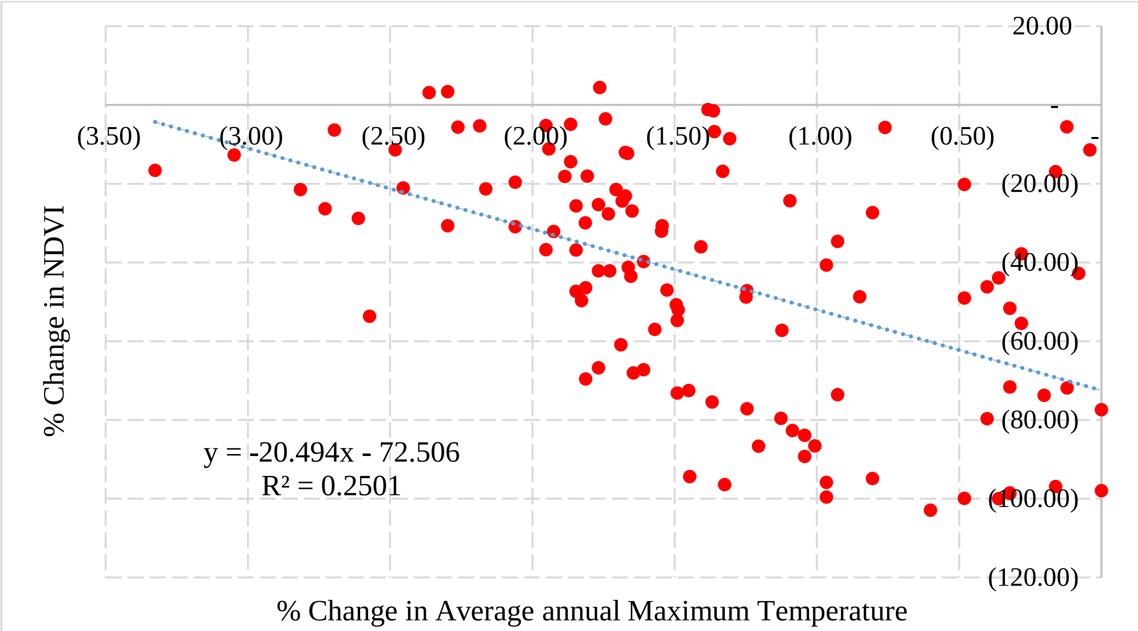


Figure 3.18: Sample Trend Analysis of Average Annual Maximum Temperature against NDVI Between 1988 And 2018

The resulting trend statistics were the rates of change (M) and the coefficient of determination (R^2). The M and R^2 were used to statistically explain the variations in either the urban form and climatic parameters against time or climatic parameters against urban form parameters.

3.8.4 Correlation Analysis

The relationship between urban form and climate was studied at the averaged city and interpolated sublocation levels. In both cases, the epochs were 1988, 1998, 2008 and 2018. The overall change considered was between 1988 and 2018. In either case, corelation analysis was conducted. Climatic data from the weather stations were averaged to get the city level data. Urban form data were used as modelled in ArcMap since the information was modelled at the city level.

Literature revealed multiple variables of urban form related to climate. The study therefore focused on the derivation of the model expressing the relationships between various urban form elements and climate. To achieve this, the county level and sublocation level climatic and urban form was entered into Statistical Package for the Social Sciences (SPSS) for correlation analysis This phenomenon argues that urban climate is a function of urban form parameters in addition to other parameters (Equation 3.9)

$$Urban\ Climate = F(BUA, F, NDVI, OSN, N) \quad (3.9)$$

Where:

- BUA is Built-Up Area (Km^2)
- F is Forest (Km^2)
- NDVI is Normalized Difference Vegetation Index (Index)
- OSN is Open Space Network (Km^2)
- N is other parameters not measured.

The data were correlated at two levels: the global city level and sublocation level. For the city level, the overall climate was derived through averaging of weather station data. The sublocation was derived from the landcover classifications and climate interpolation data (Appendix 14-17). The urban form data were then standardized using percentages (Equation 3.10) before correlation analysis.

$$Standardized\ Measure\ (\%) = \left\{\frac{UFA}{SA}\right\} * 100 \quad (3.10)$$

Where UFA is the Urban Form Area and SA is the sublocation Area.

The correlations were expressed in correlation matrices. The parameters that significantly correlated at 99% and 95% confidence intervals highlighted (Table 3.13). For instance, in the sample table, the Average annual Maximum Temperature significantly correlated with all urban form parameters at 99% confidence interval. The Pearson Correlation (r) explained the strength of the correlation.

Table 3.13: Sample Correlation Matrix Table Showing Correlations Between the Average Annual Maximum Temperature and Urban Form for the Year 2018.

		Average Annual Maximum Temp. 2018	Built-Up Area 2018	NDVI 2018	Forest 2018
Average Annual Maximum Temp. 2018	Pearson Correlation	1	.394**	-.446**	-.318**
	Sig. (2-tailed)		.000	.000	.001
	N	112	112	112	112
Built-Up Area 2018	Pearson Correlation	.394**	1	-.660**	-.622**
	Sig. (2-tailed)	.000		.000	.000
	N	112	112	112	112
NDVI 2018	Pearson Correlation	-.446**	-.660**	1	.703**
	Sig. (2-tailed)	.000	.000		.000
	N	112	112	112	112
Forest 2018	Pearson Correlation	-.318**	-.622**	.703**	1
	Sig. (2-tailed)	.001	.000	.000	
	N	112	112	112	112

Note: * Correlation is significant at the 0.05 level (2-tailed) and **. Correlation is significant at the 0.01 level (2-tailed).

3.8.5 Regression Analysis

The urban climate is therefore bound to change in response to changes in the respective urban form variables. It was inferred that these urban variables can explain the changes in climate and vice versa. Therefore, the objective of this model was to find out urban form parameters that are significantly correlated to the changes being experienced in urban climatic parameters over the 30 years. Stepwise regression was adopted in the generation of the models expressing the relationship between urban form and climate in Nairobi.

The relationship was expressed using regression models derived from the model summary, ANOVA, and Regression Coefficients tables in SPSS. The model summary table revealed the coefficient of determination and the F test for the model (Table 3.14).

Table 3.14: Sample Model Summary Regression of 2018 Average Annual Maximum Temperature Against 2018 Urban Form Elements

					Change Statistics				
Model	R	R^2	Adjusted R^2	Std. Error of the Estimate	R^2 Change	F Change	df1	df2	Sig. F Change
1	.446[a]	.199	.191	.25273	.199	27.040	1	109	.000

Note: a. Predictors: (Constant), NDVI 2018

The regression coefficients table was used to write the models and the t-test for the individual parameters (Table 3.15).

Table 3.15: Sample ANOVA for Regression Of 2018 Average annual Maximum Temperature Against 2018 Urban Form Elements

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.727	1	1.727	27.040	.000[b]
	Residual	6.962	109	.064		
	Total	8.690	110			

In the multiple regression equation, the dependent variable was a linear function of more than one urban form variable as expressed in the Equation 3.11. The significance of the overall models and the individual parameters were evaluated using the F and t-tests, respectively. The tests were conducted at 99% and 95% confidence intervals. This was read from the Sig. F Change (Table 3.15), the sig. columns (Table 3.15 and Table 3.16).

$$Y = a0 + \beta_1 BUA + \beta_2 F + \beta_3 NDVI + \beta_4 OSN + e \qquad (3.11)$$

Where:

- Y is Climate Vulnerability Index.
- a0 is a constant equivalent to the dependent variable if no independent variable is influencing the dependent variable.
- β_n is a coefficient of urban form.

- BUA is Built-Up Area (Km^2)
- F is Forest (Km^2)
- NDVI is Normalized Difference Vegetation Index
- OSN is open space network (Km^2)
- e is the error.

Table 3.16: Sample Regression Coefficients For 2018 Average annual Maximum Temperature Against 2018 Urban Form Elements

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	24.577	.035		708.742	.000
	NDVI 2018	-.004	.001	-.446	-5.200	.000

3.9 Research Credibility

Measurement is at the centre of social science. It involves the determination of the relationship between empirical indicators and unobservable concepts. The two fundamental properties of empirical measurement are reliability and validity.

3.9.1 Reliability.

The variables in the study were climatic, biophysical, and socioeconomic parameters. Questionnaires were used for the collection of expert vulnerability ranking data. Ground truthing data were collected using observation checklists. Climatic and socioeconomic data were purely secondary data and therefore not subjected to reliability and validity tests. Even though the biophysical data were also secondary, it was remodelled to extract the required parameters in the cases of landcover and normalized Difference vegetation index. As such, these components alongside expert ranking (Appendix 3 and 4) were subjected to reliability testing at a 0.7 threshold suggested by DeVellis (2016), Gliem and Gliem (2003) and Nunnally (1994)

The chance error that emanates from all objective measurements according to Carmines and Zeller (1979) and Kothari (2004) was minimized through the systematic refinement of the questionnaire. The refinement included a reduction in the length of the inquiry period, elimination of vagueness, and simplification of the measures using the Likert scale.

3.9.2 Validity

Validity is the extent to which an indicator of a concept measures the concept it purports to equate to (Carmines & Zeller, 1979). Just like reliability, validity also carries a measure of chance error known as non-random error which shows systematic bias.

The study considered two types of validity: construct and content validity. The construct validity sought to determine whether tools measured what they sought to measure. The content validity looked to show whether the tests were representative of what they sought to measure. Construct validity was determined through correlation of the items measured and other previous measurements on the subject.

3.10 Research Ethics

Research ethics forms an integral part of any research. They encompass the pre-data collection, data collection and post data collection stages (Oliver, 2003). The study is guided by the five key principles of ethical social research as outlined by MacDonald and Headlam (2008) and augmented by arguments from Oliver (2003), and Ruane (2005).

First is the principle of informed consent. The expert respondents who filled the self-administered questionnaires were issued with an Informed Consent form first Second is the confidentiality of the information supplied by research subjects and the anonymity of respondents was ensured through issuing anonymous questionnaires. None of the respondents was expected to identify themselves on the questionnaire.

Third is voluntary participation. This was ensured by seeking prior permission from participants and allowing them to halt participation when they are uncomfortable with continuing their participation. In scenarios where data collection tools such photographs were used to collect data on biophysical characteristics, no faces or identifying signage were recorded.

Fourth is safety of researcher and respondents. Since the respondents only filled questionnaires at their convenience, they were not exposed to any harm. As for the research assistants who were collecting data in the field, prior caution was taken to engage the local administration to accompany them. Permits (Appendix 20) were also acquired before the research from the National Commission for Science, Technology, and Innovation (NACOSTI).

Fifth is the research was independent and had no conflict of interests. It was partially funded by Jomo Kenyatta University of Agriculture and Technology (JKUAT) which remained impartial through the entire study. None of the respondents was induced to provide information as this would create bias according to Oliver (2003).

The research relied on both primary and secondary data. The parameters of urban form and climate were selected and processesed then analysed using Ms. Excel, SPSS and ArcGIS. The resultant models discussed urban form evolution, climate trends, and their relationships.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The chapter discusses the findings of the study, analysis, and interpretation of the findings. It commences with the urban form evolution for the city followed by the climatic trends and patterns. It then discusses the resultant vulnerability patterns and concludes with the analysis of biophysical, socioeconomic, thermal stress, flood, and overall vulnerability of the sublocations.

Reliability of the expert ranking was assessed using the Cronbach's Alpha coefficient in SPSS. The test used 12 cases (Table 4.1) and 29 items. The 12 cases were the expert respondents while the 29 items were the 29 questions that each of the 12 respondents ranked on a Likert scale system. The resultant Cronbach's alpha was 0.838 (Table 4.2) which is well above the 0.7 suggested for dependability.

Table 4.1: Case Process Summary for Expert Ranking

		N	**%**
Cases	Valid	12	100.0
	Excluded[a]	0	.0
	Total	12	100.0

Note. a. Listwise deletion based on all variables in the procedure.

Table 4.2: Reliability Statistics for Expert Ranking in SPSS

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.838	.840	29

Reliability tests for biophysical parameters considered landuse and Normalized Difference Vegetation Index in the 112 sublocations (Table 4.3). It revealed a Cronbach's alpha of 0.802 (Table 4.4) which is also above the 0.7 threshold therefore the modelled data is dependable.

Table 4.3: Case Processing Summary for Selected Biophysical Parameters

		N	%
Cases	Valid	112	100.0
	Excluded[a]	0	.0
	Total	112	100.0

Note. a. Listwise deletion based on all variables in the procedure.

Table 4.4: Reliability Statistics for Selected Biophysical Parameters in SPSS

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.802	.802	2

4.2 Results

4.2.1 Evolution of Nairobi's Urban Form Between 1988 And 2018

The urban form parameters studied included landcover, soil drainage properties, slope, elevation, Open Space Network, Normalized Difference Vegetation Index, and flow accumulation. These were grouped under biophysical parameters.

4.2.1.1 Landcover

Nairobi County was classified into five landcover typologies. These are forests, bare soils, grassland, built-up areas, and water. The rationale of the classification was guided by the influence that the different urban landcover types have on flood and thermal stress risks. All the studied landcovers changed in all the years considered. The changes were both negative and positive. Negative denoted decrease while positive denoted increase.

The most pronounced landcover change between 1988 and 2018 was the built-up area; it increased by 147.13%. Grassland and forest cover reduced by 46.26% and 46.28%

respectively. A side-by-side bar graph in Figure 4.1 and a line graph in Figure 4.2 shows the percentages of change and trends, respectively.

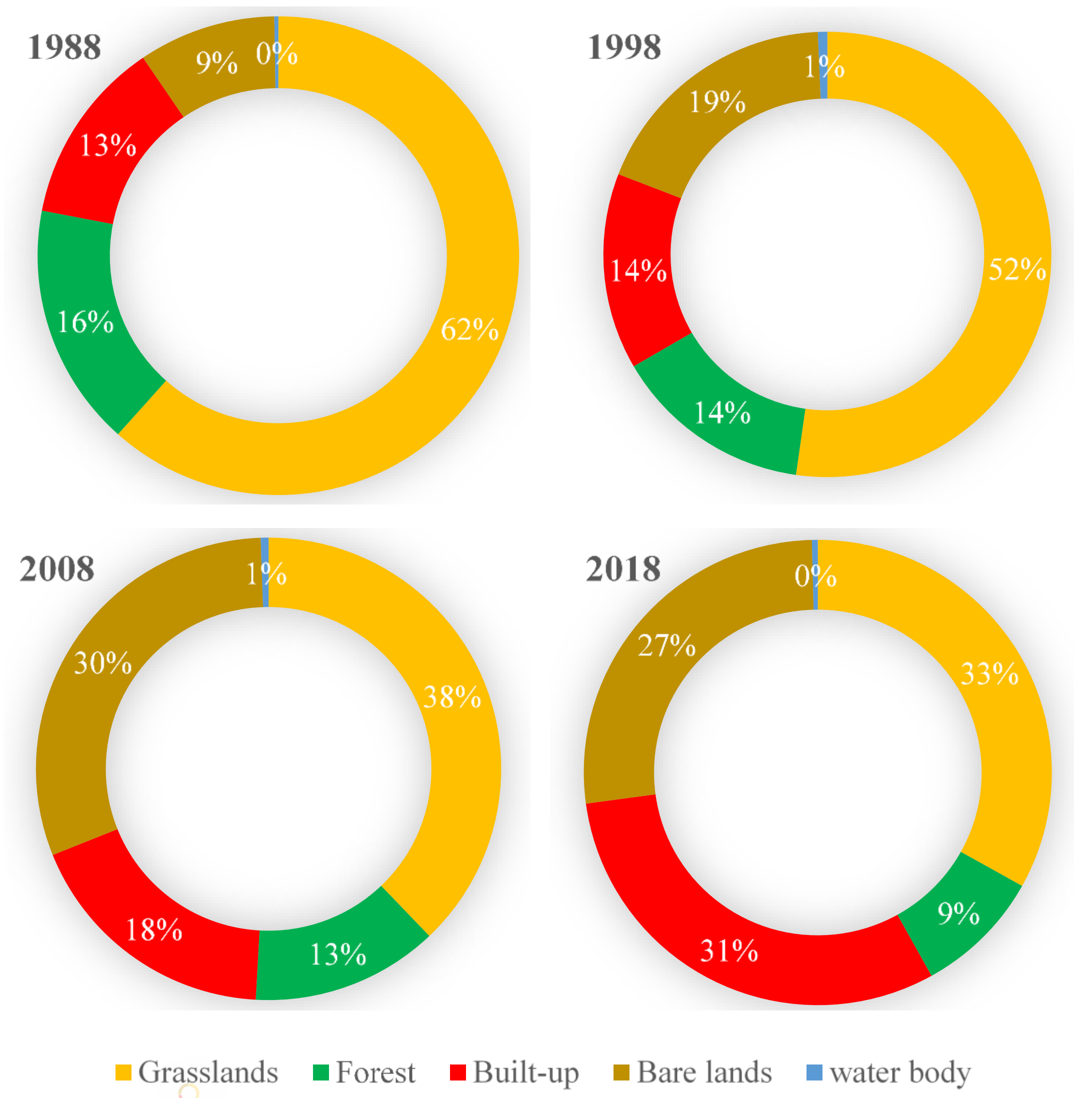


Figure 4.1: Proportions of Landcover Typologies Between 1988 and 2018

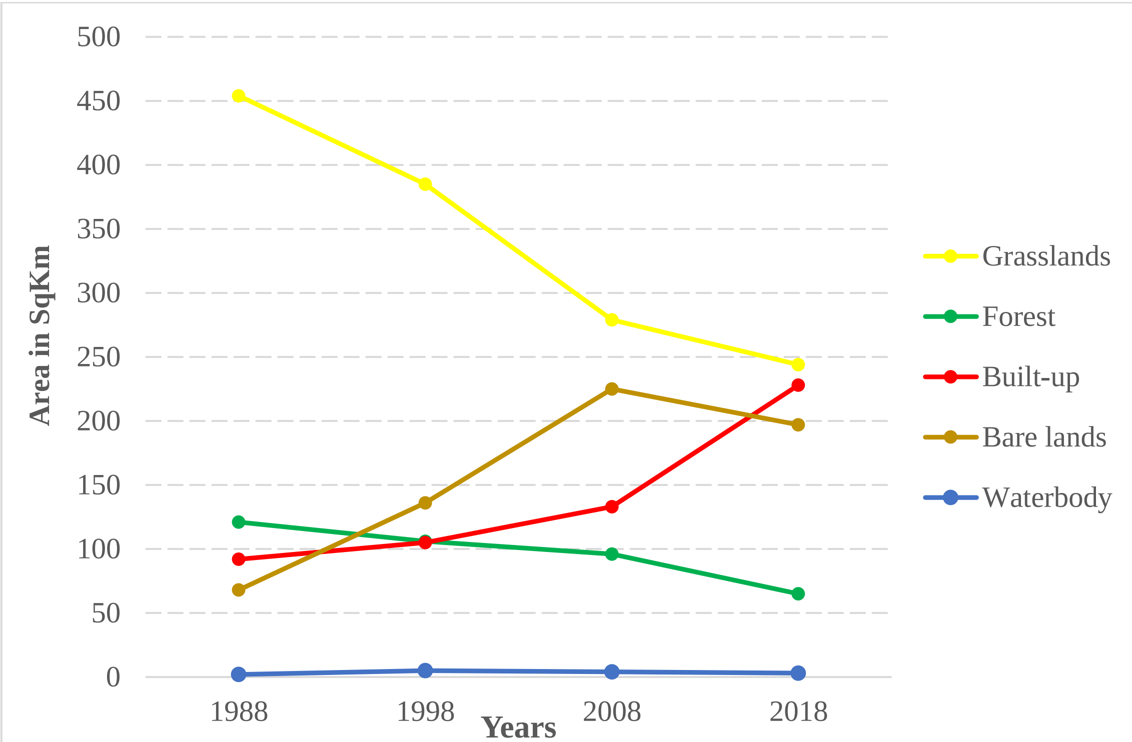


Figure 4.2: Nairobi's Landcover Trends Between 1988 and 2018

The inter-epoch change (Table 4.5 & Figure 4.3) displays similar patterns to the overall change between 1988 and 2018 except for the bare lands and water body. Bare land increased by 100% and 65% between 1988 and 2008 then decreased by 12% in 2018 while the water body increased in 1998 then reduced. The changes in bare lands could have been caused by aggravated weather patterns and increased human activity that possibly decimated the grasslands.

The significant increase of 150% in water body in 1998 can be attributed to the increased rainfall and therefore water pooling due to the El Nino phenomenon. The consistent increase in built-up area was due to rapid urbanization while the reduction in grassland and forest cover can be attributed to the increase in built-up area. The increase in bare grounds between 1988 and 2008 was attributed to the rapid urbanization without the accompanying environmental sensitivity. The reduction can be attributed to the deliberate city greening efforts by the City County of Nairobi.

Table 4.5: Landcover Trends and Percentage Change Between 1988 and 2018

Landcover	1988	1998		2008		2018		1988-2018
	Area (Km^2)	Area (Km^2)	%Change from 1988	Area (Km^2)	%Change from 1998	Area (Km^2)	%Change from 2008	% Change 1988 - 2018
Grasslands	427.21	362.29	15.20%*	262.54	27.50%*	229.60	12.50%*	46.30%*
Forest	113.86	99.75	12.40%*	90.34	9.40%*	61.17	32.30%*	46.30%*
Built-up	86.57	98.81	14.10%	125.15	26.60%	214.55	71.40%	147.80%
Bare lands	63.99	127.98	100.00%	211.73	65.40%	185.38	12.40%*	189.70%
water body	1.88	4.71	150.00%	3.76	20.00%*	2.82	25.00%*	50.00%
Sum Area	693.52	693.52		693.52		693.52		

Note: * denote reduction in area between the two epochs

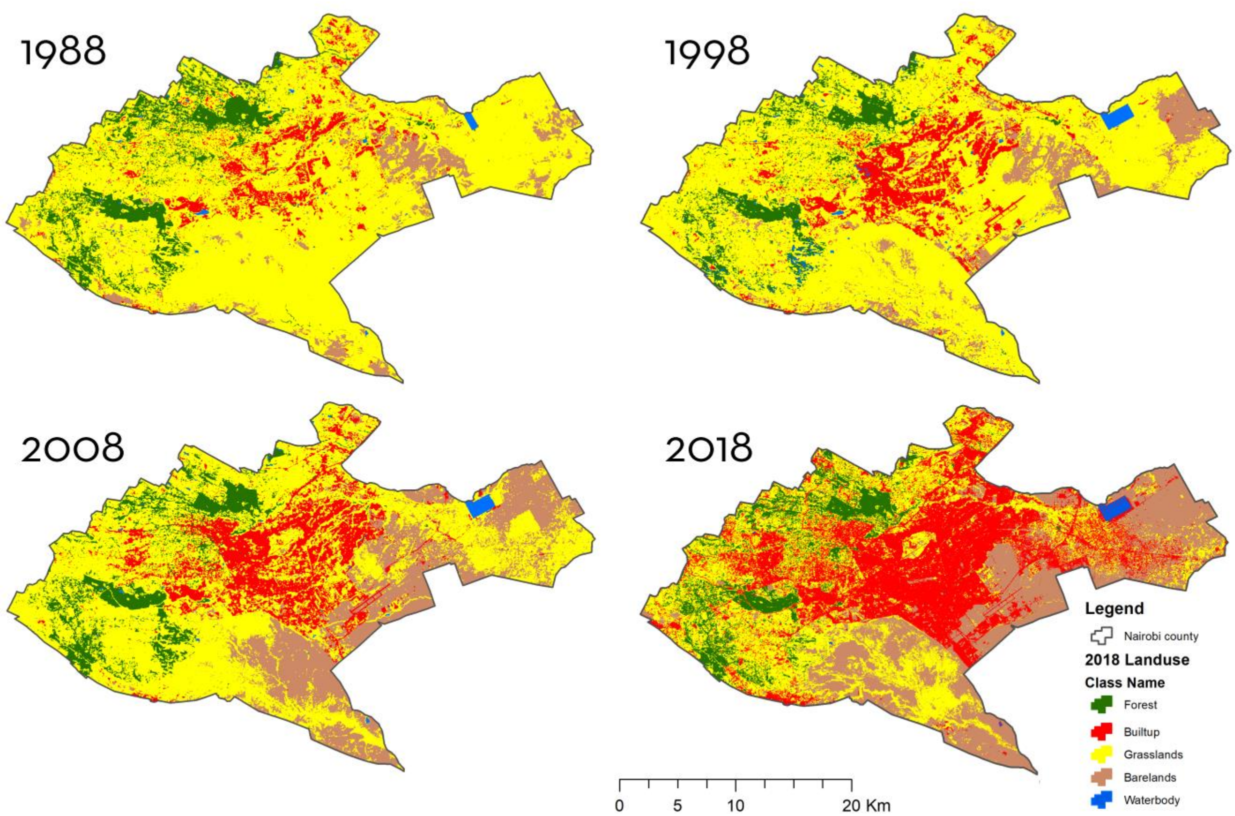


Figure 4.3: Landcover Patterns for 1988, 1998, 2008 and 2018

The spatio-temporal landcover patterns (Figure 4.4 to Figure 4.7) reveal an increase in impervious surfaces. Most of the built-up area growth between 1988 and 2018 is to the east of the city with sections to the west (Figure 4.5). Forest cover reduction of 46% between 1988 and 2018 affected both Karura and Ngong Forests (Figure 4.6). It occurred at the periphery of the forests. It also manifested as fragmentation of connecting vegetation between zones of dense forests.

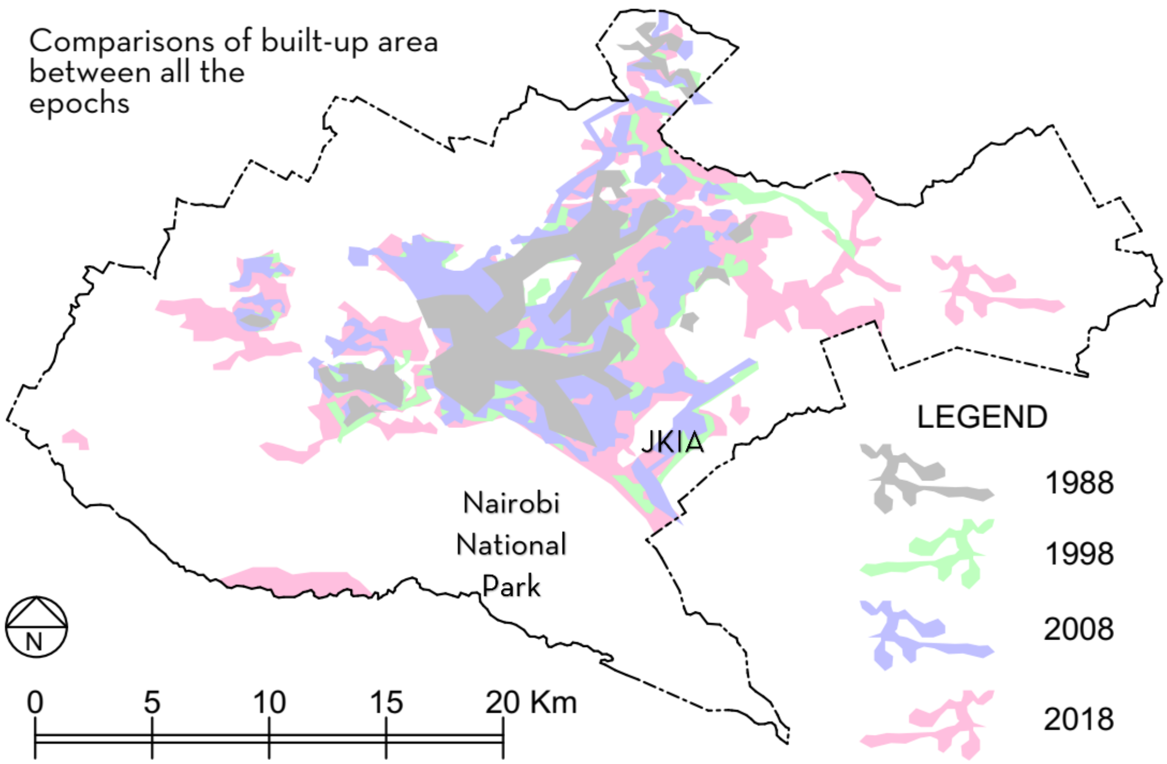


Figure 4.4: Overlay Analysis of Built-Up Area Between 1988 and 2018

Change detection analysis was conducted to determine how landcover typologies were changing over time. Change detection through cross-tabulation (Table 4.6) specified the nature of changes between the specific landcover types. This covered the quantity of landcover types that remained the same; those that changed and how much each landcover was converted to each of the others (Figure 4.8). This was conducted between two epochs. For instance, 1988 was cross tabulated with 1998 and 1998 with 2008.

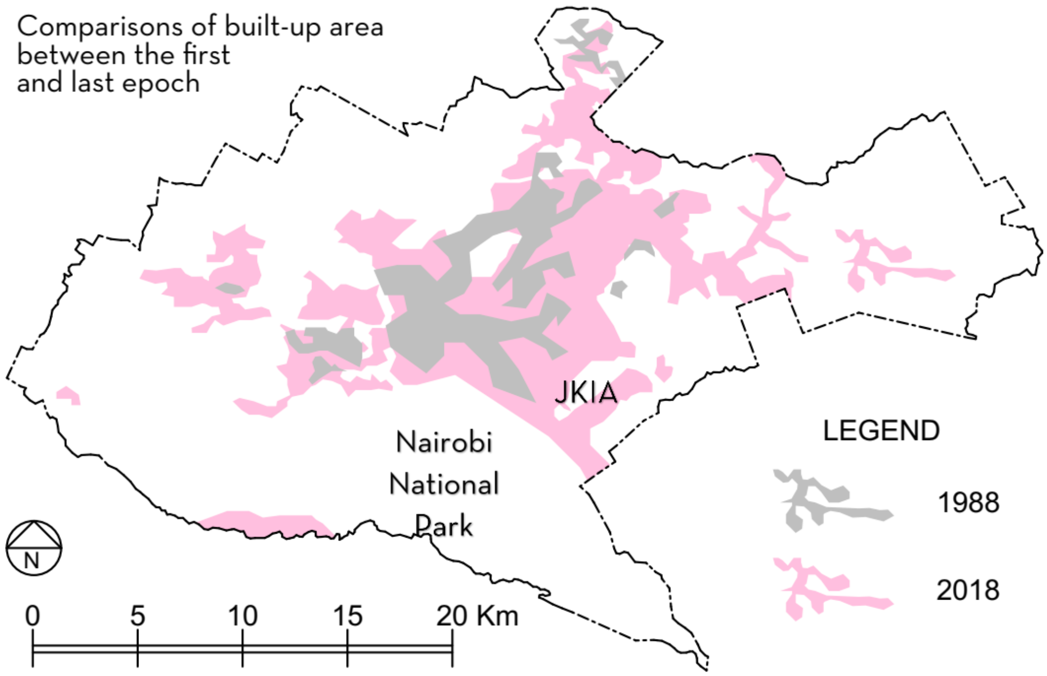


Figure 4.5: Overlay Analysis of Built-Up Area Trends Between 1988 and 2018

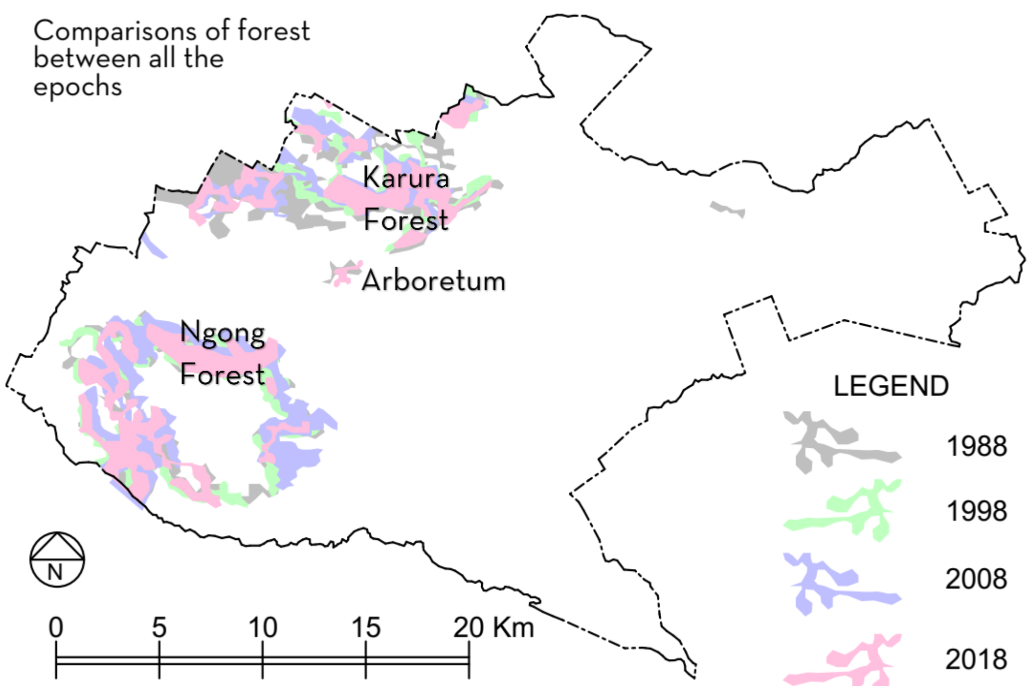


Figure 4.6: Overlay Analysis of Forest Cover Between 1988, 1998, 2008 and 2018

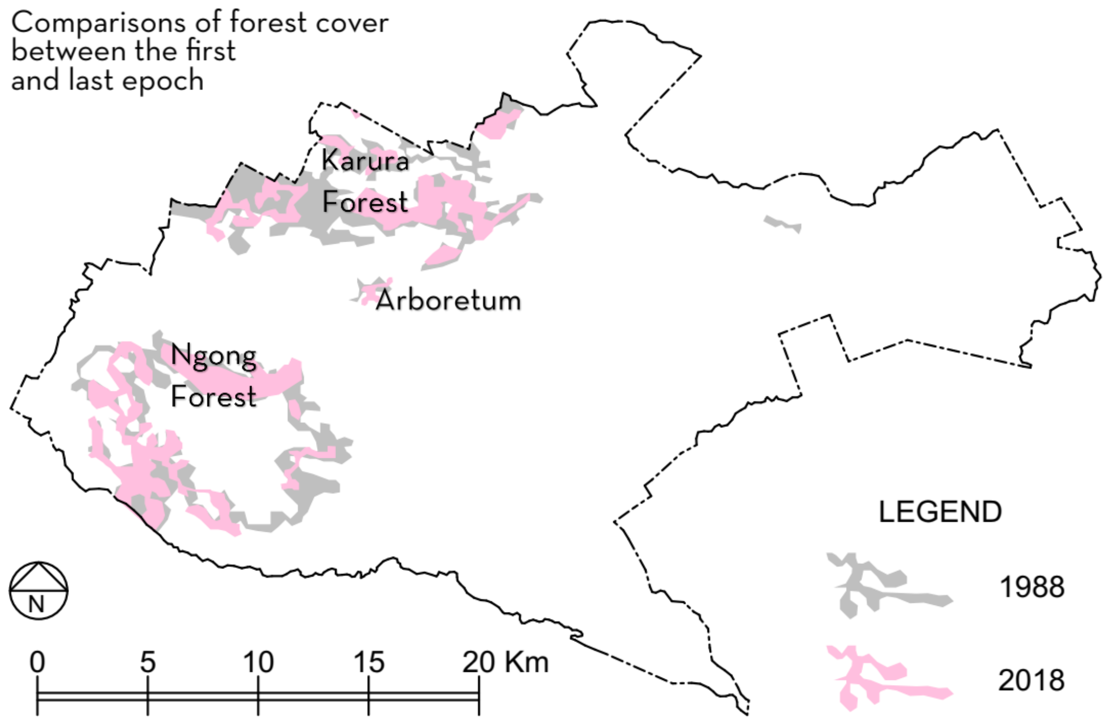


Figure 4.7: Overlay Analysis of Forest Cover Between 1988 and 2018

The landcover changes between 1988 and 2018 affected all the groups used in the classification. Table 4.6 represents which landcovers changed and to which landcover they converted to. For instance, between 1988 and 1998, a total of four km^2 of forest cover changed to built-up area, two km^2 grassland changed to water due to the El- Nino rains. It also represents the area of the landcover types that remained the same (the diagonal highlighted cells). For instance, the area of forest that remained forest between 1988 and 1998 was 77 km^2. The area of grassland that remained grassland between 1998 and 2008 was 204 km^2.

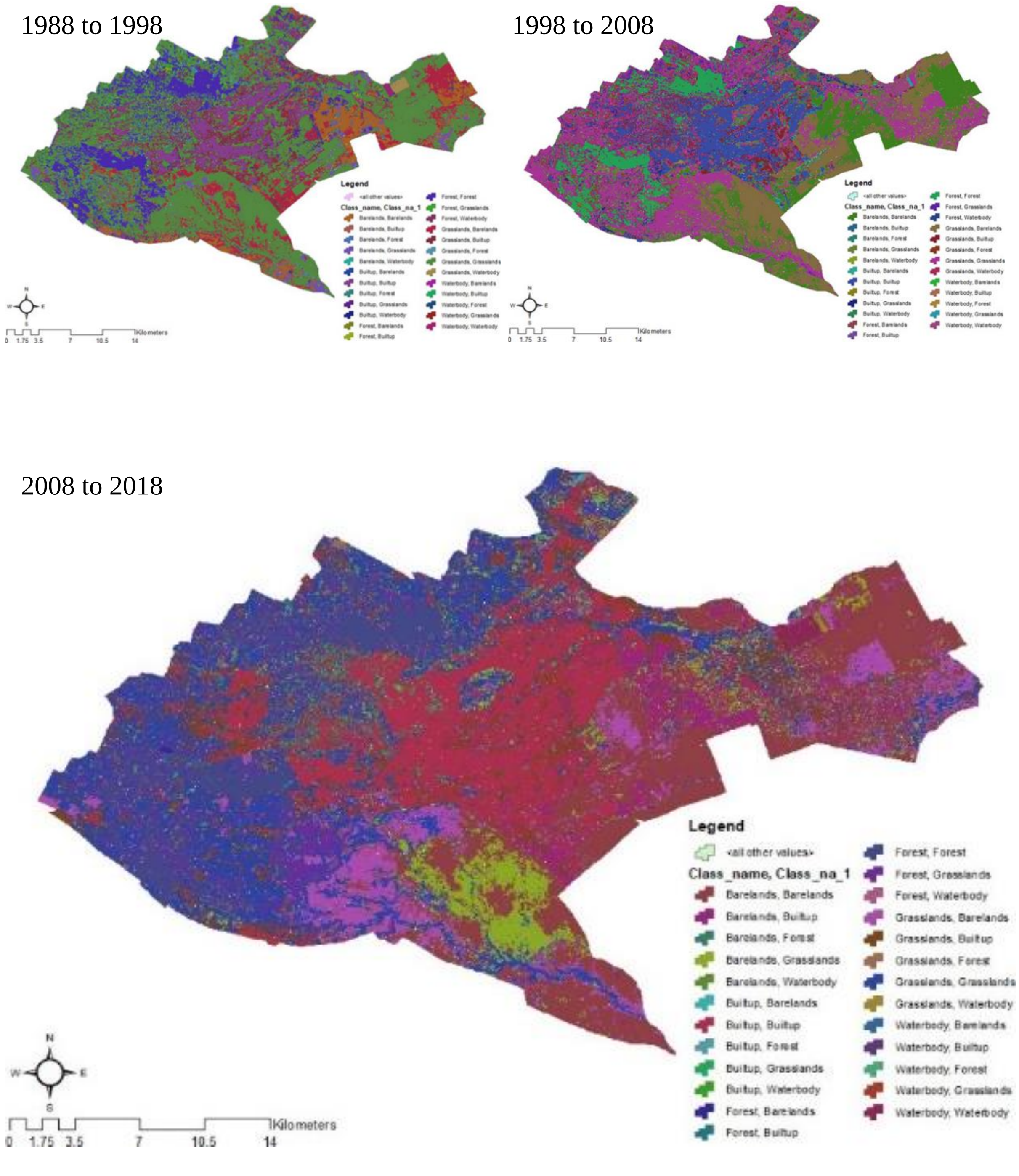


Figure 4.8: City County of Nairobi Change Detection Analysis between 1988 and 1998

Table 4.6: Cross Tabulation of Landcover Changes Between 1988 and 2018

			YEAR 1988						
		Land Cover	Forest	Built-up	Bare lands	Grasslands	Waterbody	Sum A	Total (A-B)
1998	Land Cover	Area (Km²)	121	92	68	454	2	737	
	Forest	96	77	1	0	17	0	95	-27
	Built-up	105	4	58	2	42	0	106	14
	Bare lands	136	1	11	43	80	0	135	67
	Grasslands	395	39	22	23	312	0	396	-57
	Waterbody	5	1	0	0	2	2	5	3
	Sum B	737	122	92	68	453	2		
			YEAR 1998						
2008	Land Cover	Area (Km²)	96	105	136	395	5	737	
	Forest	96	66	1	96	96	1	260	164
	Built-up	134	6	79	12	36	0	133	29
	Bare lands	225	1	8	88	127	0	224	-7
	Grasslands	279	23	16	35	204	0	278	-185
	Waterbody	3	0	0	0	0	3	3	-1
	Sum B	737	96	104	231	463	4		
			YEAR 2008						
2018	Land Cover	Area (Km²)	96	134	225	279	3	737	
	Forest	65	55	0	0	9	0	64	-33
	Built-up	228	5	119	40	63	0	227	94
	Bare lands	197	1	1	138	56	0	196	-28
	Grasslands	244	36	13	46	150	0	245	-33
	Waterbody	4	0	0	0	0	3	3	0
	Sum B	737	97	133	224	278	3		

Note: The highlighted cells reflect the percentage of the landcover area that remained the same between the two epochs

The 2018 landcover map of the city (Figure 4.9), revealed a centrally concentrated built-up area that also follows the main transportation corridors. The forests are located to the northwest and southwest of the city. The main waterbody on the map is the sewage treatment plant located to the east. Bare lands are spread to the south and east. The large swath to the south comprising grassland and bare lands is the Nairobi National Park.

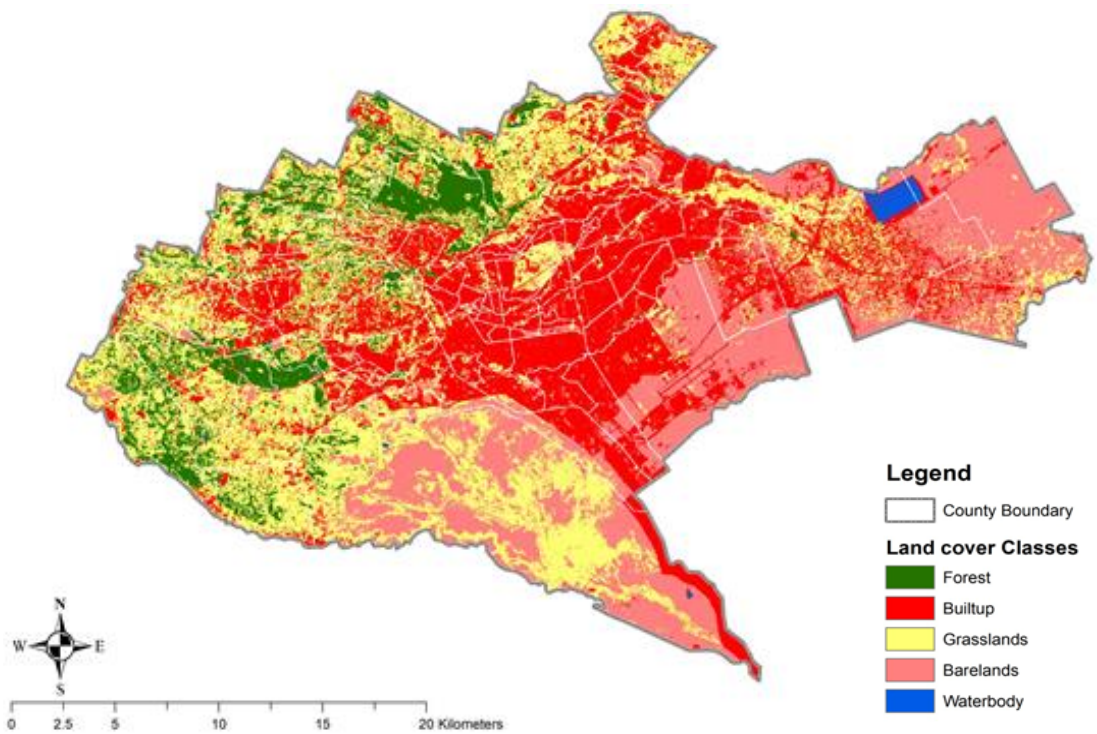


Figure 4.9: Nairobi's Landcover Patterns for 2018

4.2.1.2 Elevation

The elevation of Nairobi rises from 1452 meters Above Sea Level (ASL) on the eastern side to about 1900 meters above sea level on the western side (Figure 4.10). The elevations of the different sublocations determine their vulnerability to both flooding risk and thermal stress. The lower elevation of the city located to the eastern side is likely to receive the stormwater runoff thereby making it susceptible to flooding.

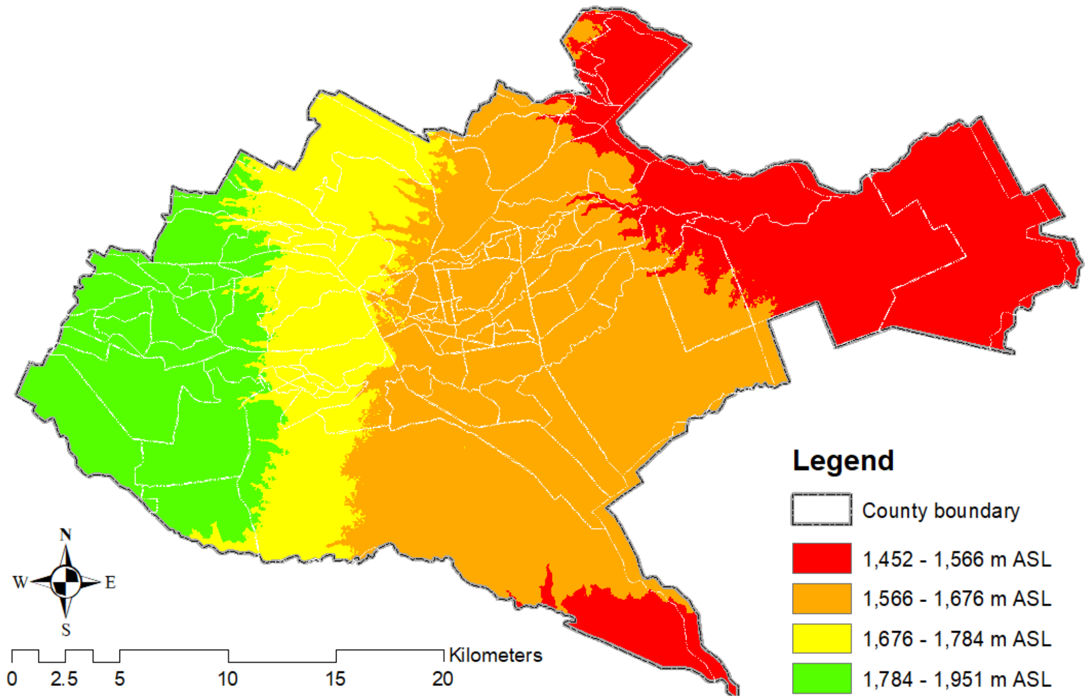


Figure 4.10: Nairobi's Elevation Map. Source: Adopted from (RCMRD)

4.2.1.3 Slope

The slope percentages for the city range between 0% and 78% (Figure 4.11). Slope ≤ 4% are concentrated on the eastern and southern sides of the city. Steeper slopes ≥16% concentrated on the Western side of the city and zones along riparian areas. The range of slope used for classification was based on the ranges argued by Nassif and Wilson (1975) and Huang, Kang, Yang, and Jin (2017) to influence surface runoff. They postulate that slopes less than 16% result in slow runoff speeds that increase the risk of flooding.

4.2.1.4 Flow Accumulation

Flow Accumulation was used as a tool to further determine the flood vulnerability of the different sublocations (Kit, Ludeke, and Reckien, 2011). It determines the accumulation of surface water over the entire landscape. Despite the county's good coverage of rivers systems, not all sublocations have rivers passing through. Withholding the aspect of constructed drained systems, these sublocations stand an elevated risk of flooding.

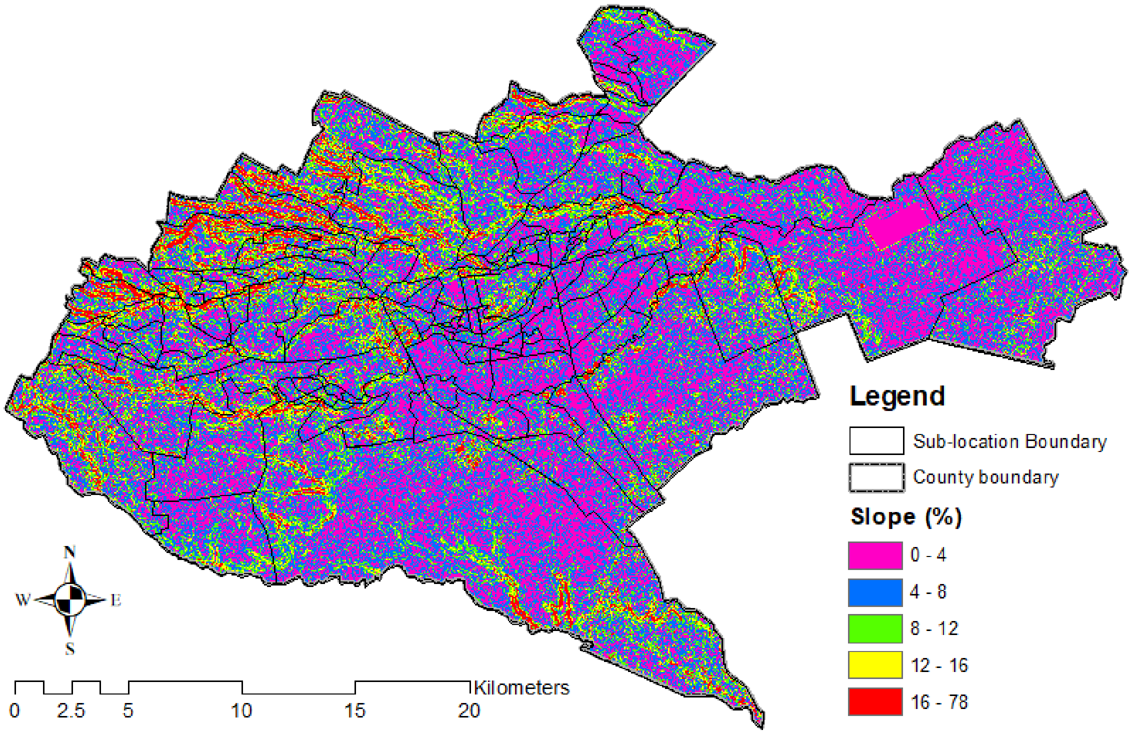


Figure 4.11: Slope Analysis Map of Nairobi

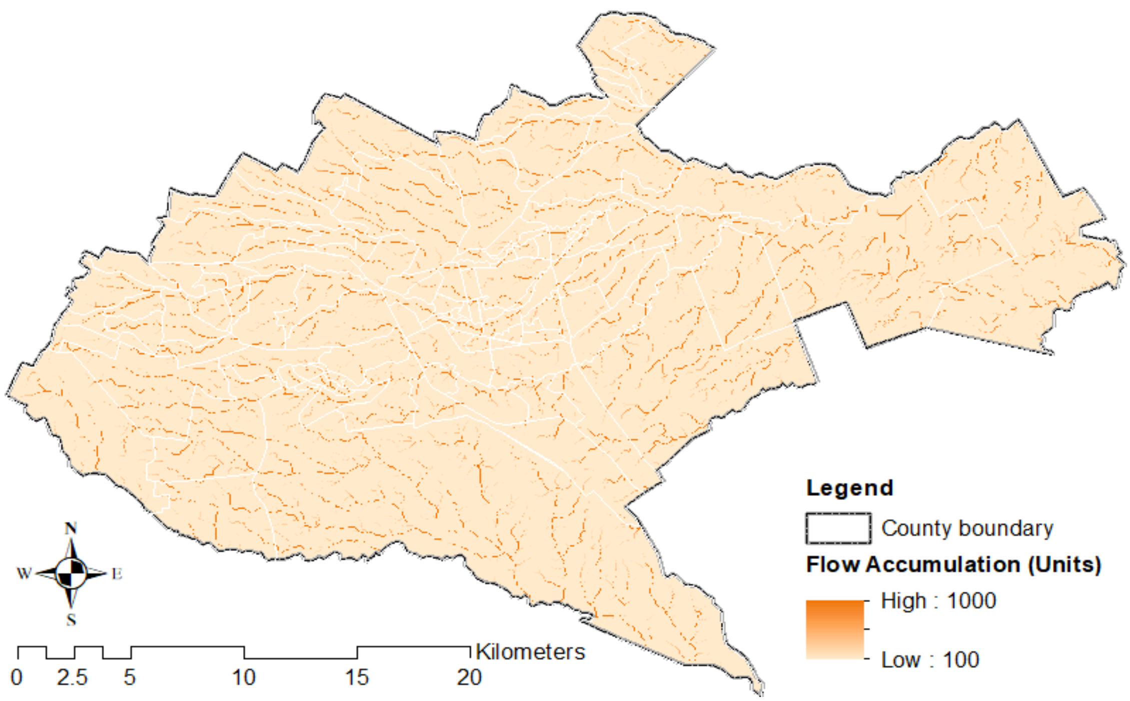


Figure 4.12: Nairobi's Flow Accumulation Ranking

Using a flow accumulation threshold of 250 units, the modelled map (Figure 4.12) displayed an even spread of flow over the county. However, they vary greatly. For instance, Bondeni, City Square, Lumumba and Mbotela sublocations displayed extremely low flow accumulation which makes them susceptible to flooding.

4.2.1.5 Soil Drainage Properties

KenSOTER classifies soil drainage properties into Excessively Well-drained (EWD), Moderately well-drained (MWD), Imperfectly drained (ID), Poorly drained (PD), Very poorly drained (VPD) and a non-classified section. The non-classified section comprises zones with densely built-up areas. Of these classifications, five exist within the City County of Nairobi County. The five are Well-drained, Imperfectly drained, Poorly drained, Very poorly drained and a non-classified section (Figure 4.13).

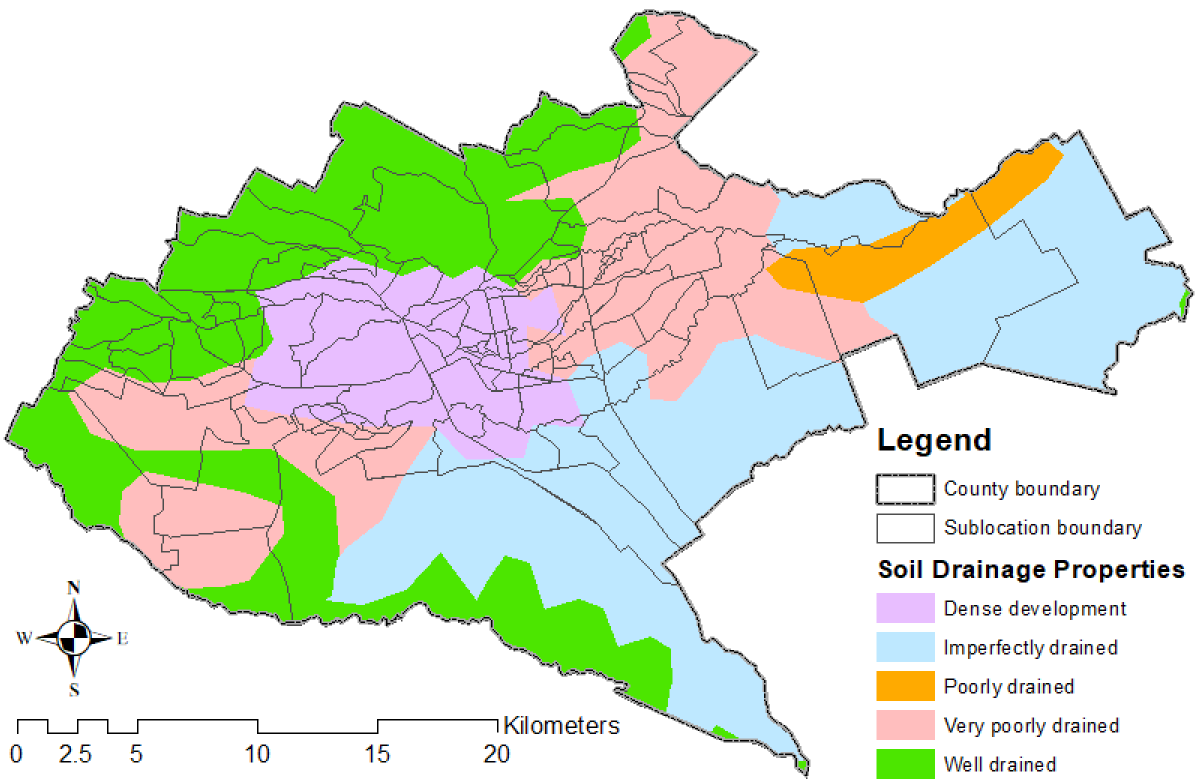


Figure 4.13: Soil Drainage Properties. Source: Adopted from Kenya Agricultural and Livestock Research Organization

The central zone of the city was densely built-up and corresponded with the landcover classification. The southern part of the city was imperfectly drained. The northern and southern western edges of the city were well-drained. A central belt together with a western patch were either poorly or very poorly drained. As a result, more than half of the city was either imperfectly, poorly, or very poorly drained. Statistically, 21 sublocations are well-drained, 31 are very poorly drained and 7 imperfectly drained. The rest is zoned as dense development.

4.2.1.6 Open Space Network

The space framework combines the Open Space Network and the Normalized Difference Vegetation Index. The Open Space Network is an inventory of the open spaces in the city; combines private and public spaces. It revealed a particularly good spread of open spaces at the city level. Nonetheless, the trends (Figure 4.14 & Figure 4.15) reveal reducing open space concentrated at the central zone of the city with patches to the east and west. This is in tandem with the built-up area expansion trends.

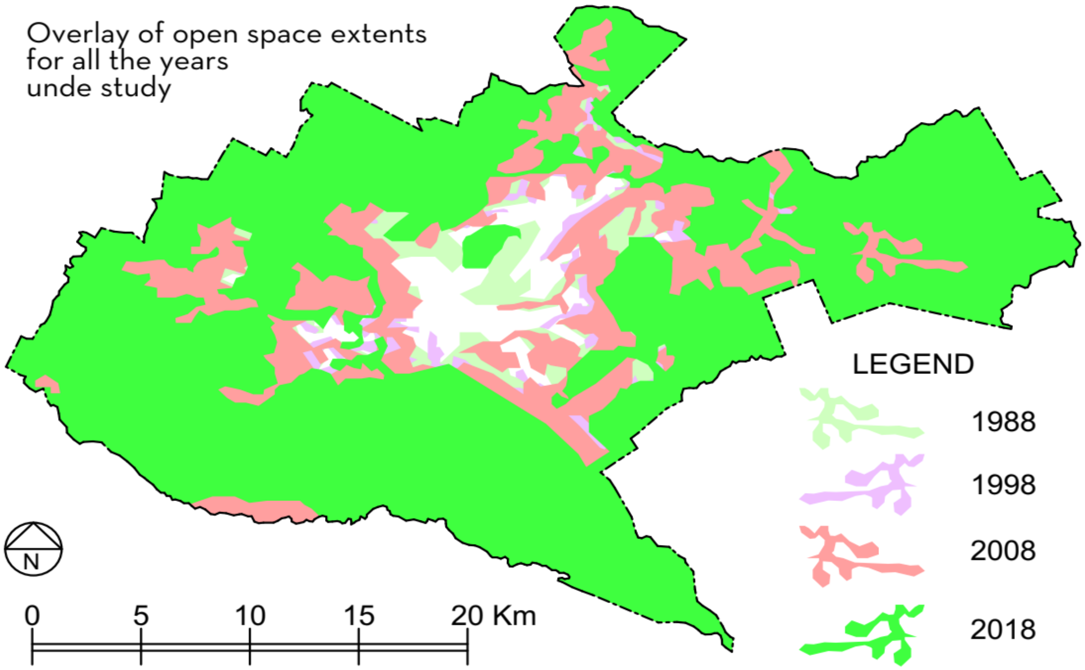


Figure 4.14: Overlay Analysis of Open Space Networks for 1988, 1998, 2008 and 2018

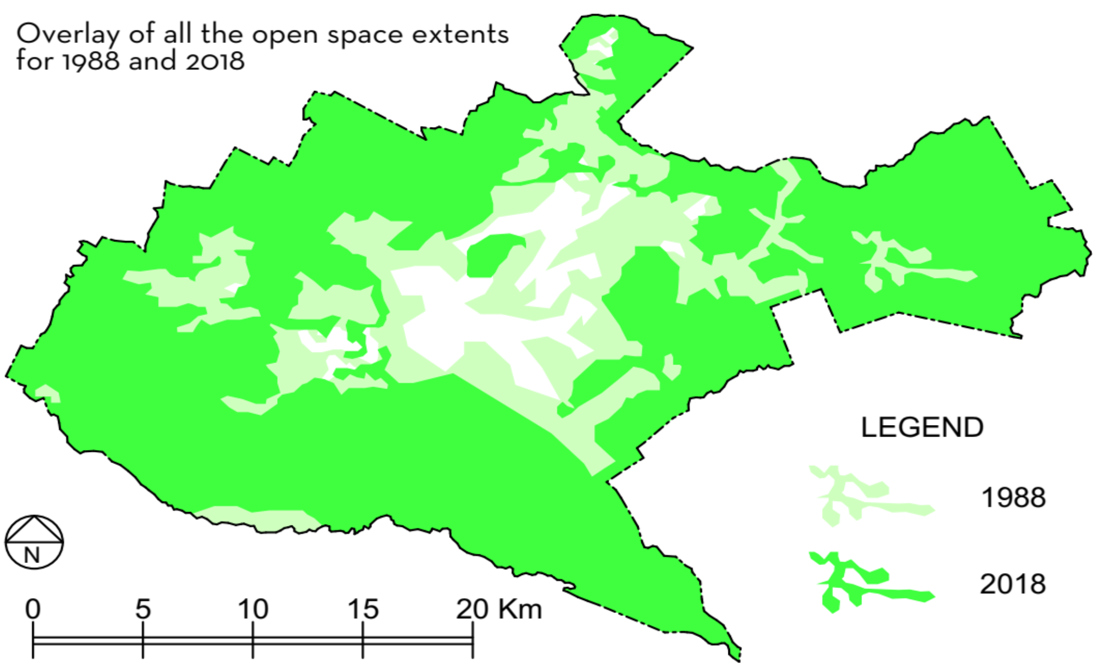


Figure 4.15: Overlay Analysis of Open Space Networks Between 1988 and 2018

4.2.1.7 Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) analyzed the health of the vegetation using Landsat images from the dry month. The trend points to a sustained reduction in healthy vegetation between 1988 and 2018 (Figure 4.16 and Table 4.7). The highest reduction of 13% occurred between 2008 and 2018. This could be attributed to the rapid urbanization rates that led to increase in built-up area.

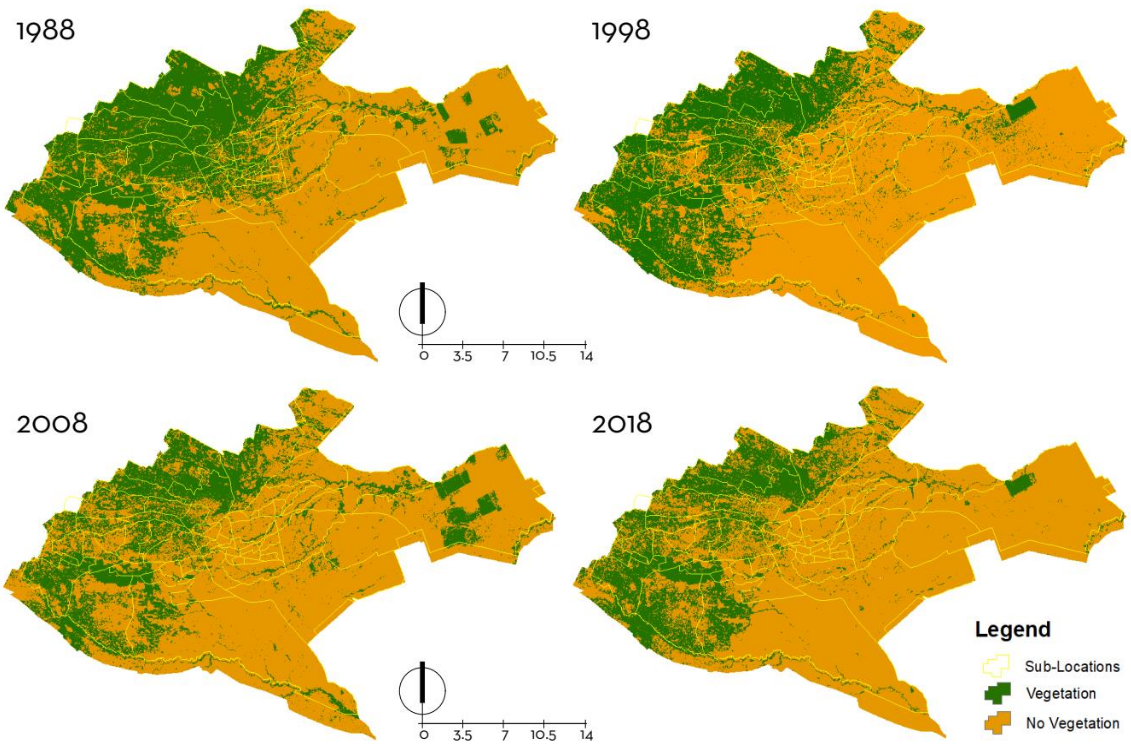


Figure 4.16: Normalized Difference Vegetation Index showing Vegetation Presence and Health

Table 4.7: Open Space and Normalized Difference Vegetation Index Change Patterns

Parameter	1988	1998		2008		2018		1988-2018
	Area (Km^2)	Area (Km^2)	%Change from 1988	Area (Km^2)	%Change from 1998	Area (Km^2)	%Change from 2008	% Change
OSN	278.8	171.8	25.25*	141.3	17.56*	208.4	17.75*	49.32*
NDVI	652.2	614.5	5.78*	597.5	2.77*	515.1	13.79*	21.02*

Note: * denote reduction in area between the two epochs.

An overlay analysis revealed remarkable reduction in healthy vegetation in the central zone of the city. The reduction was concentrated on the southeastern edge of the western forest cover (Figure 4.18) and affected riparian areas as well. The largest patch to the eastern side was the sewage treatment plant at Ruai. The most affected sublocations included City Square, and Mbotela.

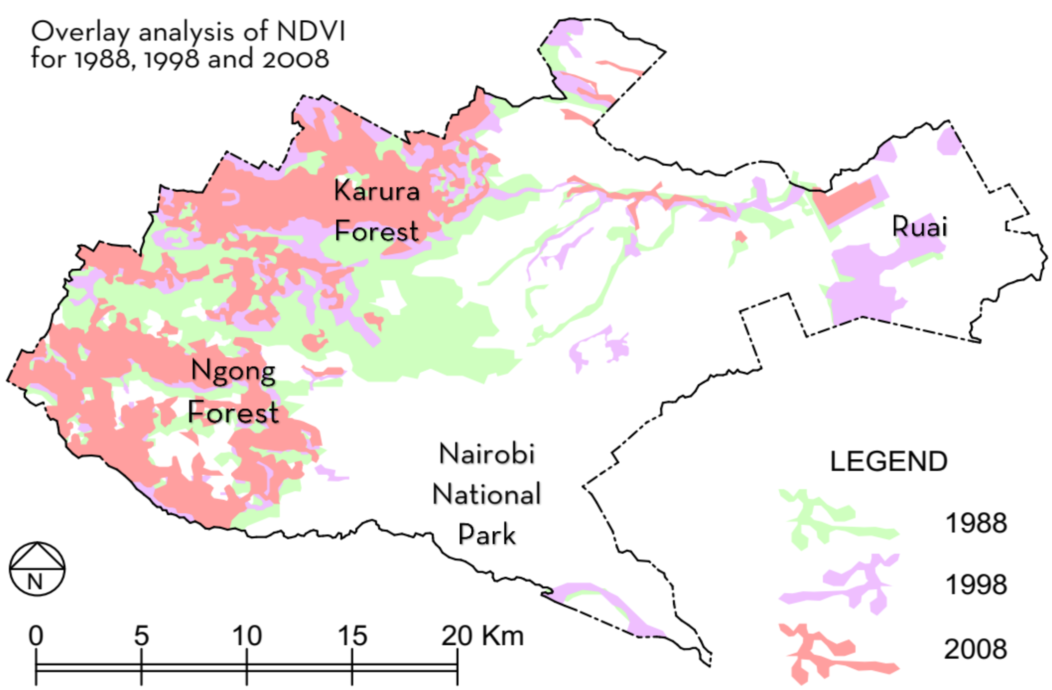


Figure 4.17: Overlay Analysis of Normalized Difference Vegetation Index

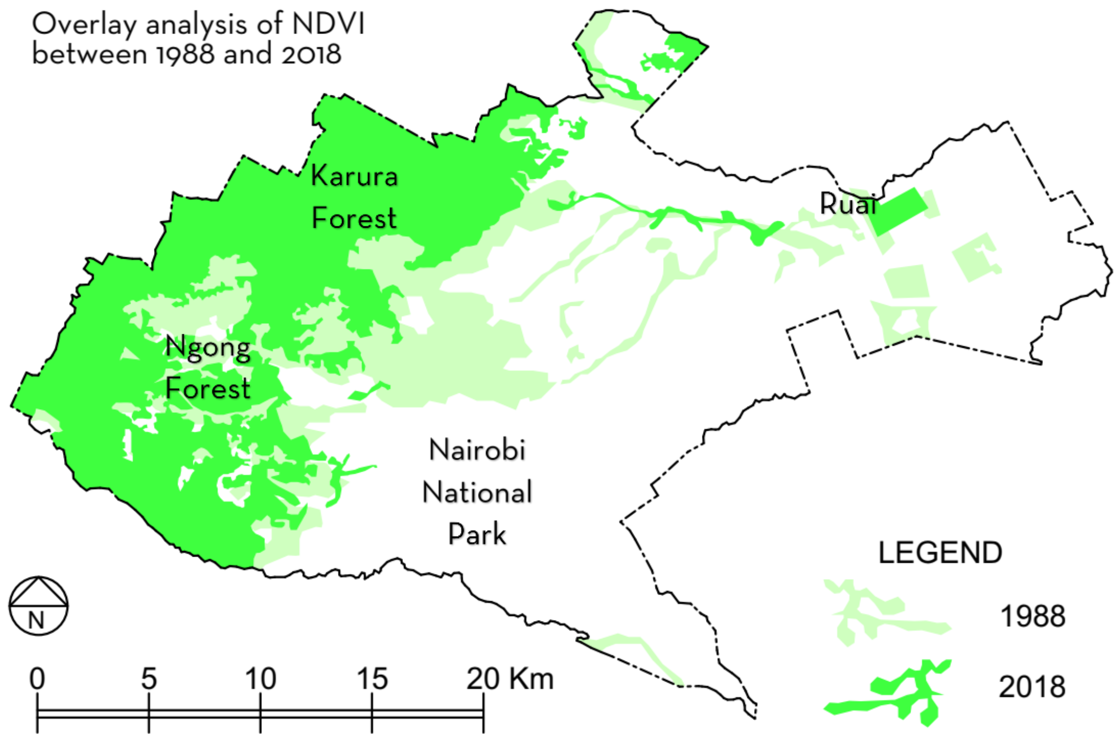


Figure 4.18: Overlay Analysis of NDVI between 1988 & 2018

4.2.1.8 Summary of Urban Form Evolution

There were two types of urban form parameters: the evolving and non-evolving. The non-changing urban form parameters were elevation, slope flow accumulation and soil drainage properties. The changing urban form parameters that theoretically had a relationship with climate were built-up area, open space network and Normalized Difference Vegetation Index.

Forest cover had the lowest rates of reduction at 16.75 Km^2 per 5-year epoch. Change in time explained over 90% of the changes in urban form with two out of the four cases statistically significant at 99% confidence interval (Table 4.8).

Table 4.8: Evolution of Urban Form Parameters

Parameter	Rate of Change	R^2	Significance	
			95%	99%
Built-Up Area	41.03	.916	No	No
Normalized Difference Vegetation Index	-42.83	.956	Yes	No
Forest	-16.75	.970	Yes	No
Open Space Network	-86.01	.995	Yes	Yes

The built-up area had lowest coefficient of determination at 0.916 which was also not flagged as statistically significant at either 95% or 99%. This finding could be attributed to the wide range of factors that define settlement patterns such as development control, urbanization patters and legal frameworks.

The negative rates of change in the NDVI, Forest and Open Space Networks meant that as the built-up area increased, the green and open space elements reduced. These changes could be significantly explained by the passage of time.

Some of the urban form parameters significantly correlated with each other. For instance, the correlation between built-up area and forest cover was negatively statistically significant at -.972 (Table 4.9). This implied that as built-up area increased, the forest cover reduced. The correlation between Open Space Networks (OSN) and forest cover was positive at .954. The correlation between OSN and Built-Up area was -.994. The negative correlation implied that as the Built-Up Area increased, the OSN reduced: the built-up elements took over the hitherto open spaces within the city. Furthermore, the correlation was statistically significant at 99% confidence level. Even though it was not statistically significant, the correlation reflects the relationship between forest cover and OSN. These correlations were akin to those revealed in the cross-tabulation.

Table 4.9: Correlation Matrix of Changing Urban Form Parameters

	Open Space Network	NDVI	Built-Up Area	Forest Cover
Open Space Network	1	.958**	-.994**	.954**
NDVI	.958**	1	-.976**	.998**
Built-Up Area	-.994**	-.976**	1	-.972**
Forest cover	.954**	.998**	-.972**	1

Note.
**. Correlation is significant at the 0.01 level (2-tailed).

4.2.1.9 Projected Urban Form Elements between 2018 And 2048

Projection of landcover values for the year 2048 was based on the trends between 1988 and 2018. Overall, the data revealed reducing trends in Open Space Networks (OSN) and Normalized Difference Vegetation Index (NDVI), increasing trends in population density and built-up area (Table 4.10). Population density was projected to increase by 66.61% by 2048; normalized Difference vegetation index to reduce by 60.88%.

Table 4.10: Projected Urban Form Trends Between 2023 And 2048

Year	Open Space Network (OSN)		Population Density		Built-up Area		NDVI	
	% Area	% Change	People/ Km^2	% Change	% Area	% Change	% Area	% Change
2018	69.06		6204.00		30.94		8.82	
2028	66.04	4.38%*	7437.86	10.80	32.93	9.69	7.84	12.30*
2038	59.96	4.82%*	8887.57	8.88	38.74	8.09	5.65	16.17*
2048	53.89	5.34%*	10337.29	7.54	44.56	6.99	3.45	24.18*
Total	15.17*	21.97*	4133.29	66.62	13.62	44.02	5.37*	60.88*

Note: * indicates reducing trends

Both increasing and reducing trends were revealed in the forecasts. The reducing trends were noted in the natural elements while increasing trends were associated with manmade elements. OSN and NDVI project a reducing rate of change of 0.54 and 0.19, respectively. The population density and built-up area project increasing rates of change of 140.35 and 0.50, respectively. Over 95% of the projected changes in urban form can be explained by the change in time (Table 4.11).

Table 4.11: Projected Urban Form Evolution Between 2018 And 2048

Parameter	Rate of Change	Coefficient of Determination (R^2)
Open Space Network	-0.54	0.98
Population Density	140.35	0.99
Built-Up Area	0.50	0.96
Normalized Difference Vegetation Index	-0.19	0.97
Forest	-0.20	0.97

4.2.2 Nairobi's climatic trends and patterns

Climatic data modelling was based on the five weather stations' data. They include Moi Air Base, Jomo Kenyatta International Airport, Kabete Agrovet, Wilson Airport, and Dagoretti Corner (Figure 3.1). The climatic parameters were average annual minimum temperature, average annual maximum temperature, lowest annual temperature, and highest annual temperature and rainfall.

4.2.2.1 Average Annual Maximum Temperatures.

The average annual maximum temperature data (Table 4.12) analysis was reduced from 10 years to 5 years epochs to reveal trends hitherto disguised by unique climatic phenomena such as El Nino and La Nina. Dagoretti Corner station showed the highest variations in the annual means at 0.9℃ while the years 1998 and 2008 had the least variations for all the weather stations at 0.2℃

Table 4.12: Average Annual Maximum Temperature per Weather Station per Epoch

Weather Station	Temperature (°C) per Epoch							Stn. σ
	1988	1993	1998	2003	2008	2013	2018	
JKIA	24.5	25.4	24.8	25.4	24.7	26.1	23.9	0.7
Wilson Airport	24.9	24.9	24.9	25.4	24.9	25.2	24.9	0.2
Dagoretti Corner	24.8	23.7	25.0	26.4	24.8	24.3	24.2	0.9
Kabete Agrovet	24.2	22.8	24.6	23.5	24.5	23.5	23.7	0.6
Eastleigh MAB	24.9	25.3	25.0	25.5	24.9	25.7	24.8	0.3
Epoch σ	0.3	1.1	0.2	1.1	0.2	1.1	0.5	

Note: JKIA is Jomo Kenyatta International Airport; MAB is Moi Air Base; σ is standard deviation and Stn. Is Station

The stations exhibit high epoch to epoch variability. All the stations display consistent trends except for Kabete Agrovet Station (Figure 4.19). Rate of change comparisons between the stations (Table 4.13) reveal similarity between some of the stations. For instance, JKIA and Wilson Airport are similar in trends at 0.02. Kabete Agrovet and Eastleigh MAB were similar as well at 0.01. The weather station whose variability patterns were closest to overall city's was Kabete Agrovet at <1% (Table 4.13).

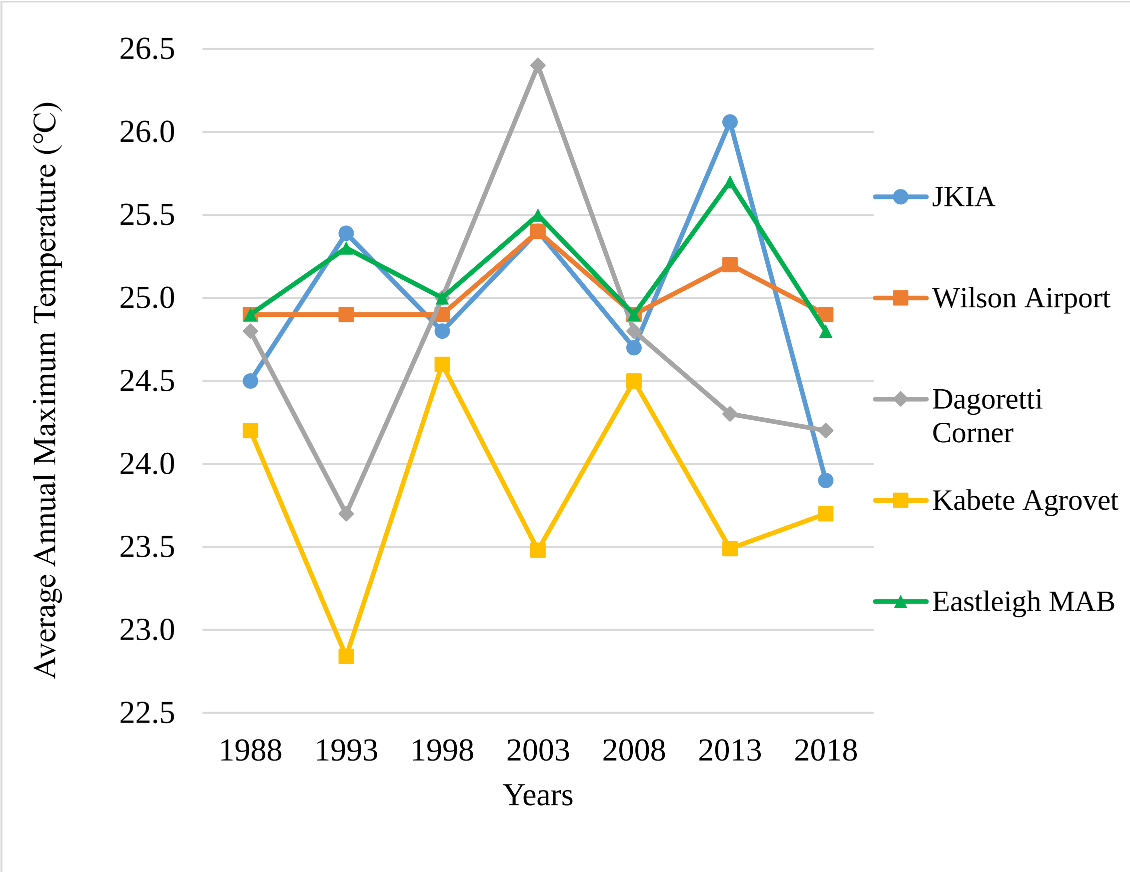


Figure 4.19: Average Annual Maximum Temperature Trends per Stations

Table 4.13: Average Annual Maximum Temperature Trend Values for the Weather Stations Compared with City Values

Weather Station	m	r^2	R^2	D (R^2- r^2)
JKIA	0.02	0.04		-0.04
Wilson Airport	0.02	0.05		-0.05
Dagoretti Corner	0.03	0.01	0.001	-0.01
Kabete Agrovet	0.01	0.00		0.00
Eastleigh MAB	0.01	0.01		0.01

Note: r^2 is the station coefficient of determination; R^2 is the City's coefficient of Determination and D is the difference between weather station and city-wide values

Spatially, except for 1998, the patterns showed reducing temperature at the central belt of the city that extends southwards between 2008 and 2018 (Figure 4.20 and Appendix 9). There is also a noticeable cooling on the eastern and western peripheries of the city. The temperature lower end of the Average annual maximum temperature reduces from 23.5 °C to 23.3 °C. The decrease in temperatures is occurring on the western and eastern zones

Since the average annual maximum temperature fell within the thermal stress range defined by Abdel-Ghany, Al-Helal, and Shady (2013), Matzarakis and Amelung (2008), Matzarakis and Mayer (1996), the study selected an isotherm temperature of 24.8°C to model the change in the four epochs (Figure 4.21). The changes revealed an inconsistent trend in the spatial changes of the average annual maximum temperature.

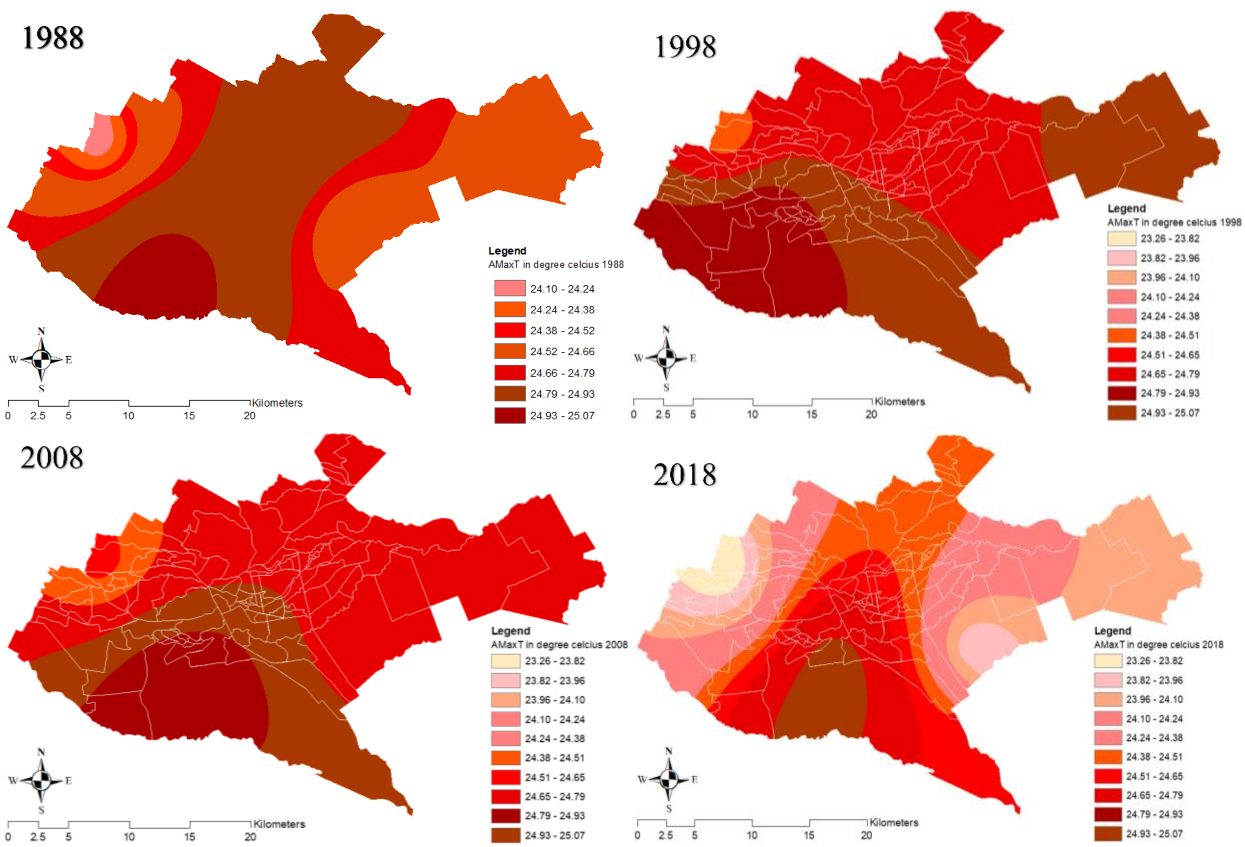


Figure 4.20: Average Annual Maximum Temperature Spatio-Temporal Patterns

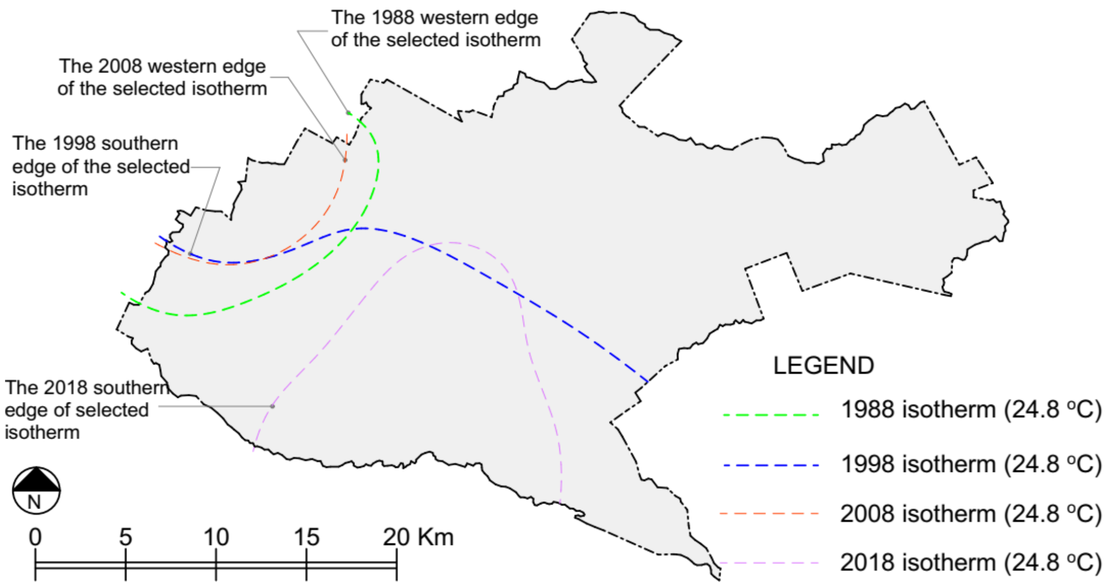


Figure 4.21: Average annual Maximum Temperature Inter-Epoch Isotherm

4.2.2.2 Average Annual Minimum Temperatures

The average annual minimum temperature was modelled using the 5-year epoch as well. This was informed by the outlier noted in 1993 data for all the weather stations. The station-to-station variability is highest at JKIA and Wilson Airport at 0.6℃ and lowest at Kabete Agrovet at 0.2℃ (Table 4.14).

Table 4.14: Average Annual Minimum Temperature per Weather Station per Epoch

Weather Station	Temperature (℃) per Epoch							Stn. σ
	1988	1993	1998	2003	2008	2013	2018	
JKIA	13.3	12.7	14.1	14.0	14.0	13.9	14.3	0.6
Wilson Airport	14.2	12.9	13.9	14.2	14.3	14.7	14.9	0.6
Dagoretti Corner	13.2	13.0	13.9	14.0	13.7	13.8	13.7	0.4
Kabete Agrovet	13.2	12.9	13.3	13.4	13.4	13.3	13.5	0.2
Eastleigh MAB	14.3	13.1	14.0	14.2	14.2	14.5	15.0	0.6
Epoch σ	0.6	0.1	0.3	0.3	0.4	0.6	0.7	

Note: JKIA is Jomo Kenyatta International Airport, MAB is Moi Air Base

The spatio-temporal distribution of the Average annual minimum temperature for the city (Figure 4.22) pointed to a consistent increase in the minimum temperatures between 1988 and 2008 except for the year 1993.

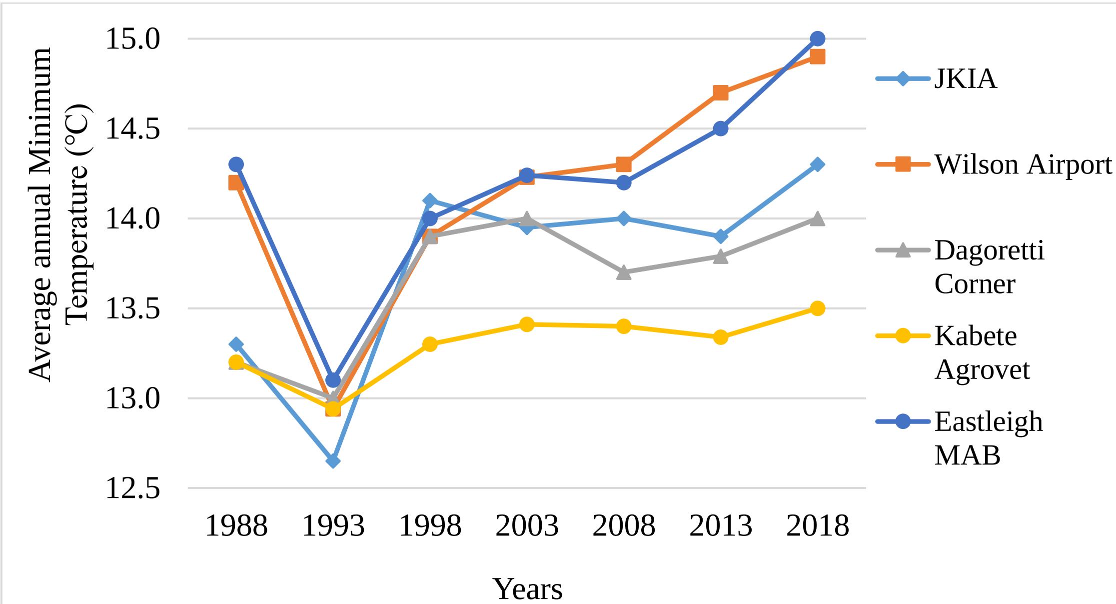


Figure 4.22: Average annual Minimum Temperature Trends for five Weather Stations

This trendline showed a consistent linear increase in the average annual minimum temperatures between 1988 and 2018. The study also compared the average annual minimum temperature trendlines with and without the 1993 outlier data (Table 4.15). Even though there were significant differences in the two cases, the study retained the 1993 data since it was consistent for all the weather stations.

With 1993 data incorporated no weather stations showed similar rates of change. However, without the 1993 data, Dagoretti and Kabete showed similar rates of change at 0.01. The case was contrary for variability where JKIA, Wilson and Dagoretti revealed similar variability with the 1993 data incorporated (Table 4.15).

Variability comparison between the citywide scale and weather stations revealed differences with and without the 1993 data. With the 1993 data, the Kabete showed the closest variability comparison with the city-wide scale at 2% while Eastleigh MAB showed the furthest comparison at 12%. JKIA, Wilson and Dagoretti had similar values of variability difference between them and the city at 6% in the data with 1993 epoch included (Table 4.15).

Table 4.15: Average annual Minimum Temperature Trendline Values for Weather Stations Compared with City-Wide Values

Weather station	m_1	m_2	r^{2*}	r^{2**}	R^{2*}	R^{2**}	D_1 (R^{2*}- r^{2*})	D_2 (R^{2**}- r^{2**})
JKIA	0.19	0.02	0.53	0.61	0.59	0.87	0.06	0.26
Wilson	0.22	0.03	0.53	0.64			0.06	0.23
Dagoretti	0.13	0.01	0.53	0.23			0.06	0.64
Kabete	0.06	0.01	0.57	0.74			0.02	0.13
Eastleigh	0.18	0.02	0.47	0.47			0.12	0.4

Note: m_1 is the rate of change with the 1993 outlier data, m_2 is the rate of change without the 1993 outlier data, r^{2*} amount of variability at the stations with 1993 data, r^{2**} amount of variability at the stations without the 1993 data, R^{2*}city-wide variability with the 1993 data, R^{2**}city-wide variability without the 1998 data, D_1 the difference between city wide and weather station variability with the 1993 data *and* D_2 the difference between city wide and weather station variability without the 1993 data

Year to year trends revealed an increase of 4.24% in the lower range and 5.4% in the higher range of the Average annual minimum temperature. The lower range increased from 13.08 ℃ in 1988 to 13.66 ℃ in 2018. The higher range increased from 14.23 ℃ in 1988 to 15.00 ℃ in 2018. The most affected zones are the western and southern zones of the city. Even though the western zone remained the coldest, its temperatures increased by 0.58 ℃ between 1988 and 2018. In the same period, the south-central zone Average annual minimum temperature increased by 0.77 ℃.

The Average annual minimum temperature had increased in an east to west direction (Figure 4.23 & Appendix 10). Except for 1998, the average annual minimum temperature increase was consistent (Figure 4.24). The 1998 exception can be attributed the El Nino phenomena that affected the country and region at large.

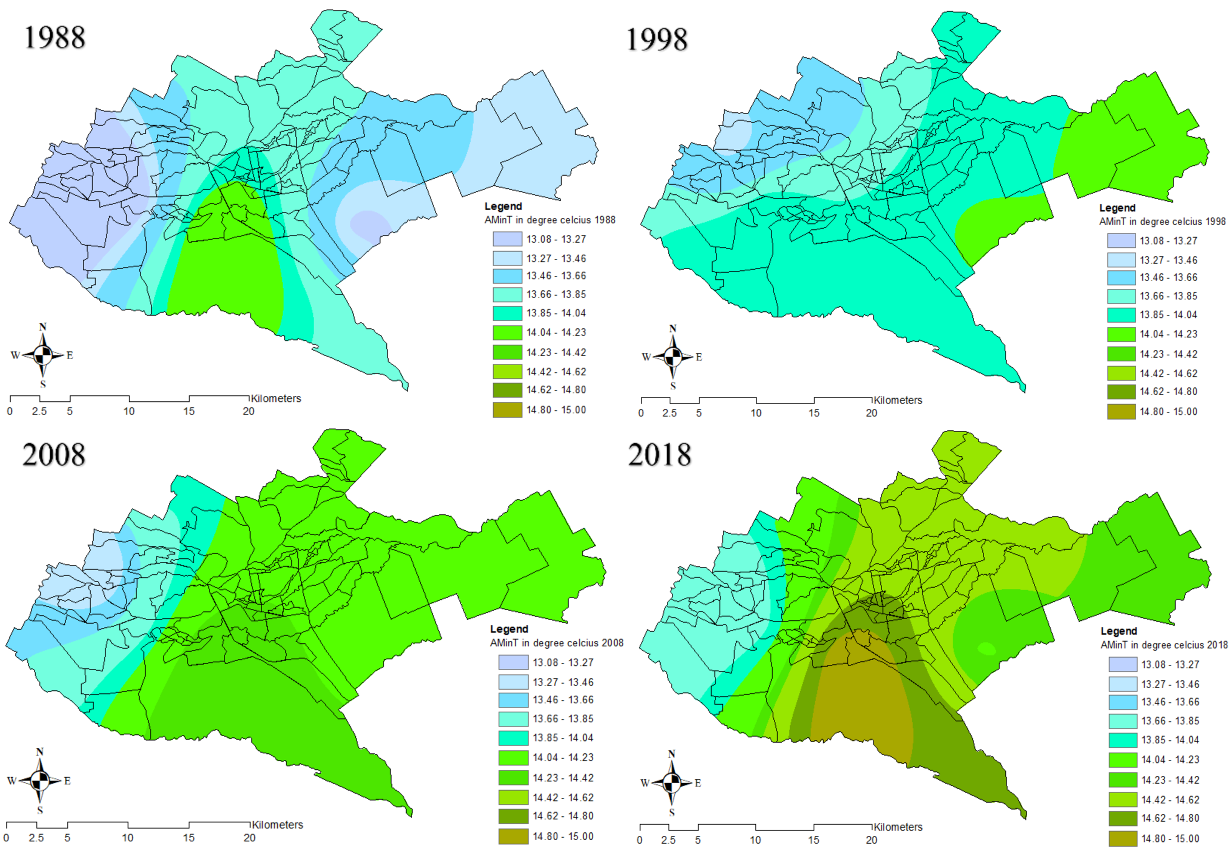


Figure 4.23: Spatio-Temporal Average annual Minimum Temperature Patterns

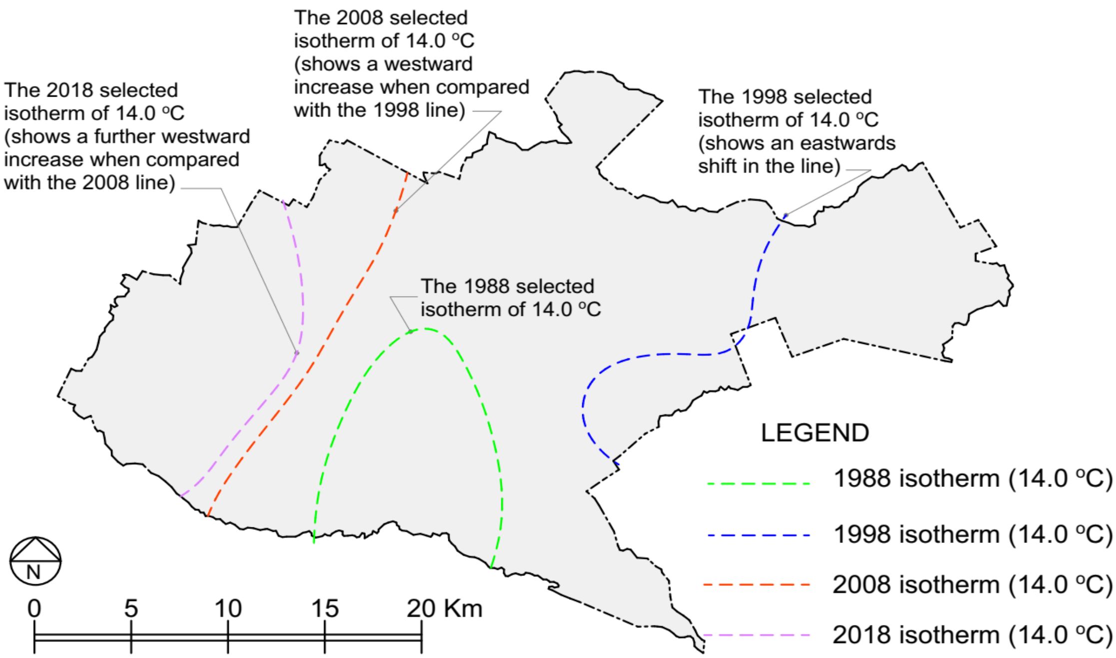


Figure 4.24: Average annual Minimum Temperature Inter-Epoch Isotherm

4.2.2.3 Highest Annual Temperatures

Wilson airport had data gaps for 1993, 2003 and 2013. The highest variability per station is 1.5°C at Wilson Airport and Dagoretti Corner. For the epochs, 1993 and 2013 had the highest variability at 2.0°C and the lowest in 1998 and 2018 at 1.1°C (Table 4.16).

Table 4.16: Highest Annual Temperature per Weather Station per Epoch

Weather Station	Temperature (°C) per Epoch				Mean	Stn. σ
	1988	1998	2008	2018		
JKIA	31.5	30.1	30.8	31.3	30.9	0.7
Wilson Airport	29.8	32.1	29.0	28.7	29.9	1.5
Dagoretti Corner	29.6	32.3	28.2	28.4	29.6	1.5
Kabete Agrovet	28.2	27.2	27.8	29.8	28.3	0.9
Eastleigh MAB	31.8	32.4	30.5	31.7	31.6	1.0
Mean	30.2	30.8	29.7	30.0		
Epoch σ	1.5	1.1	1.5	1.1		

Note: JKIA is Jomo Kenyatta International Airport and MAB is Moi Air Base

Aside from the missing data, the stations exhibited high variability. Kabete Agrovet station and JKIA deviated from the other stations' trends in 1998 and 2013 respectively. All the stations exhibited a drop between 1988 and 1993 (Figure 4.25). The low variability at JKIA can be attributed to stabilized landcover changed due to the development control at the airport.

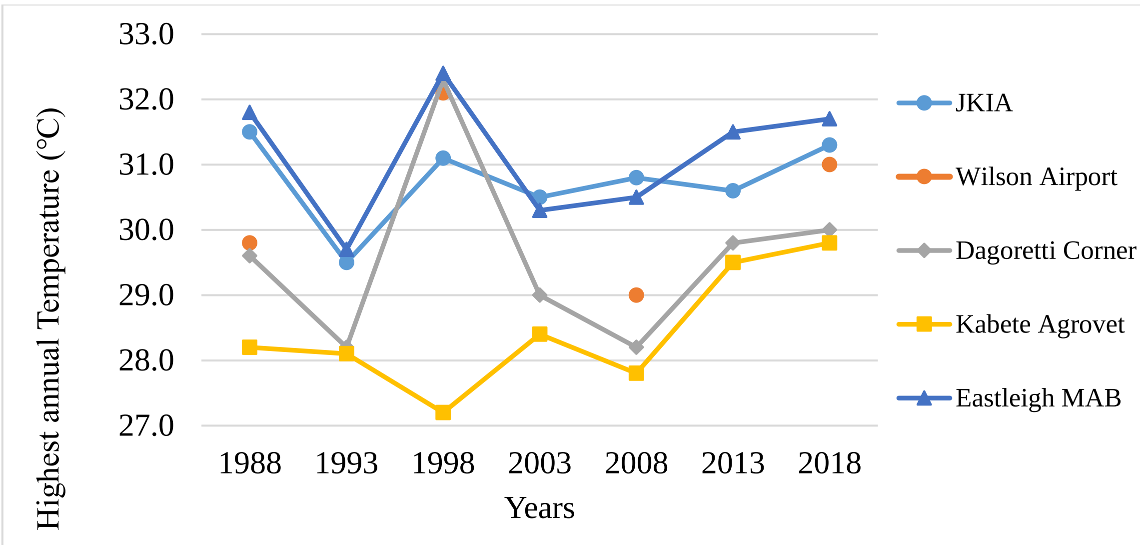


Figure 4.25: Highest annual Temperature Trends for Five Weather Stations

The rate of change was highest for Kabete Agrovet station and lowest for Dagoretti weather station. The variability at station level showed similarity between Wilson airport and Dagoretti at 0.00. Kabete agrovet with the highest rate of change also exhibited the highest variability at 47% (Table 4.17).

Table 4.17: Highest annual Temperature Stations vis-a-vis City-Wide Trends

Weather Station	m	r^2	R^2	D (R^2- r^2)
JKIA	0.05	0.23		0.40
Wilson Airport	0.03	0.00		0.63
Dagoretti	0.01	0.00	0.63	0.63
Kabete Agrovet	0.29	0.47		0.16
Eastleigh MAB	0.05	0.01		0.62

Note: r^2 is the station coefficient of determination; R^2 is the City's coefficient of Determination and D is the difference between weather station and city-wide values.

A comparison between station and city-wide data revealed least variability between Kabete Agrovet and the city. This was followed by JKIA at 40% and the rest of the stations at variability > 63% (Table 4.17).

Except for 1998, the highest annual temperature displays a widening zone of increasing temperatures from the western to the eastern side of the city. The overall highest annual temperature range increased by 100% from 3.19 °C in 1988 to 6.1 in 2018. The upper range increased by 6% while the lower range reduced by 4.52%. Except for 2018, the western zone remained the coolest while the northern zone was the warmest (Figure 4.26 & Appendix 11).

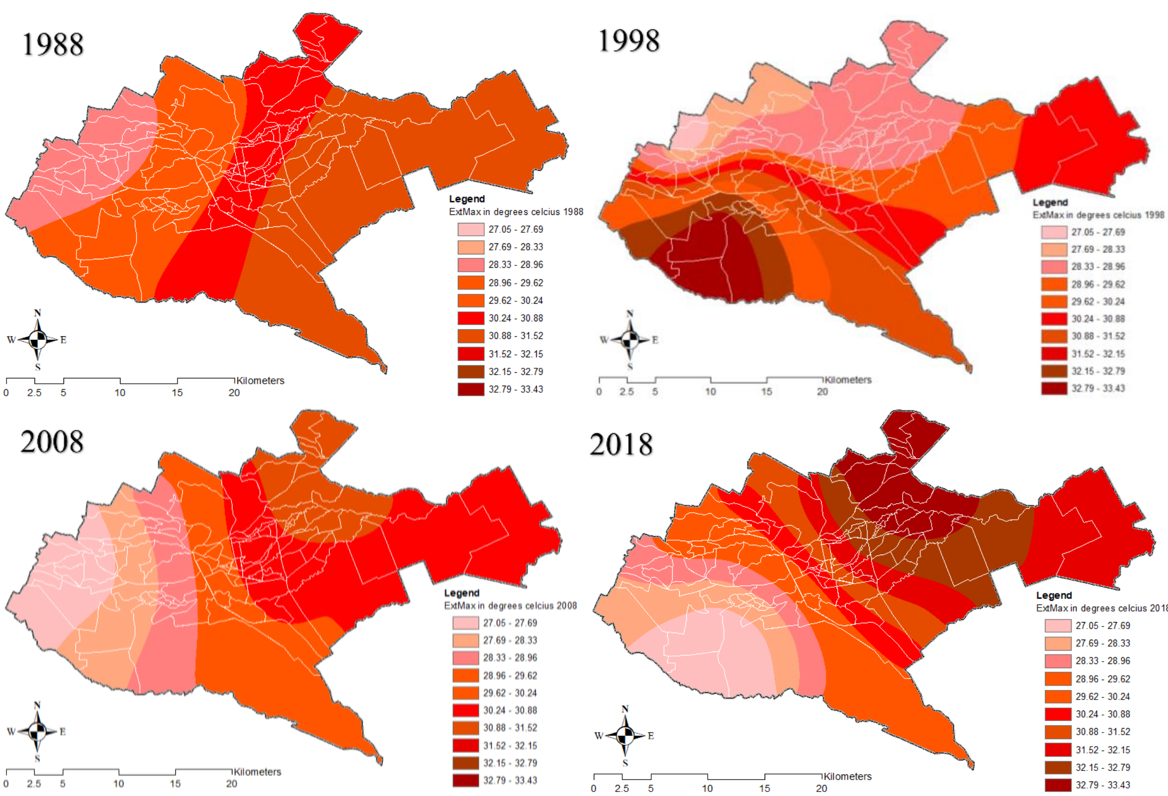


Figure 4.26: Spatio-Temporal Patterns of Highest annual Temperature

The study selected an isotherm line of 30.08°C since the entire city fell above the proposed thermal stress range of 25°C. The isotherm oriented in a North-South direction in 1988, this switched to an East-West orientation before tilting to a Northwest-Southeast line. This orientation remained in 2018 but the line shifted westwards (Figure 4.27). This revealed a northern warming at the city scale.

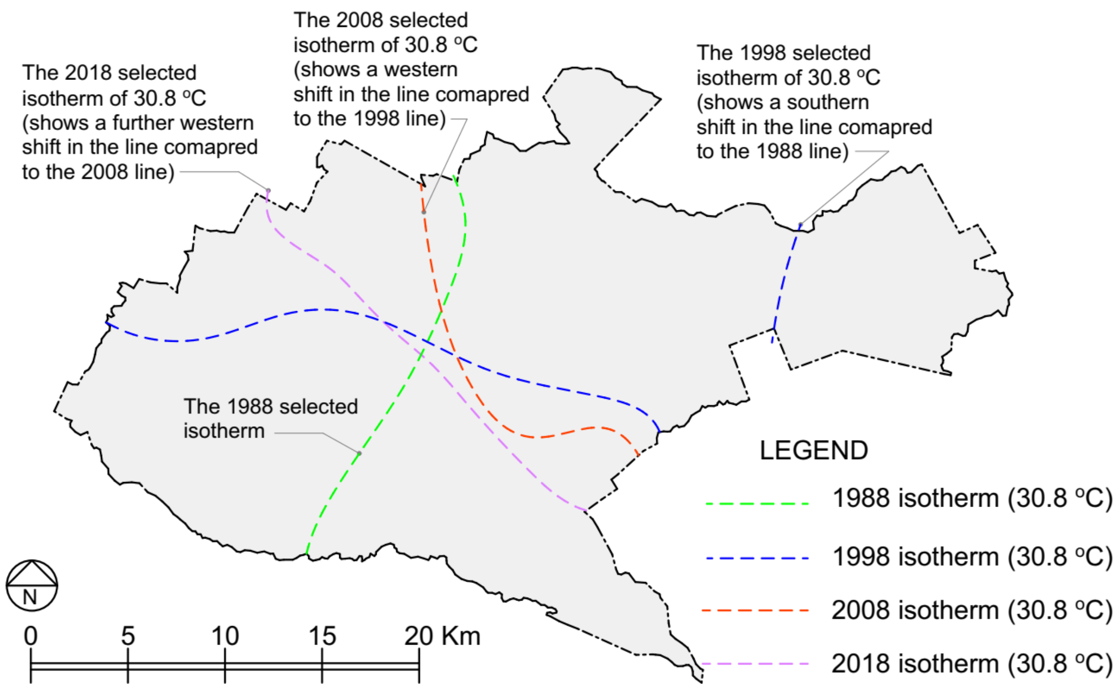


Figure 4.27: Highest annual Temperature Inter-Epoch Isotherm

The notable difference between Kabete Agrovet and the other weather stations in the Average Annual Maximum, Average Annual Minimum and Highest Annual Temperatures (Figures 5.19, 5.22 and 5.25) parameters is because of the difference in landcover and elevation characteristics. Kabete Agrovet is at a high elevation with high forest cover compared to the others in low elevation, low forest cover and high built-up areas.

4.2.2.4 Lowest Annual Temperatures

Wilson airport had data gaps for 1993 and 2003. Station to station variability is highest at Eastleigh MAB at 2.1 °C and lowest at Kabete Agrovet at 0.4°C. On the epochs, the highest variability is 2018 at 2.7°C and the lowest is 1988 at 0.7°C (Table 4.18). Except for 1993, 2003 and 2013, the year-to-year trends exhibit a consistent increasing variability.

The high station-to-station variability at Eastleigh MAB can be attributed to the significant urban development in the eastern zone of the city close to the Central Business District (CBD). The low variability at Kabete Agrovet can be explained by the low rated of landcover change in the western zone of the city. The consistent increase in variability between 1988 and 2018 can be attributed to the consistent increase in built-up area and reduction in green systems as well as the influence of global climate patterns.

Table 4.18: Lowest annual Temperature Per Weather Station

Weather Station	Temperature (°C) per Epoch				Mean	Stn. σ
	1988	1998	2008	2018		
JKIA	6.5	5.8	8.5	8.2	7.3	1.1
Wilson Airport	8.0	9.0	10.5	8.2	8.9	1.2
Dagoretti Corner	6.9	8.5	7.3	7.0	7.4	0.9
Kabete Agrovet	7.4	7.9	7.3	8.1	7.7	0.4
Eastleigh MAB	8.0	9.8	10.6	13.9	10.6	2.1
Means	7.4	8.2	8.8	9.1		
Epoch σ	0.7	1.5	1.6	2.7		

The trends exhibit inter-epoch variability of consistent increase and decrease except for Kabete Agrovet from 1998 onwards (Figure 4.28).

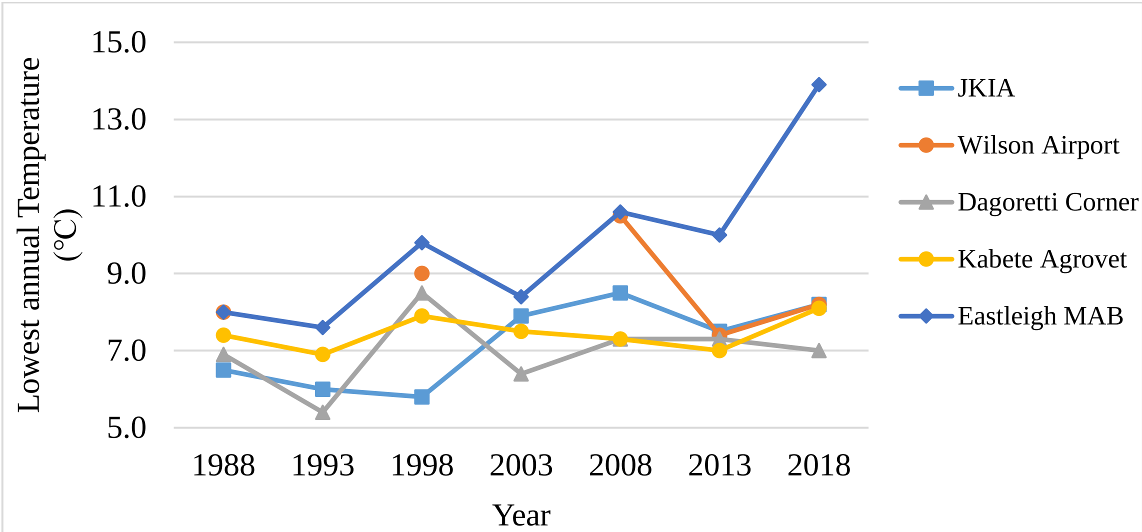


Figure 4.28: Lowest annual Temperature Trends for Five Weather Stations

Wilson airport showed the lowest rate of change at 0.02 while JKIA showed the highest rate of change at 0.39. All the other stations were ≤ 0.10 (Table 4.19). Wilson also showed the lowest variability at < 1% while Eastleigh MAB showed the highest variability at 70%. Compared with the city-wide variability patterns, JKIA is the closest at 4% difference followed by Eastleigh MAB at 8%. The rest of the stations range between 53% and 62%.

Table 4.19: Weather Station Lowest Annual Temperature Trends Compared with City-Wide Values

Weather Station	Rate of Change	Station Variability (r^2)	City Variability (R^2)	D (R^2- r^2)
JKIA	0.39	0.58		0.04
Wilson Airport	0.01	0.00		0.62
Dagoretti	0.10	0.06	0.62	0.56
Kabete Agrovet	0.06	0.09		0.53
Eastleigh MAB	0.08	0.70		-0.08

Note: r^2 is the station coefficient of determination; R^2 is the City's coefficient of Determination and D is the difference between weather station and city-wide values.

JKIA is Jomo Kenyatta International Airport and MAB is Moi Air Base

The lowest annual temperature illustrates a consistently increasing trend in the four epochs (Figure 4.29 & Appendix 12). The increase between 1988 and 1998 is in the northern part of the city. The overall range of the lowest annual temperature increased by 900% from 0.98 °C in 1988 to 9.83 °C in 2018. The largest increase in the intra-epoch patterns was in 2018. Between 2008 and 2018, temperatures increased in the northern and central zone of the city. The western zone remained the coolest all through the years.

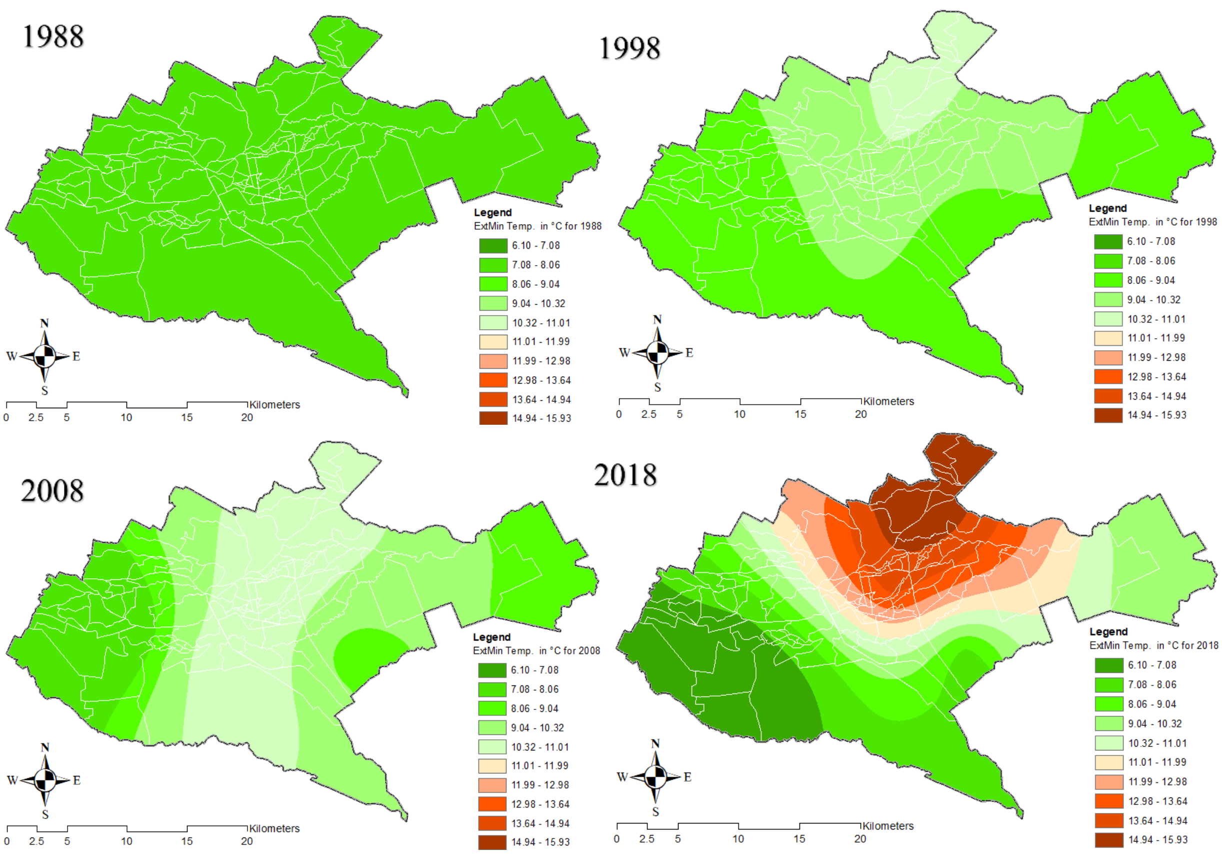


Figure 4.29: Spatio-Temporal Patterns of Lowest annual Temperature

The isotherms map revealed a consistent trend between 1998 and 2018 (Figure 4.30). In 1998, the selected isotherm of 8°C was not plotted as the entire city experienced temperatures below 8°C. The 1998 line commenced northwest of the city, travelled south then east, and joined the northern edge to the Northeast of the city. The 2008 followed the 1998 orientation but expanded further south. The 2018 trend reverted to near the 1998 line (Figure 4.30).

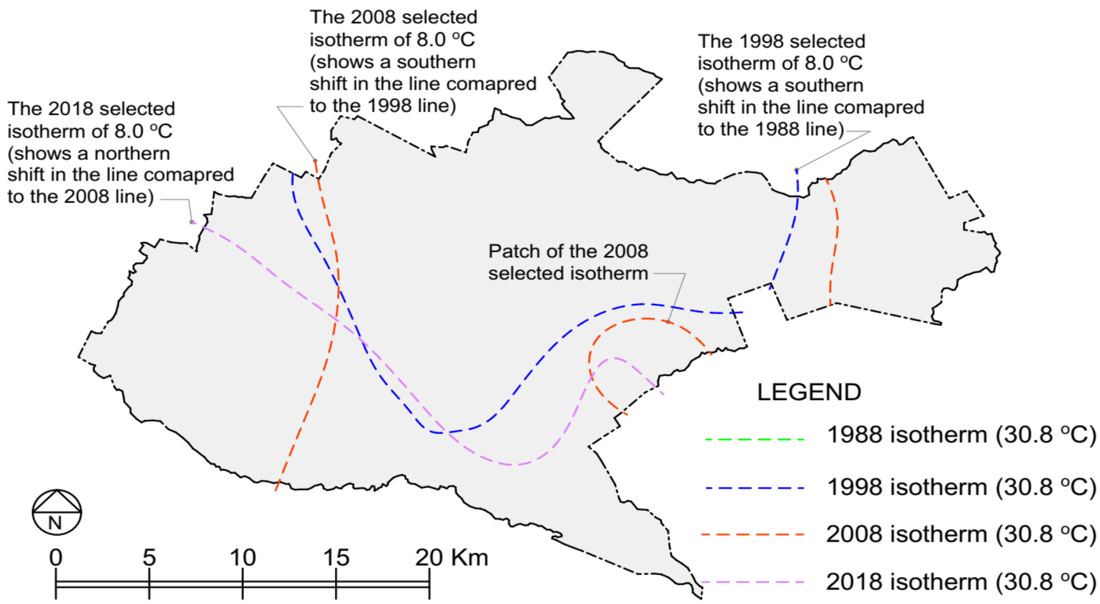


Figure 4.30: Lowest annual Temperature Inter-Epoch Isotherm

4.2.2.5 Annual Rainfall Volumes.

The annual rainfall data had missing data for Kabete Agrovet for the year 2013 (Table 4.20). The year 1998 stands out as all the weather stations annual rainfall volume >1000mm compared to the other years where at least one station had <1000mm of rainfall.

Table 4.20: Annual Rainfall per Weather Station per Epoch

Weather Station	Annual Rainfall (mm) per Epoch				Mean	Standard Deviation
	1988	1998	2008	2018		
JKIA	714.8	1162.3	605.2	848.1	832.6	241.1984
Wilson Airport	1115.3	1410.2	857.0	1030.7	1103.3	231.132
Dagoretti	1267.1	1415.4	775.1	1156.8	1153.6	273.675
Kabete Agrovet	1401.0	1301.0	1093.2	777.7	1143.2	275.3494
Eastleigh MAB	1144.6	1512.3	650.3	1007.1	1078.5	356.3729
Mean	1128.6	1360.2	796.2	964.1		
Standard Dev.	257.4	133.6	193.7	151.3		

Note: JKIA is Jomo Kenyatta International Airport and MAB is Moi Air Base

The station-to-station trends showed a peak in 1998 for all the weather stations (Figure 4.31). The peak was because of the El Nino phenomena that resulted in above normal rainfall. The station-to-station trend also showed similar patterns except for Kabete Agrovet in 2008 where it increases despite the other stations recording a decrease in rainfall.

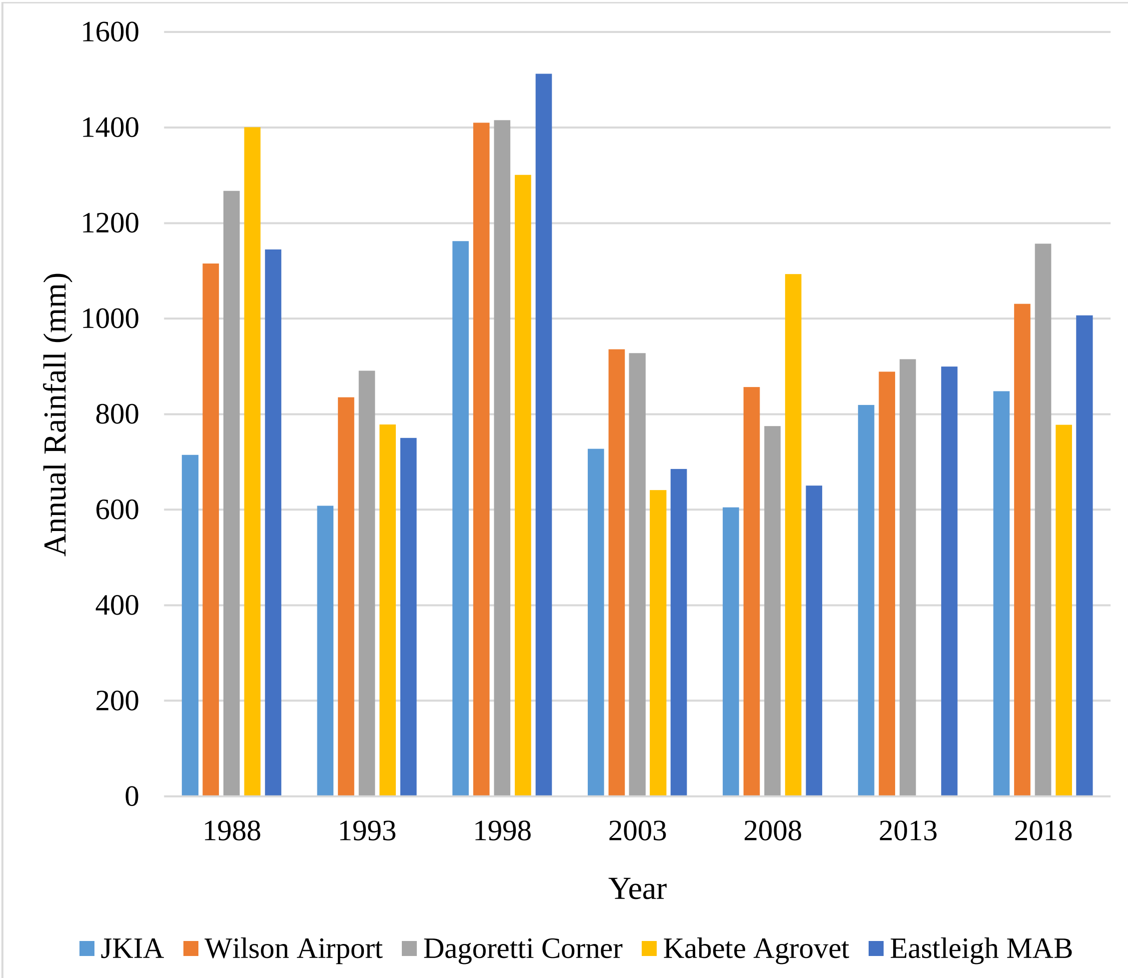


Figure 4.31: Annual Rainfall Volume for per Weather Stations per Epoch

Between 1988 and 2018, there is an overall reduction in the amount of rainfall for all the weather stations except for JKIA. Nonetheless, the highest rate of change at -70.15 was recorded at Kabete Agrovet. The lowest was recorded at Wilson Airport at -9.46. At JKIA, 93% of the changes in rainfall could be sufficiently explained by the change in time while at Wilson Airport, only 1% of the changes in rainfall could be explained by passage of time. At the city level, the only 9% of the changes in rainfall could be explained by the passage of time (Table 4.21).

Table 4.21: Station to Station and City-Wide Rainfall Trends

Weather Station	m	r^2	R^2	D (R^2- r^2)
Wilson Airport	-9.46	0.01		0.08
Dagoretti	-25.01	0.71		-0.62
JKIA	32.96	0.93	0.09	-0.84
Kabete Agrovet	-70.15	0.24		-0.15
Eastleigh MAB	-34.83	0.06		0.03

Note: m is rate of change, r^2 is the station coefficient of determination; R^2 is the City's coefficient of Determination and D is the difference between weather station and city-wide values. JKIA is Jomo Kenyatta International Airport and MAB is Moi Air Base

The rainfall spatial patterns displayed high variability (Figure 4.32 & Appendix 13).

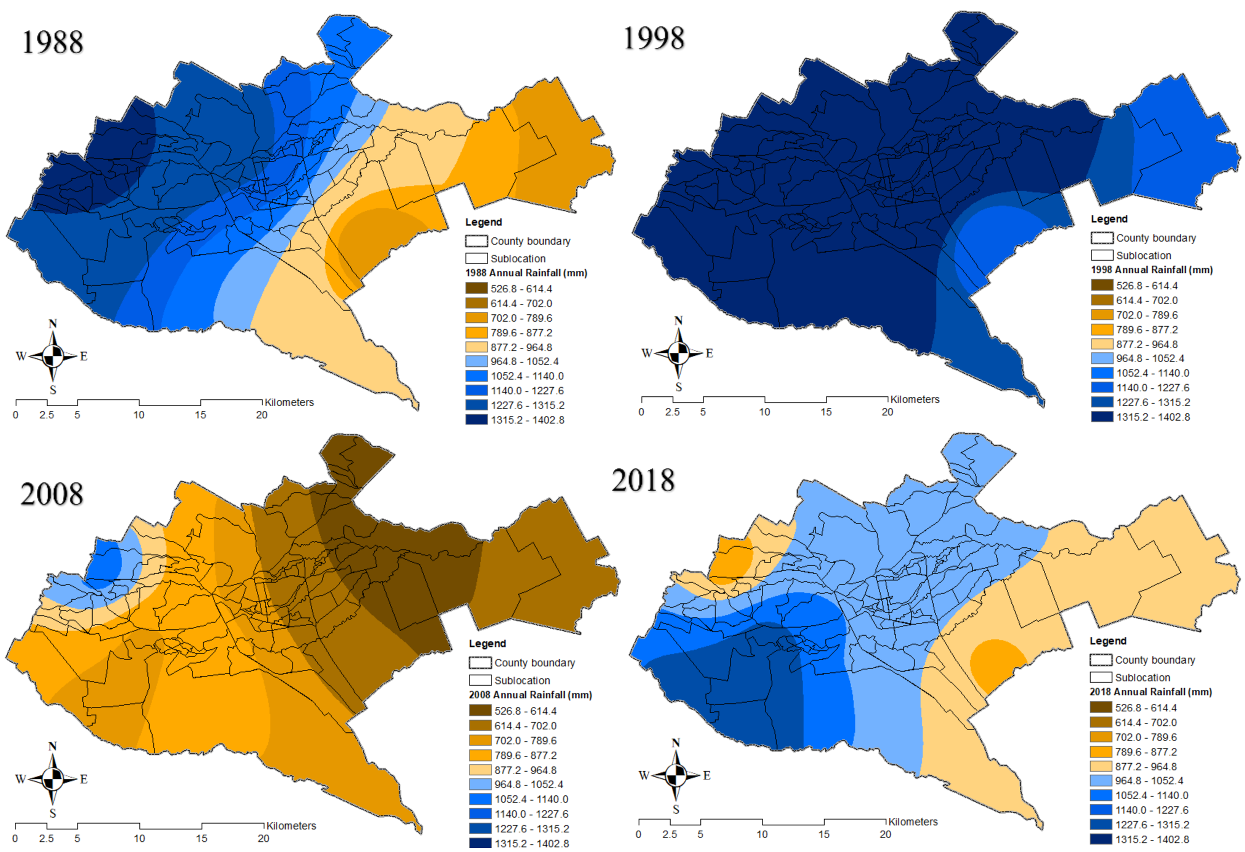


Figure 4.32: Annual Rainfall Spatio-Temporal Patterns

The Year 1998 was an outlier due to the El Niño phenomenon. It had exceptionally high rainfall volumes of between 1100 mm and 1500 mm. Spatial patterns indicated the western zone as the highest except for 2018 (Figure 4.32). The eastern zone consistently received the lowest amount of rainfall except for 2008.

The study selected 964 mm as the isohyet value. The 1988 isohyet shifted to the extreme western side of the city in 2008. This reverted to the 1988 line in 2018 (Figure 4.33). The 1998 isohyet was not plotted since all the weather stations received above 964 mm of. Rainfall. This above normal rainfall was attributed to the El Nino phenomenon.

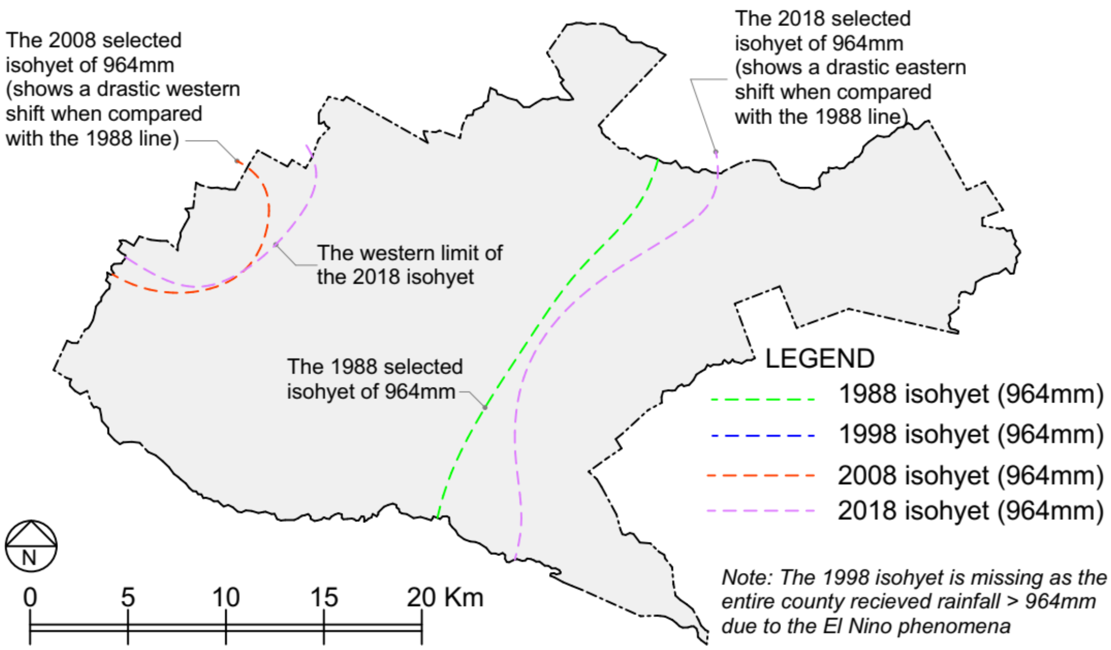


Figure 4.33: Annual Rainfall Inter-Epoch Isotherm

In summary, all the climatic parameters changed over time. Of the temperature parameters, the lowest annual temperatures had the highest rate of change at 0.3°C while highest annual temperature had the lowest rate of change at 0.02°C (Table 4.22). The variations in average annual minimum temperature could be significantly explained by 96.6% of the change in time at a 95% confidence interval (Table 4.22).

Table 4.22: Climatic Trends Between 1988 and 2018

Parameter	Rate of Change	R^2	Significance	
			95%	99%
Avg. Monthly Maximum Temperature	-0.118	-0.624	No	No
Avg. Monthly Minimum Temperature	0.1514	0.966	Yes	No
Highest annual Temperature	0.0282	-0.434	No	No
Lowest annual Temperature	0.3046	0.974	Yes	No
Rainfall	-213.14	-0.567	No	No

4.2.2.6 Projected Climatic Parameters between 2018 and 2048

The Average annual minimum temperature, highest annual temperature and lowest annual temperature were the only climatic parameters projected using SPSS forecasting. Projected values for the years 2023 to 2048 were based on the trends between 1988 and 2018. All the forecasts revealed increasing trends (Table 4.23).

Table 4.23: Projected Climatic Values Between 2018 and 2048

Year	Average annual Minimum Temperature		Highest annual Temperature		Lowest annual Temperature	
	Temp. (℃)	% Change	Temp. (℃)	% Change	Temp. (℃)	% Change
2018	14.10±0.1	-	27.96 ±0.1	-	11.00±0.1	-
2028	14.39 ±0.1	1.05	28.50±0.1	0.78	11.61±0.1	2.11
2038	14.68 ±0.1	1.03	28.93±0.1	0.77	12.09±0.1	2.03
2048	14.97 ±0.1	1.01	29.37±0.1	0.75	12.57±0.1	1.95
Total Change	0.87 ± 0.1	6.17	-1.41±0.1	5.04	-1.57±0.1	14.27

The average annual minimum temperature was projected to increase by 0.73℃. Highest and lowest annual temperatures were projected to increase by 1.09℃ and 1.20℃ respectively. The lowest annual temperature projected the highest increase of 14.27%. between 2018 and 2048. The lowest change in temperature was exhibited by the highest annual temperature at 5.04%. The epoch to epoch change projection was for lowest annual temperature at 3.36% between 2018 and 2023.

The change in time could explain 99% of the changes in the three climatic parameters. (Table 4.24). Only the three parameters of average annual maximum and minimum and lowest annual temperature were projected using the time series algorithm.

Table 4.24: Climatic Trend Projections Between 2018 and 2048

Climatic Parameter	Rate of Change	Coefficient of Determination (R^2)
Average annual Minimum Temperature	0.03	0.99
Highest annual Temperature	0.05	0.99
Lowest annual Temperature	0.05	0.99

4.2.3: Relationship between Urban Form and Climate

The relationship between urban form and climate in Nairobi was studied at two levels: at the weather station level and at the city-wide level. The weather station level considered five sublocations that hosted the weather stations. The city-wide level considered the 112 sublocations.

4.2.3.1 Relationship at the Weather Station Sublocations

The correlation at the weather station level revealed the NDVI as the dominant explainer of the variations in climatic parameters. It significantly correlated to the average annual minimum, highest annual, and lowest annual temperatures at 95% confidence interval in 2008. It also correlated significantly to rainfall in 1988 (Table 4.25).

Table 4.25: Correlation Matrix of Urban Form and Climate at the Weather Station Level

	Built-Up Area	Normalized Difference Vegetation Index	Forest
Average annual Maximum Temp 2018	.261	-.302	-.053
Average annual Maximum Temp. 2008	-.405	.408	.832
Average annual Maximum Temp. 1998	.093	-.022	.063
Average annual Maximum Temp. 1988	.378	-.029	.151
Average annual Minimum Temp 2018	.672	-.689	-.530
Average annual Minimum Temp. 2008	.646	-.955*	-.599
Average annual Minimum Temp. 1998	-.005	-.178	-.038
Average annual Minimum Temp. 1988	.337	-.264	-.589
Highest annual Temperature 2018	.719	-.803	-.743
Highest annual Temperature 2008	.789	-.911*	-.485
Highest annual Temperature 1998	-.446	.768	.849
Highest annual Temperature 1988	.251	-.743	-.702
Lowest annual Temperature 2018	.844	-.759	-.629
Lowest annual Temperature 2008	.646	-.955*	-.599
Lowest annual Temperature 1998	.749	-.544	-.535
Lowest annual Temperature 1988	-	-	-
Rainfall 2018	-.339	.220	.622
Rainfall 2008	-.531	.540	-.186
Rainfall 1998	.201	.418	.339
Rainfall 1988	.282	.938*	.567

Note * Correlation is significant at the 0.05 level (2-tailed).

The Open Space Network parameter was not reported as it was collinear with Built-Up Area.

The regression at the sublocation level generated four models (Table 4.26). All the models and urban form parameters tested at 95% confidence interval only. The Normalized Difference Vegetation Index (NDVI) was the main predictor revealed in all the models. For instance, the changes in NDVI explained 91.2% of the variations in the Average annual Minimum Temperature and Lowest annual Temperatures in 2008 (Equation 5.1 and 5.3). None of the models captured the relationship in 2018 and 1998.

Table 4.26: Regression Models of the Relationship Between Urban Form and Climate at the Five Sublocations with Weather Station

Eq.	Model	R^2	t-test		F-Test	
			99%	95%	99%	95%
5.1	$Y_{08}^{AMTn} = 14.341 - 0.015_{NDVI}$	0.912	No	Yes	No	Yes
5.2	$Y_{08}^{HMT} = 30.721 - 0.046_{NDVI}$	0.829	No	Yes	No	Yes
5.3	$Y_{08}^{LMT} = 115.575 - 0.076_{NDVI}$	0.912	No	Yes	No	Yes
5.4	$Y_{88}^{R} = 748.414 + 6.517_{NDVI}$	0.881	No	Yes	No	Yes

Note: NDVI is Normalized Difference Vegetation Index, R is Rainfall, AATx is Average annual Maximum Temperature, HAT is Lowest annual Temperature and LAT is Lowest annual Temperature

4.2.3.2 Relationship at City-wide Level

Trend analysis of urban form against climatic parameters revealed marked differences between the different parameters. These differences reflected in the rates of change (M) and the coefficients of determination (R^2). For instance, the NDVI was the highest explainer of the variations in Average annual Minimum Temperature at 25%. When plotted against Forest, the Highest annual Temperature dropped by 0.05℃ (Table 4.27).

Table 4.27: Trends of Climate Against Urban Form

Climate	Forest		Built-Up Area		Open Space Network		NDVI	
	M	R^2	M	R^2	M	R^2	M	R^2
Average annual Maximum Temperature	0.87	0.00	3.92	0.02	-4.57	0.07	-20.49	0.25
Average annual Minimum Temperature	2.59	0.13	4.57	0.07	-4.57	0.07	-3.20	0.02
Highest annual Temperature	-0.05	0.00	0.39	0.00	-0.39	0.00	-0.94	0.01
Lowest annual Temperature	0.04	0.01	0.13	0.04	-0.13	0.04	-0.40	0.20

Note: NDVI is Normalized Difference Vegetation Index, M is rate of change and R^2 is the coefficient of determination

The trend analysis was followed by correlation analysis. This was conducted per climatic parameter for each of the years as shown in Tables 4.28 – 5.32.

Table 4.28: Correlation Matrix of Average annual Maximum Temperature and Urban Form

	AAT_x. 2018	Built-Up Area 2018	NDVI 2018	Forest 2018
AAT_x. 2018	1	.394**	-.446**	-.318**
Built-Up Area 2018	.394**	1	-.660**	-.622**
NDVI 2018	-.446**	-.660**	1	.703**
Forest 2018	-.318**	-.622**	.703**	1
	AAT_x 2008	Built-Up Area 2008	NDVI 2008	Forest 2008
AAT_x. 2008	1	.222*	-.284**	-.136
Built-Up Area 2008	.222*	1	-.645**	-.458**
NDVI 2008	-.284**	-.645**	1	.709**
Forest 2008	-.136	-.458**	.709**	1
	AAT_x 1998	Built-Up Area 1998	NDVI 1998	Forest 1998
AAT_x 1998	1	-.056	-.001	.077
Built-Up Area 1998	-.056	1	-.414**	-.246**
NDVI 1998	-.001	-.414**	1	.744**
Forest 1998	.077	-.246**	.744**	1
	AAT_x 1988	Built-Up Area 1988	NDVI 1988	Forest 1988
AAT_x 1988	1	.306**	.018	-.110
Built-Up Area 1988	.306**	1	.081	-.434**
NDVI 1988	.018	.081	1	.350**
Forest 1988	-.110	-.434**	.350**	1

Note: *. Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed). NDVI is Normalized Difference Vegetation Index

With exception of 1998, the urban form parameters that significantly correlated with the average annual maximum temperature increased in number. In 1988, only Built-Up Area significantly correlated with climate at 99% confidence interval. In 2008, the urban form parameters increased to two and in 2018 all the urban form parameters significantly correlated with the average annual maximum temperature at 99% confidence interval (Table 4.29).

Table 4.29: Correlation Matrix of Average Annual Minimum Temperature and Urban Form

	AAT_n 2018	BUA 2018	NDVI 2018	Forest 2018
AAT_n 2018	1	.542**	-.718**	-.563**
Built-Up Area 2018	.542**	1	-.660**	-.622**
NDVI 2018	-.718**	-.660**	1	.703**
Forest 2018	-.563**	-.622**	.703**	1
	AAT_n 2008	**BUA 2008**	**NDVI 2008**	**Forest 2008**
AAT_n. 2008	1	.530**	-.699**	-.500**
Built-Up Area 2008	.530**	1	-.645**	-.458**
NDVI 2008	-.699**	-.645**	1	.709**
Forest 2008	-.500**	-.458**	.709**	1
	AAT_n 1998	**BUA 1998**	**NDVI 1998**	**Forest 1998**
AAT_n. 1998	1	.175	-.401**	-.144
Built-Up Area 1998	.175	1	-.414**	-.246**
NDVI 1998	-.401**	-.414**	1	.744**
Forest 1998	-.144	-.246**	.744**	1
	AAT_n 1988	**BUA 1988**	**NDVI 1988**	**Forest 1988**
AAT_n. 1988	1	.492**	.091	-.374**
Built-Up Area 1988	.492**	1	.081	-.434**
NDVI 1988	.091	.081	1	.350**
Forest 1988	-.374**	-.434**	.350**	1

Note: *. Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed). NDVI is Normalized Difference Vegetation Index

The urban form parameters that significantly correlated with the average annual minimum temperature increased as well. In 1988, only Built-Up Area and forest correlated with the climatic parameter at 99%. This increased to all the three changing urban form parameters in 2008 and 2018 (Table 4.30). Except for 1988, the Normalized Difference vegetation Index had the highest Pearson correlation value of all the urban form parameters.

Table 4.30: Correlation Matrix of Highest annual Temperature and Urban Form

	Highest annual Temp. 2018	Built-Up Area 2018	NDVI 2018	Forest 2018
Highest annual Temp. 2018	1	.341**	-.468**	-.413**
Built-Up Area 2018	.341**	1	-.660**	-.622**
NDVI 2018	-.468**	-.660**	1	.703**
Forest 2018	-.413**	-.622**	.703**	1
	Highest annual Temp. 2008	Built-Up Area 2008	NDVI 2008	Forest 2008
Highest annual Temp. 2008	1	.187*	-.377**	-.340**
Built-Up Area 2008	.187*	1	-.645**	-.458**
NDVI 2008	-.377**	-.645**	1	.709**
Forest 2008	-.340**	-.458**	.709**	1
	Highest annual Temp. 1998	Built-Up Area 1998	NDVI 1998	Forest 1998
Highest annual Temp. 1998	1	-.090	.097	.331**
Built-Up Area 1998	-.090	1	-.414**	-.246**
NDVI (NDVI) 1998	.097	-.414**	1	.744**
Forest 1998	.331**	-.246**	.744**	1
	Highest annual Temp. 1988	Built-Up Area 1988	NDVI 1988	Forest 1988
Highest annual Temp. 1988	1	.306**	-.461**	-.518**
Built-Up Area 1988	.306**	1	.081	-.434**
NDVI 1988	-.461**	.081	1	.350**
Forest 1988	-.518**	-.434**	.350**	1

Note: *. Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed). NDVI is Normalized Difference Vegetation Index

The correlations between urban form and Highest annual Temperature (HAT) fluctuated between 1988 and 1998 although it ended with all the parameters of urban form correlating significantly in 2018. In 1988, all the changing parameters of urban form significantly correlated with HAT at 99% confidence interval. This dropped to only forest in 1998 followed by an increase to three parameters in 2008 and 2018 (Table 4.31).

Table 4.31: Correlation Matrix of Lowest annual Temperature and Urban Form

	Lowest annual Temp. 2018	Built-Up Area 2018	NDVI 2018	Forest 2018
Lowest annual Temp. 2018	1	.418**	-.462**	-.411**
Built-Up Area 2018	.418**	1	-.660**	-.622**
NDVI 2018	-.462**	-.660**	1	.703**
Forest 2018	-.411**	-.622**	.703**	1
	Lowest annual Temp. 2018	Built-Up Area 1998	NDVI 2008	Forest 2008
Lowest annual Temp 2008	1	.290**	-.654**	-.491**
Built-Up Area 1998	.290**	1	-.344**	-.265**
NDVI 2008	-.654**	-.344**	1	.709**
Forest 2008	-.491**	-.265**	.709**	1
	Lowest annual Temp 1998	Built-Up Area 1998	NDVI 1998	Forest 1998
Lowest annual Temp 1998	1	.029	-.203*	-.254**
Built-Up Area 1998	.029	1	-.414**	-.246**
NDVI 1998	-.203*	-.414**	1	.744**
Forest 1998	-.254**	-.246**	.744**	1
	Lowest annual Temp 1988	Built-Up Area 1988	NDVI 1988	Forest 1988
Lowest annual Temp 1988	.[a]	.[a]	.[a]	.[a]
Built-Up Area 1988	.[a]	1	.081	-.434**
NDVI 1988	.[a]	.081	1	.350**
Forest 1988	.[a]	-.434**	.350**	1

Note: *. Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed) and a. Cannot be computed because at least one of the variables is constant. NDVI is Normalized Difference Vegetation Index

Except for 1988, the number of urban form parameters that significantly correlated with the Lowest annual Temperature (LAT) consistently increased. In 1998, the Normalized Difference Vegetation Index (NDVI) and Forest significantly correlated with the LAT at 99% and 95% confidence intervals, respectively. This increased to 99% confidence interval for all the urban form parameters in 2008 and 2018 (Table 4.31).

The 1988 correlations did not reveal any Pearson's r values since the temperature value was consistently low that it all fell within one range and as such became a constant value as highlighted in Table 4.32.

Table 4.32: Correlation Matrix of Rainfall and Urban Form

	Rainfall 2018	Built-Up Area 2018	NDVI 2018	Forest 2018
Rainfall 2018	1	-.092	.205*	.295**
Built-Up Area 2018	-.092	1	-.660**	-.622**
NDVI 2018	.205*	-.660**	1	.703**
Forest 2018	.295**	-.622**	.703**	1
	Rainfall 2008	**Built-Up Area 2008**	**NDVI 2008**	**Forest 2008**
Rainfall 2008	1	-.348**	.493**	.318**
Built-Up Area 2008	-.348**	1	-.645**	-.458**
NDVI 2008	.493**	-.645**	1	.709**
Forest 2008	.318**	-.458**	.709**	1
	Rainfall 1998	**Built-Up Area 2008**	**NDVI 1998**	**Forest 1998**
Rainfall 1998	1	.179	.095	.088
Built-Up Area 2008	.179	1	-.644**	-.408**
NDVI 1998	.095	-.644**	1	.744**
Forest 1998	.088	-.408**	.744**	1
	Rainfall 1988	**Built-Up Area 1988**	**NDVI 1988**	**Forest 1988**
Rainfall 1988	1	.042	.496**	.285**
Built-Up Area 1988	.042	1	.081	-.434**
NDVI 1988	.496**	.081	1	.350**
Forest 1988	.285**	-.434**	.350**	1

Note: *. Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed) and a. Cannot be computed because at least one of the variables is constant. NDVI is Normalized Difference Vegetation Index

Like the Highest annual Temperature correlations, the rainfall parameters also had fluctuating patterns. In 1988, only the Normalized Difference Vegetation Index (NDVI) and Forest significantly correlated with rainfall at 99% confidence interval. This reduced to zero urban form parameters in 1998 then rose to all in 2008 and finally dropped to Forest and NDVI at 99% and 95% confidence intervals, respectively (Table 4.32)

Urban Form Influence on Average annual Maximum Temperature

The Normalized Difference Vegetation Index (NDVI) and Built-Up Area (BUA) emerged as the main urban form predictors of Average annual Maximum Temperature (AAT_x). The NDVI presented the health of vegetation. The BUA was the key predictor of AAT_x in 1988 (Equation 5.7). In 1998, the regression did not reveal a model due to the outlier parameters caused by the El Nino phenomena. The NDVI predicted 19.9% and 8.1% of the changes in AAT_x in 2018 and 2008 respectively (Table 4.33).

All the models of average annual maximum temperature and urban form parameters in the models were statistically significant at 95% confidence interval (Table 4.33). However, at 99% confidence interval, Equation 5.6, and the Normalized Difference Vegetation Index (NDVI) as a predictor of AAT_x were not statistically significant.

Table 4.33: Regression Models of Average annual Maximum Temperature Against Urban Form

Eq.	Model	R^2	t-test		F-Test	
			99%	95%	99%	95%
5.5	$Y_{18}^{AMTx} = 24.577 -.004_{NDVI}$	0.199	Yes	Yes	Yes	Yes
5.6	$Y_{08}^{AMTx} = 24.908 -.002_{NDVI}$	0.081	No	Yes	No	Yes
5.7	$Y_{88}^{AMTx} = 24.723 -.002_{BUA}$	0.094	Yes	Yes	Yes	Yes

Note: Y is the climatic parameter, AATx is the Average annual Maximum Temperature, NDVI is Normalized Difference Vegetation Index, BUA is Built-Up Area., R^2 is the Coefficient of Determination The 1998 data did not yield a model

Urban Form Influence on Average annual Minimum Temperature

The Normalized Difference Vegetation Index (NDVI), Built-Up Area (BUA) and forest emerged as the main predictors of changes in Average annual Minimum Temperature (AAT_n) between 1988 and 1998. The NDVI's prediction of changes in Average annual minimum temperature increased from 16% in 1998 to 51% in 2018. This showed a very strong correlation between NDVI and Average annual Minimum Temperature in the period.

Both 1998 and 1988 data generated two regression models (Table 4.34). In both cases, the second model was at 95% confidence interval with the added urban form parameter being forest. These combined parameters of Normalized Difference Vegetation Index and Forest in 1998 explained 21% of the variations in Average annual Minimum Temperature while in 1988, the combined predictors explained 27% of the variations in the Average annual Minimum Temperature. In both cases (Eq. 5.11 and Eq. 5.13), the t-tests for the model and the added parameter were at 95% confidence interval.

Table 4.34: Regression Models of Average annual Minimum Temperature against Urban Form

Eq.	Model	R^2	t-test		F-Test	
			99%	95%	99%	95%
5.8	$Y_{2018}^{AMTn} = 14.621 - 0.010_{NDVI}$	0.515	Yes	Yes	Yes	Yes
5.9	$Y_{08}^{AMTn} = 14.304 - 0.009_{NDVI}$	0.489	Yes	Yes	Yes	Yes
5.10	$Y_{98}^{AMTn} = 13.788 - 0.002_{NDVI}$	0.160	Yes	Yes	Yes	Yes
5.11	$Y_{98}^{AMTn} = 13.796 - 0.004_{NDVI} + 0.004_{Forest}$	0.213	Yes* No**	Yes* Yes**	No	Yes
5.12	$Y_{88}^{AMTn} = 14.101 - 0.006_{BUA}$	0.242	Yes	Yes	Yes	Yes
5.13	$Y_{88}^{AMTn} = 14.057 - 0.005_{BUA} - 0.003_{Forest}$	0.273	Yes* No**	Yes* Yes**	No	Yes

Note: Y is the climatic parameter, AATx is the Average annual Maximum Temperature, NDVI is Normalized Difference Vegetation Index, BUA is Built-Up Area., R^2 is the Coefficient of Determination

*is the t-test for the first urban form parameter in the model and ** is the t-test for the second urban form parameter in the model

Urban Form Influence on Lowest annual Temperature

The Normalized Difference Vegetation Index, Built-Up Area (BUA) and forest emerged as the main predictors of variations in Lowest annual Temperature (Table 4.35). Forest was the lowest predictor of the variations in the climatic parameter in 1998 at 6% while the NDVI was the single highest predictor of the variations in the Lowest annual Temperature in 2008 at 42%.

The year 2008 generated two models with the addition of Built-Up Area in Eq. 5.12 (Table 4.35). With that addition, the two predictors of Normalized Difference Vegetation Index and Built-Up Area explained 46% of the variations in the Lowest annual Temperature (Table 4.35). Notable is that the confidence interval of the model changed but that of the urban form parameters did not.

Table 4.35: Regression Models for Lowest annual Temperature against Urban Form

Eq.	Model	R^2	t-test		F-Test	
			99%	95%	99%	95%
5.14	$Y_{18}^{LMT} = 12.673 - 0.043_{NDVI}$	0.211	Yes	Yes	Yes	Yes
5.15	$Y_{08}^{LMT} = 10.980 - 0.039_{NDVI}$	0.428	Yes	Yes	Yes	Yes
5.16	$Y_{08}^{LMT} = 11.443 - 0.029_{NDVI} - 0.012_{BUA}$	0.463	Yes* Yes**	Yes* Yes**	No	Yes
5.17	$Y_{98}^{LMT} = 8.954 - 0.013_{Forest}$	0.064	Yes	Yes	Yes	Yes

Note: Y is the climatic parameter, AATx is the Average annual Maximum Temperature, NDVI is Normalized Difference Vegetation Index, BUA is Built-Up Area., R^2 is the Coefficient of Determination

*is the t-test for the first urban form parameter in the model and ** is the t-test for the second urban form parameter in the model

Urban Form Influence on Highest annual Temperature

This relationship generated the highest number of models. All the changing urban form parameters emerged as predictor (Table 4.36). Nonetheless, forest was the dominant predictor. All the models except Eq. 5.21 and 5.24 tested at 99% confidence interval. The rest tested at 95% confidence intervals for at least one urban form parameter and the model. (Table 4.36). Forest was the highest explainer of the variation in Highest annual Temperature at 26% in 1988 (Eq. 5.22). Of the combined predictors, the combination of forest, Normalized Difference Vegetation Index and Built-Up Area (Eq. 5.20) was the highest explainer of variations in the climatic parameter at 39% (Table 4.36).

Table 4.36: Regression Models of Highest annual Temperature against Urban Form

Eq.	Model	R^2	t-test		F-Test	
			99%	95%	99%	95%
5.18	$Y_{18}^{HMT} = 31.418 - 0.024_{NDVI}$	0.217	Yes	Yes	Yes	Yes
5.19	$Y_{08}^{HMT} = 30.544 - 0.028_{NDVI}$	0.142	Yes	Yes	Yes	Yes
5.20	$Y_{98}^{HMT} = 29.753 + 0.030_{Forest}$	0.110	Yes	Yes	Yes	Yes
5.21	$Y_{98}^{HMT} = 29.956 + 0.053_{Forest} - 0.016_{NDVI}$	0.160	Yes* No**	Yes* Yes**	No	Yes
5.22	$Y_{88}^{HMT} = 30.360 - 0.025_{Forest}$	0.268	Yes	Yes	Yes	Yes
5.23	$Y_{88}^{HMT} = 31.037 - 0.020_{Forest} - 0.010_{NDVI}$	0.357	Yes* Yes**	Yes* Yes**	Yes	Yes
5.24	$Y_{88}^{HMT} = 30.912 - 0.015_{Forest} - 0.012_{NDVI} + 0.08_{BUA}$	0.389	Yes* Yes** No***	Yes* Yes** Yes***	No	Yes

Note: Y is the climatic parameter, AATx is the Average annual Maximum Temperature, NDVI is Normalized Difference Vegetation Index, BUA is Built-Up Area., R^2 is the Coefficient of Determination

*is the t-test for the first urban form parameter in the model, ** is the t-test for the second urban form parameter in the model and *** is the t-test for the third urban form parameter in the model

Urban Form Influence on Lowest annual Temperature

The relationship between rainfall and urban form generated the least number of models at three. There was no model generated for the year 1998 due to the outlier rainfall amounts caused by the El-Nino phenomena. The Normalized Difference Vegetation Index was the dominant predictor (Table 4.37).

All the models and predictors tested at 99% confidence interval. Forest explained 8% of the variations in rainfall in 2018. Normalized Difference Vegetation Index explained 24% of the variations in rainfall in 1988 and 2008 (Eq. 5.26 and Eq. 5.27).

Table 4.37: Regression Models of Rainfall against Urban Form

Eq.	Model	R^2	t-test		F-Test	
			99%	95%	99%	95%
5.25	$Y_{18}^{R} = 991.457 + 1.646_{Forest}$	0.087	Yes	Yes	Yes	Yes
5.26	$Y_{08}^{R} = 732.211 + 2.597_{NDVI}$	0.243	Yes	Yes	Yes	Yes
5.27	$Y_{88}^{R} = 916.625 + 3.487_{NDVI}$	0.246	Yes	Yes	Yes	Yes

Note: Y is the climatic parameter, AATx is the Average annual Maximum Temperature, NDVI is Normalized Difference Vegetation Index, BUA is Built-Up Area., R is Rainfall.

*is the t-test for the first urban form parameter in the model and ** is the t-test for the second urban form parameter in the model

4.2.3.3 Comparison between Weather Station Level and All Sublocations

There are three urban form parameters that influence climate in Nairobi. These are the Normalized Difference Vegetation Index (NDVI), Built-Up Area and Forest cover. At the weather station level, only the NDVI emerged as the urban form element that influenced climate. However, as the sample was expanded to include the interpolated data for the 112 sublocations (Appendix 14-17), Built-Up Area and Forest emerged. The NDVI emerged as the dominant predictor of variations in climatic parameters both at the weather station and city-wide levels.

4.2.4 Socioeconomic Trends and Patterns

Other than urban biophysical characteristics, Krellenberg (2016) and Satapathy et al., (2014) advocate for the inclusion of socioeconomic parameters. Socioeconomic parameters' classification was based on Table 2.5, 2.6 and 2.7. Studied parameters included population density, gender distribution (female-headed households), age (>65 years), poverty levels, and access to services (water, sanitation, and energy). Population density determined the magnitude of the population at risk.

4.2.4.1 Population Density

The population densities were normalized due to the very wide range. All the four ranges yielded sublocation classifications (Figure 4.34).

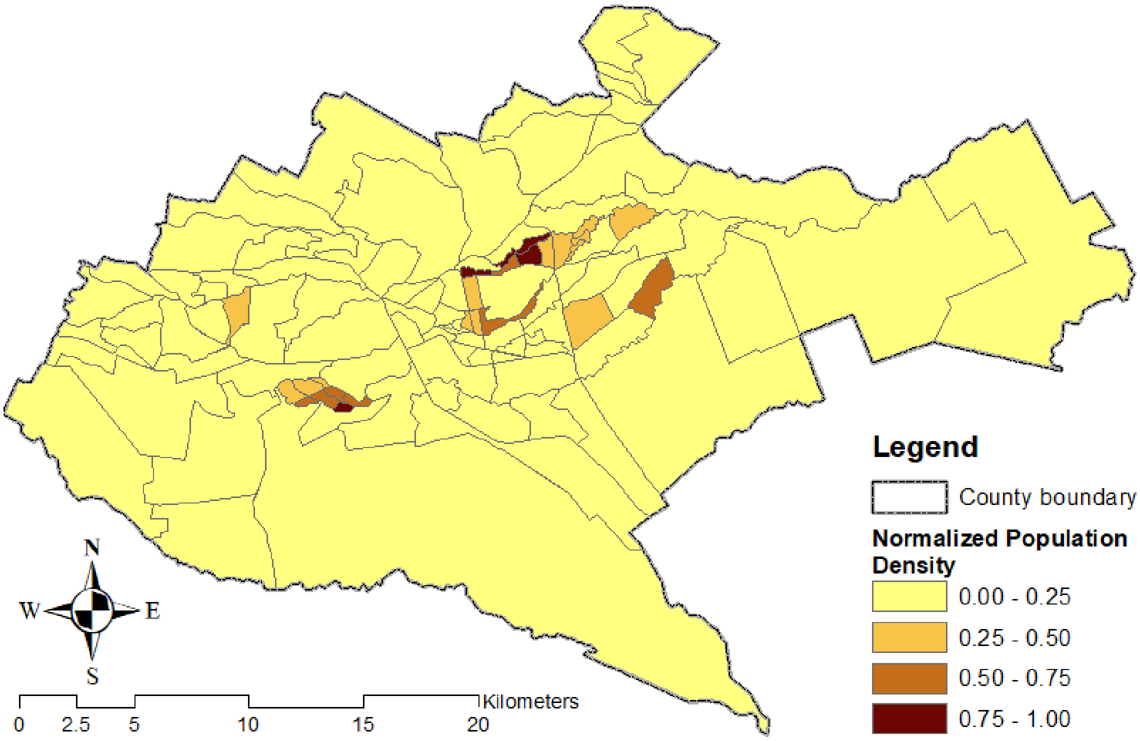


Figure 4.34: Normalized Population Densities per Sublocation

Out of 112 sublocations, 85 displayed normalized densities ≤ 0.25. Five sublocations had densities ≥ 0.75 normalized population density. They included Mathare 4A, Huruma, Mathare North, Silanga, and Mlango Kubwa. The remaining 22 sublocations had normalized densities between 0.25 and 0.75.

4.2.4.2 Percentage of the Population Above 64 years

The age composition parameter considered those above 65 years old. This is the demographic that is most at risk of thermal stress. The distribution is mainly towards the North-Western and South-Western parts of the city (Figure 4.35).

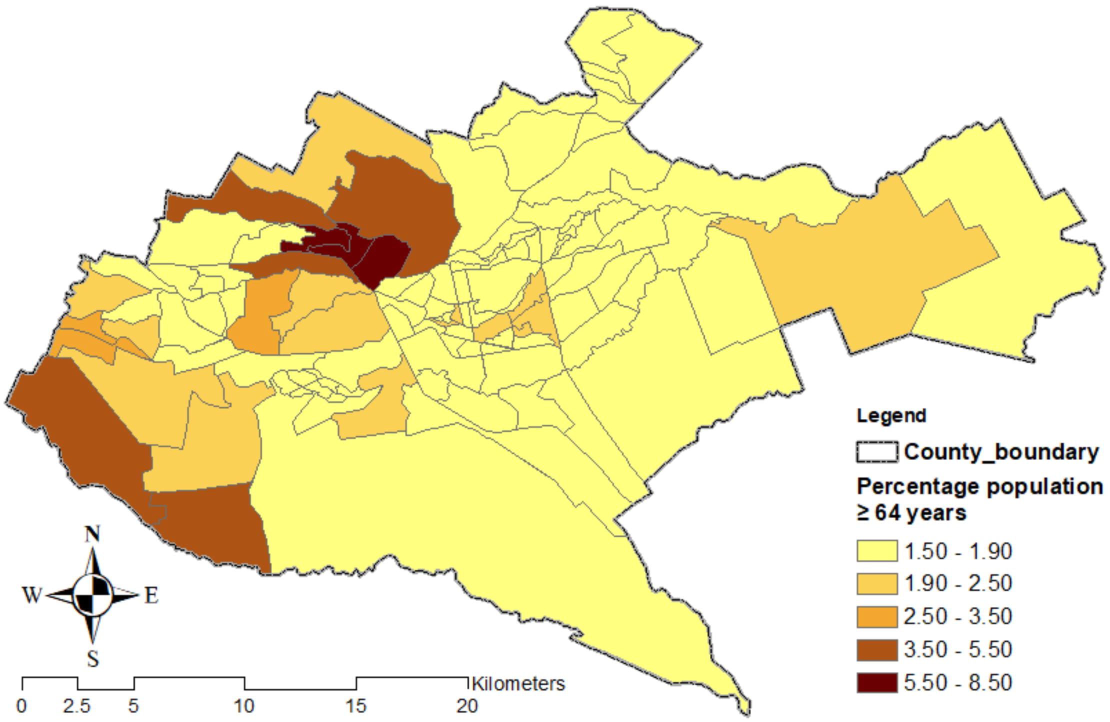


Figure 4.35: Normalized Percentage of Population Above 65 Years

The sublocations with the highest risk because of age are Spring Valley Upper Parklands and Highridge. These are followed by Muthangari, Muthaiga, Kitisuru, Karen and Hardy. These are also very high-income sublocations.

4.2.4.3 Female-Headed Households

Female-headed households are at a higher risk to flood and thermal discomfort due to gender bias in employment or work opportunities. The sublocation with the highest population of the female-headed households is City Square (Figure 4.36). This is followed by Zimmerman, Kileleshwa, Kilimani, Woodley, Mugumoini, Ngara East, Pangani, and Ziwani.

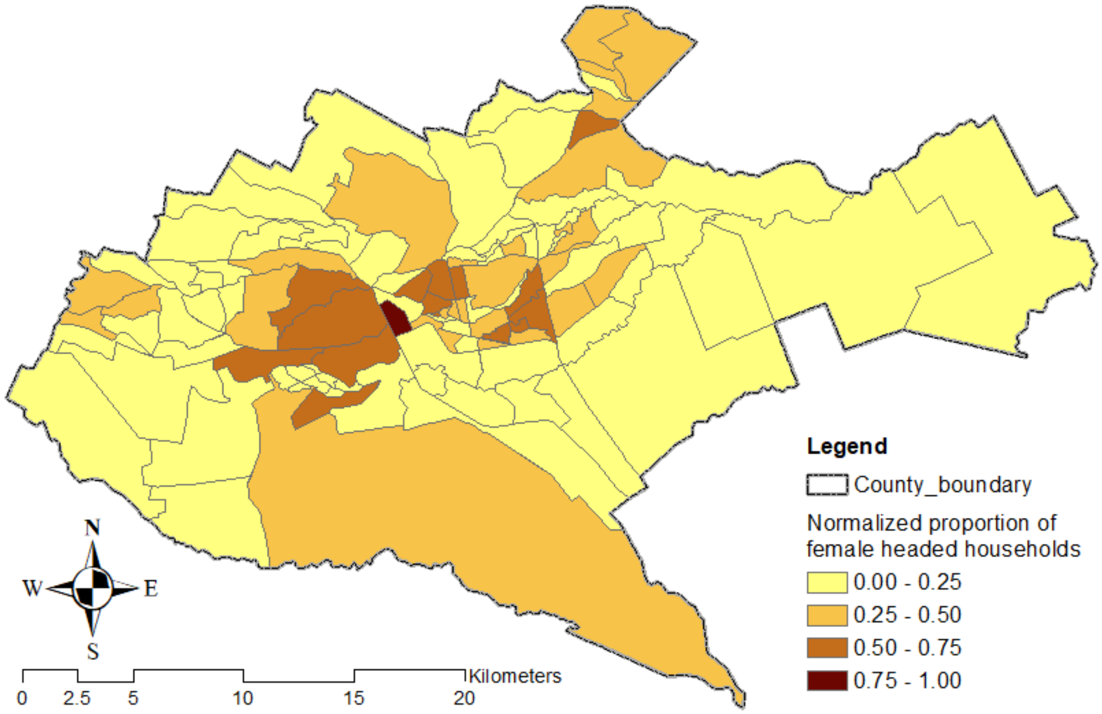


Figure 4.36: Normalized Proportion of the Population with Female-Headed Households

4.2.4.4 Poverty Levels

The poverty levels considered the percentage of the population living below the poverty line as defined by the World Bank. The modelled data revealed that City Square sublocation had over 80% of the population living below the poverty line. This population largely comprises of street families and homeless individuals. The sublocations with percentages between 40% and 60% are made up of the informal settlements. They include Laini Saba, Soweto, Silanga, Lindi, Mathare, Mathare 4A, Mlango Kubwa, Mabatini, Korogocho, Nyayo, Gitathuru and Njathaini (Figure 4.37).

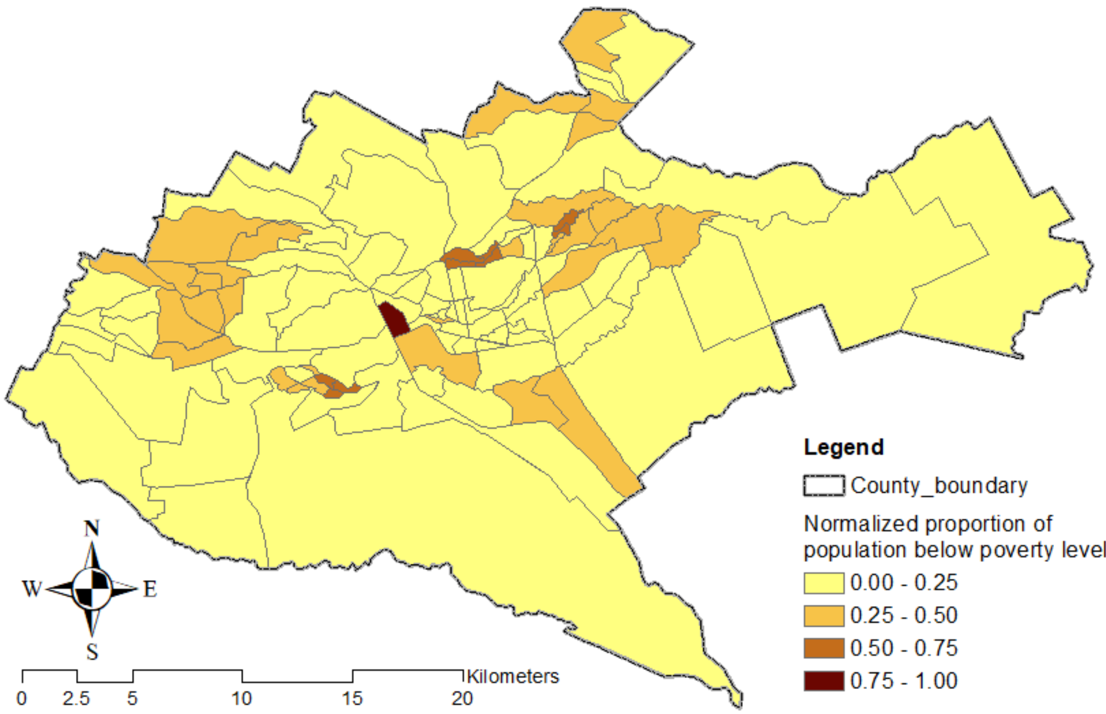


Figure 4.37: Normalized Proportion of the Population Below the Poverty Line

4.2.4.5 Access to Services

Access to services analyzed three components namely water, sanitation, and energy. These parameters are within the concept of adaptive capacity. For instance, inhabitants of locations with good access to piped water, proper sanitation, and electrical energy are deemed to better cope with climate-oriented shocks like flooding and thermal stress better than those in locations without.

Access to water captured two components: the percentage of households with access to clean water and the source of water. Overall access to clean water is high (Figure 4.38) at 100%. 107 out of 112 sublocations had over 40% of the households with access to clean water. Ngandu, Hamza, Lumumba, Kamukunji and Kaloleni had less than 25% of the households with access to clean water.

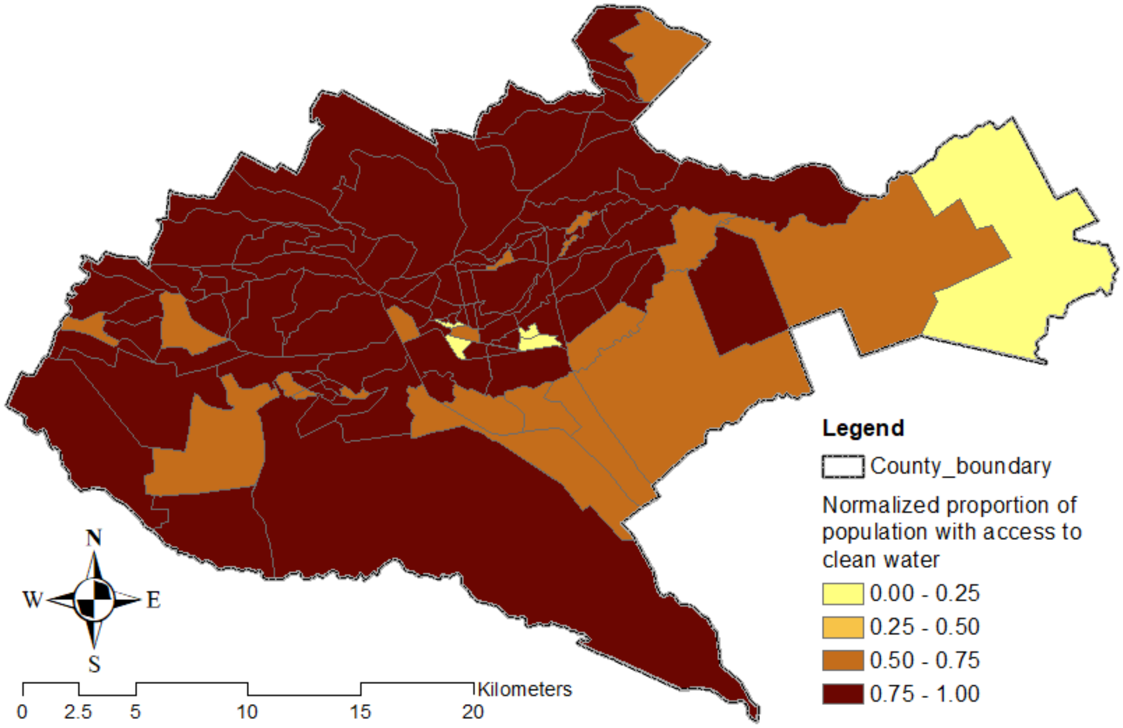


Figure 4.38: Normalized Proportion of Households with Access to Clean Water

The sources of water in the county are piped water to dwellings, piped to a communal water point, borehole and well. The central zone of the city is supplied by piped water (Figure 4.39).

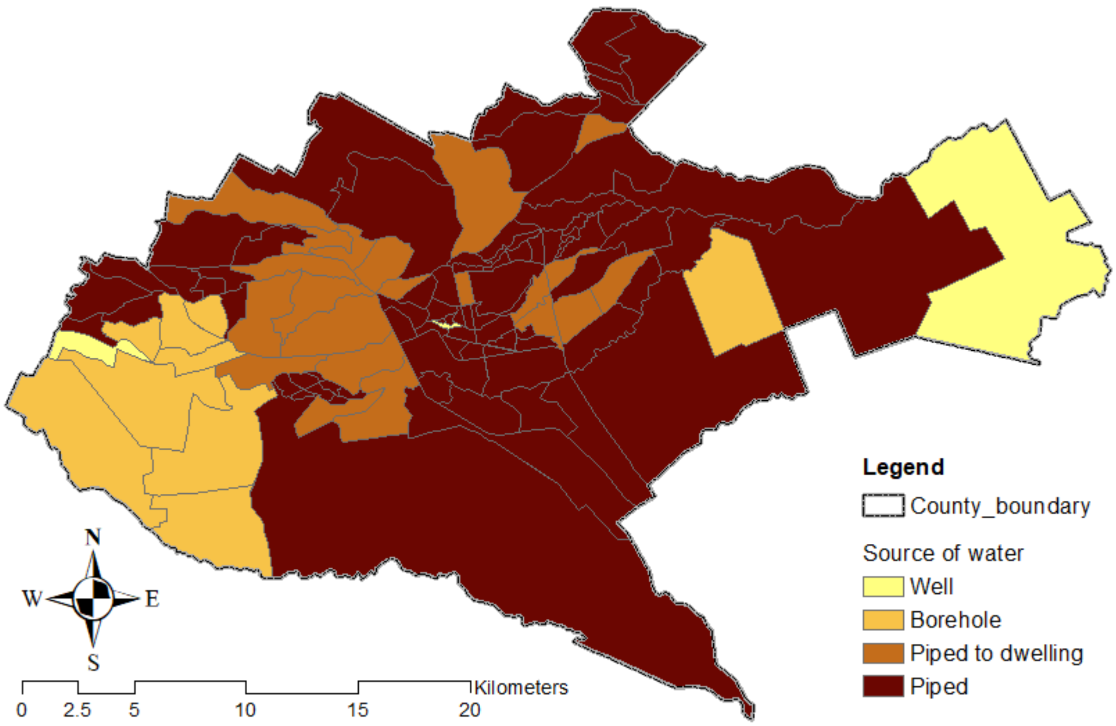


Figure 4.39: Most Used Source of Water Per Sublocation

This accounts for over 70% of the sublocations with access to piped water either at the dwelling or to a communal point. The eastern and western tips of the city are supplied by wells and boreholes, respectively. The sublocations with wells as the most used source of water include Ngandu, Mutuini, and Kamukunji. These, therefore, are the most vulnerable within the context of access to water-based on the source.

Improved sanitation encompassed sewer lines and latrines. 65 sublocations had over 75% of the households with access to improved sanitation. 2.7% of the sublocations have less than 25% of the population with access to improved sanitation. These were sublocations with informal settlements such as Korogocho, Gitathuru, and Nyayo (Figure 4.40).

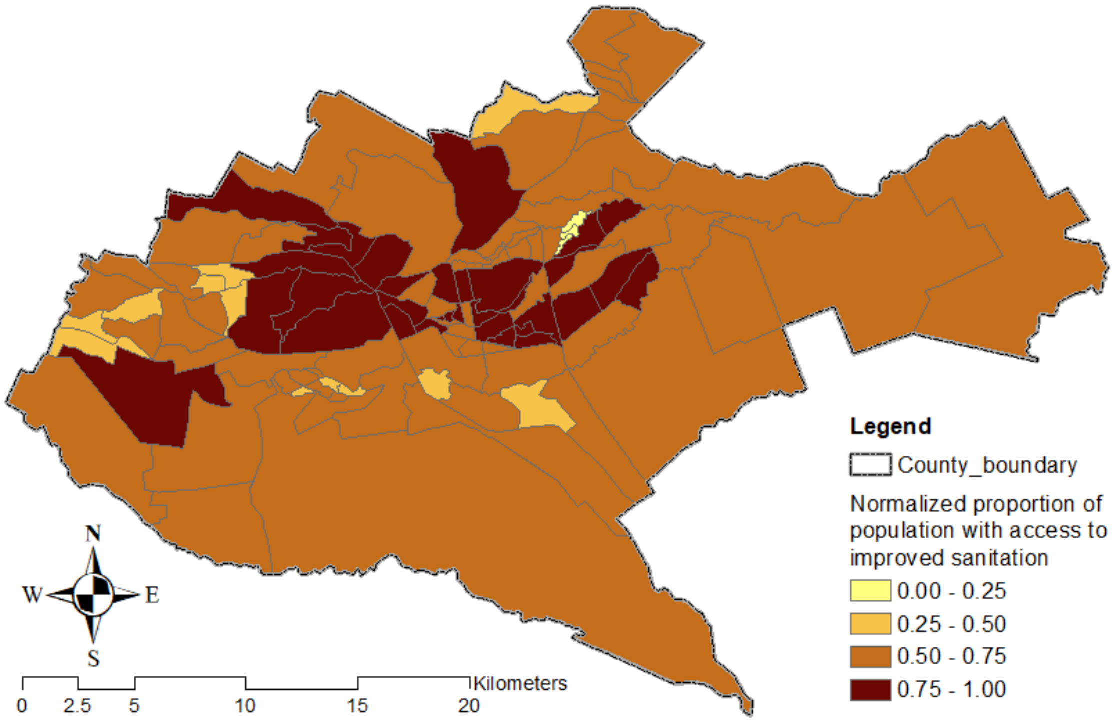


Figure 4.40: Normalized Proportion of Households with Access to Improved Sanitation

The energy coverage considered electricity connections. Eighty-three percent of the sublocations had over 80% of the households with access to electricity. Sublocations with between 50% to 75% of the households having access to electricity as a source of energy include Ngandu, Njiru, Saika, Mowlem, Nyayo, Korogocho, Shauri Moyo and Kamukunji (Figure 4.41). These are scattered at the central zone of the city.

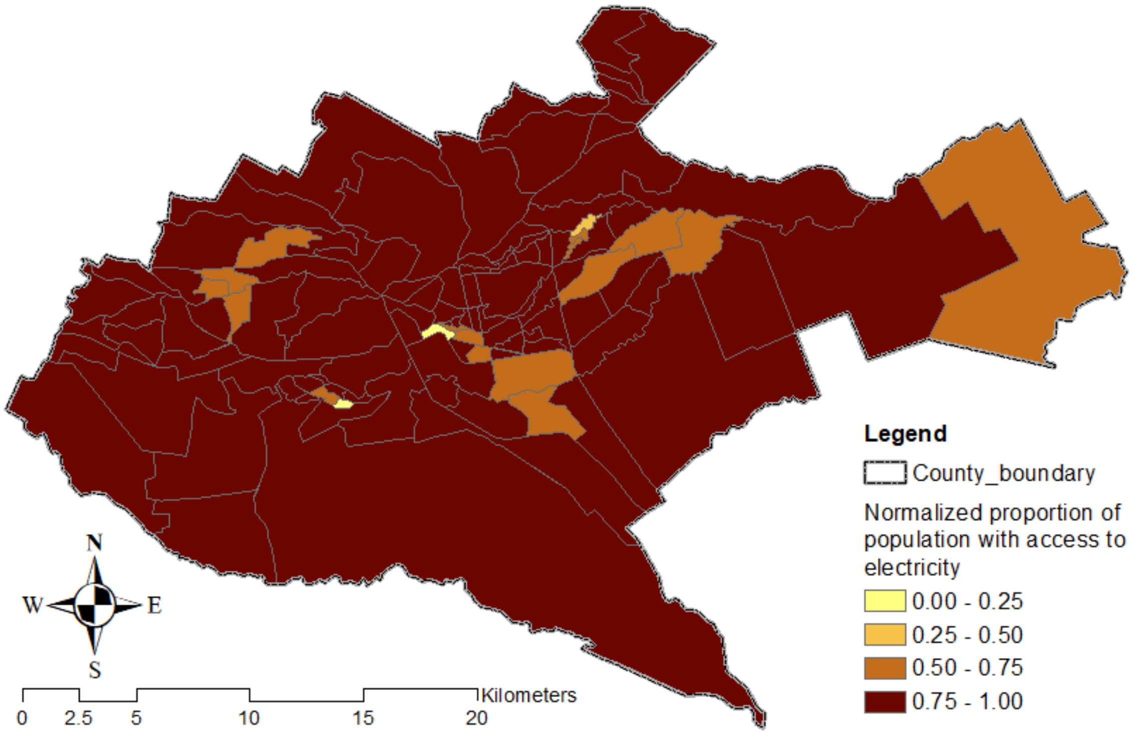


Figure 4.41: Normalized Proportion of Households with Access to Electricity

4.2.5 Climate Vulnerability Patterns

Climate vulnerability patterns were modelled based on the relationship between urban form, socioeconomic, and climatic parameters. The interaction between climatic parameters and urban elements determines vulnerability within the framework of exposure, sensitivity, and adaptive capacity. It is on this basis that the vulnerability ranks were modelled. For instance, extremely high heat in a heavily built-up area has the potential for high vulnerability to thermal stress.

The modelling was based on each of the parameters of urban form and climate. Socioeconomic parameters were also modelled. They were ranked on a 4 four-point scale of Very High Vulnerability (VHV), High Vulnerability (HV), Moderate Vulnerability (MV) and Low Vulnerability (LV). Parameters modelled under biophysical characteristics included landcover, elevation, slope, flow accumulation, soil drainage properties, and Open Space Network.

Landcover influences both flood and heat vulnerability. The influence is determined by the interaction between climatic parameters and urban surfaces. For instance, impervious built-up areas translate to more runoff and heat stress. On the contrary, forested, and green open spaces have lower vulnerability to flooding risk but possible high vulnerability to thermal cold stress. A total of 60 out of 112 exhibited very high vulnerability (Table 4.38). Vulnerability patterns from landcover reveal very high vulnerability in the central zone of the city. The northwestern and southwestern zones exhibit low vulnerability (Figure 4.42).

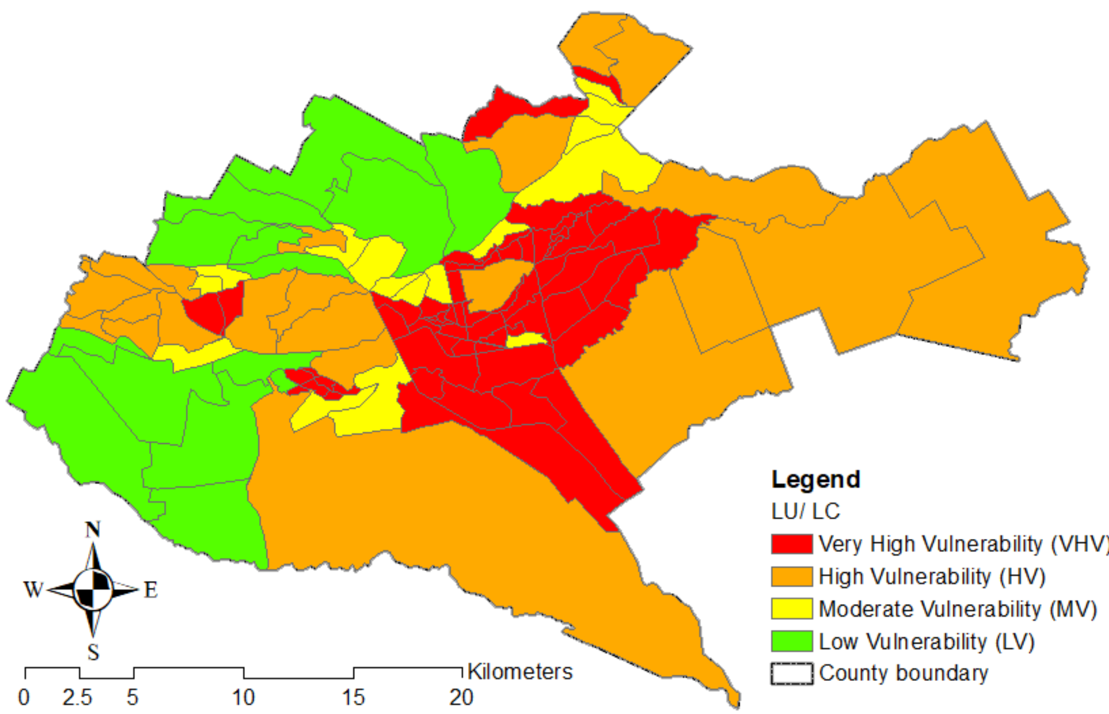


Figure 4.42: Sublocation Vulnerability Based on Landcover

Elevation modelling considered both heat and flood vulnerability. Zones of low elevation receive consolidated runoff and exhibit higher temperatures compared to high elevations. Majority of the sublocations fall in the lower elevation thereby exhibiting high vulnerability (Table 4.38). Only 9 out of 112 sublocations had very high vulnerability. With an east to west rising elevation, the sublocations on the east showed very high vulnerability while those in the west displayed low vulnerability (Figure 4.43).

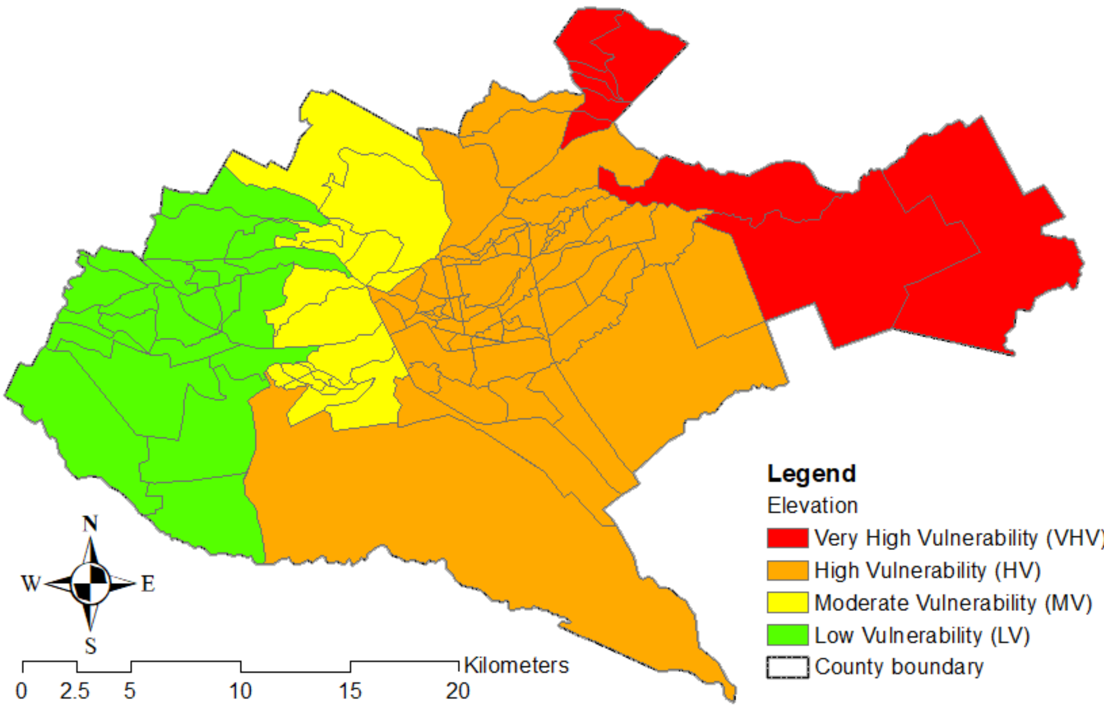


Figure 4.43: Sublocation Vulnerability Based on Elevation

Slope vulnerability levels were determined to only affect runoff thus flood vulnerability. The ranking was based on the slope percentages, the gentler the slope the higher the vulnerability. The county showed overall low vulnerability at 90 sublocations (Table 4.38). Moderate vulnerability is prevalent in the eastern zone apart from Ngando sublocation (Figure 4.44). The gentle slopes ≤ 4% predisposes the eastern and southern side of the city to flood hazards because of slower stormwater runoff.

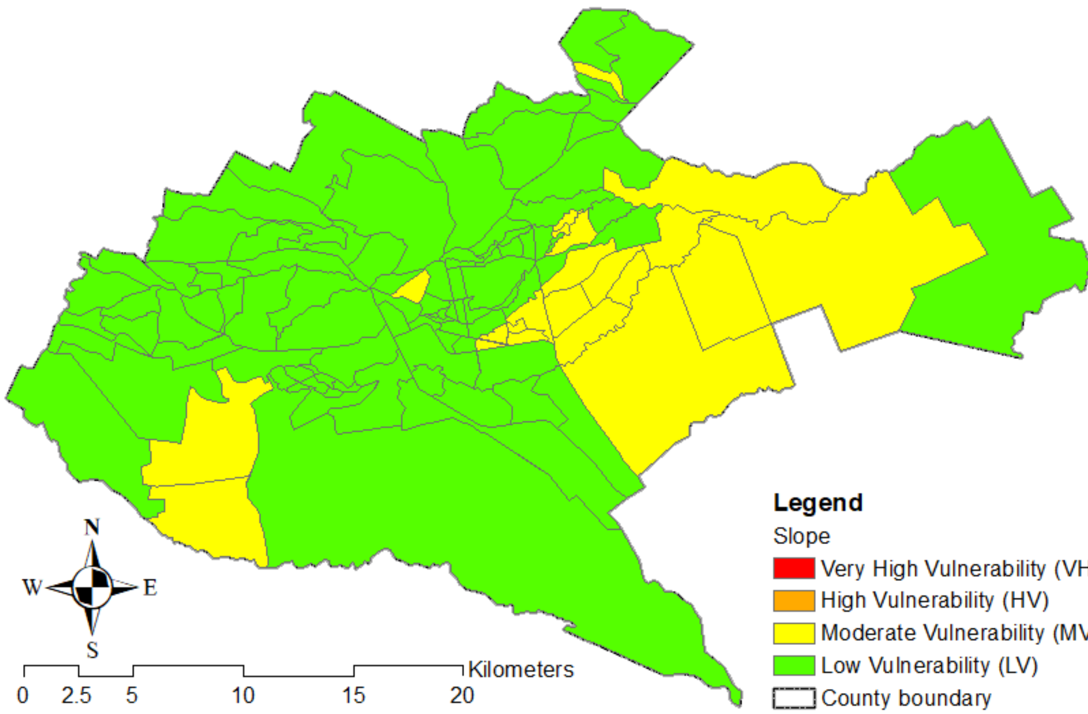


Figure 4.44: Sublocation Vulnerability Based on the Slope

Flow accumulation is pertinent to flooding. Its vulnerability ranking held constant the parameter of constructed drains. No sublocation exhibited very high vulnerability. Majority of the sublocations showed moderate vulnerability at 56 out of 112 (Table 4.38). The high vulnerability and moderate vulnerability were concentrated in the central zone and the northern tip of the city (Figure 4.45). Some of the sublocations such as Lindi and Laini Saba that display low to moderate vulnerability because of river systems are very highly vulnerable to riverine flooding.

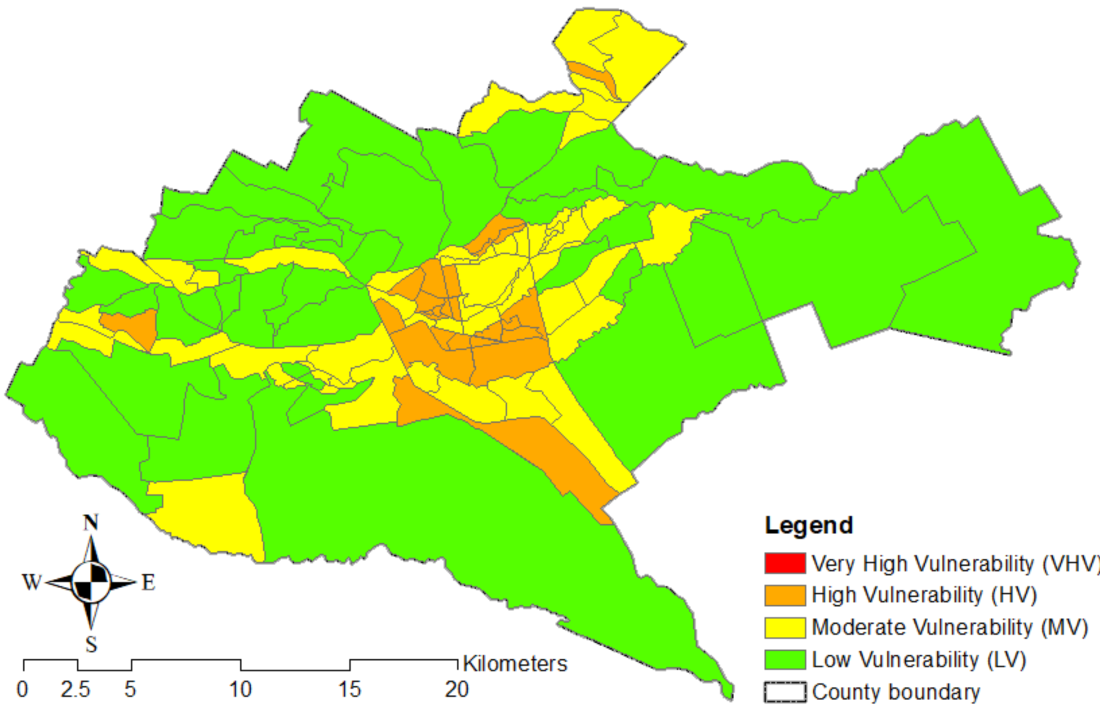


Figure 4.45: Sublocation Vulnerability Based on Flow Accumulation

Vulnerability modelling for soil drainage properties combines the dense development and very poorly drained soils under very high vulnerability. Soil drainage properties' vulnerability is concentrated on the extremes. Out of 112 sublocations, 72 displayed very high vulnerability and 21 showed low vulnerability (Table 4.38). This is due to the extremes of the soil types in the county. Spatially, the very high vulnerability is concentrated in the central zone of the city where either the soils were very poorly drained or there was very dense development (Figure 4.46).

The vulnerability index for the Open Space Network (OSN) is based on the ability of green open spaces to ameliorate urban temperatures and manage stormwater. Despite the good spread at the city level, vulnerability ranks still capture all the four groups at the sublocation level (Table 4.38 and Figure 4.47). The open spaces are either exceedingly small or not dispersed at the sublocation level. The vulnerability index of the 2018 The NDVI revealed very high vulnerability in the eastern zone of the city (Figure 4.48).

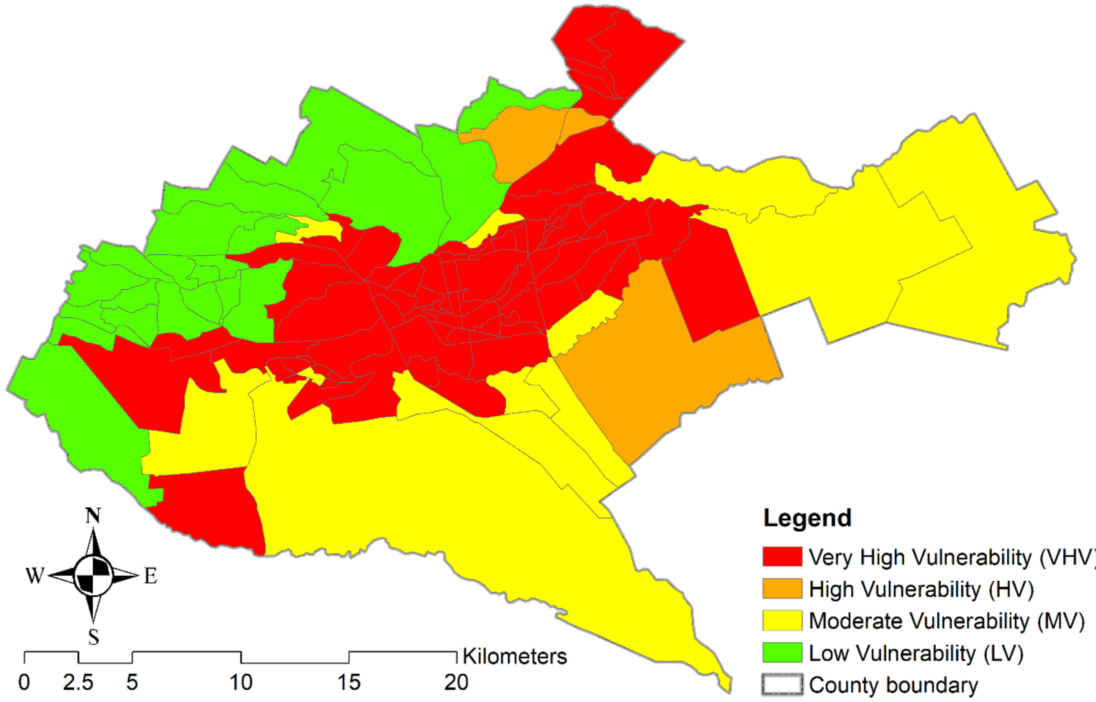


Figure 4.46: Sublocation Vulnerability Based on Soil Drainage Properties

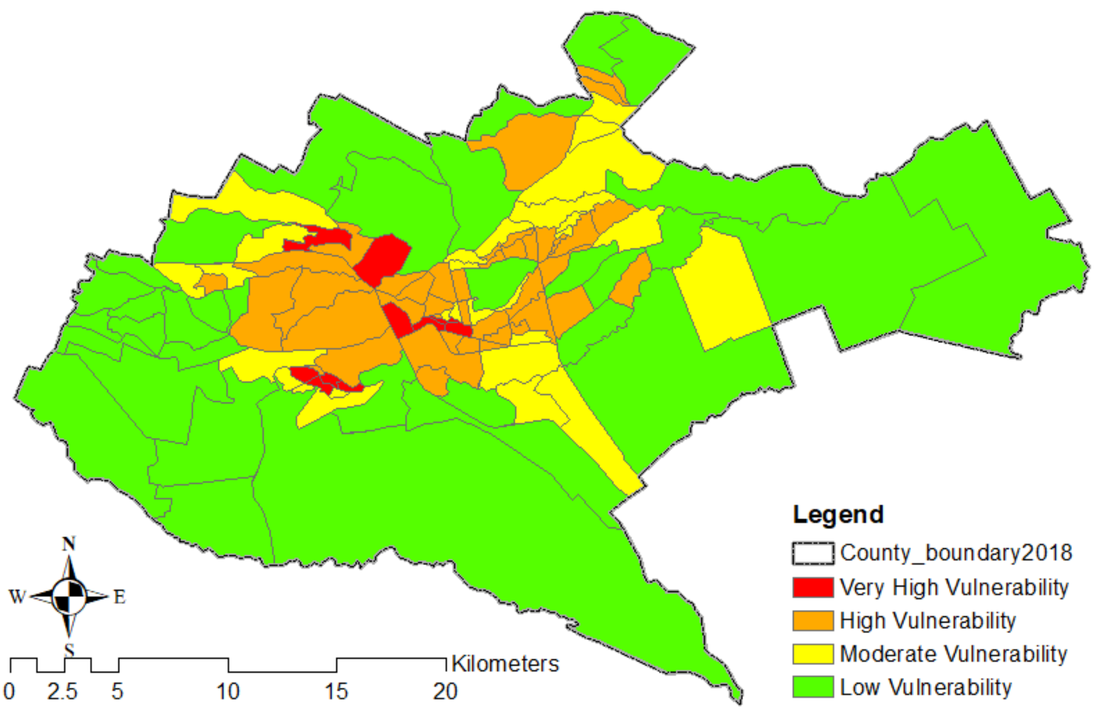


Figure 4.47: Sublocation Vulnerability Based on Open Space Network

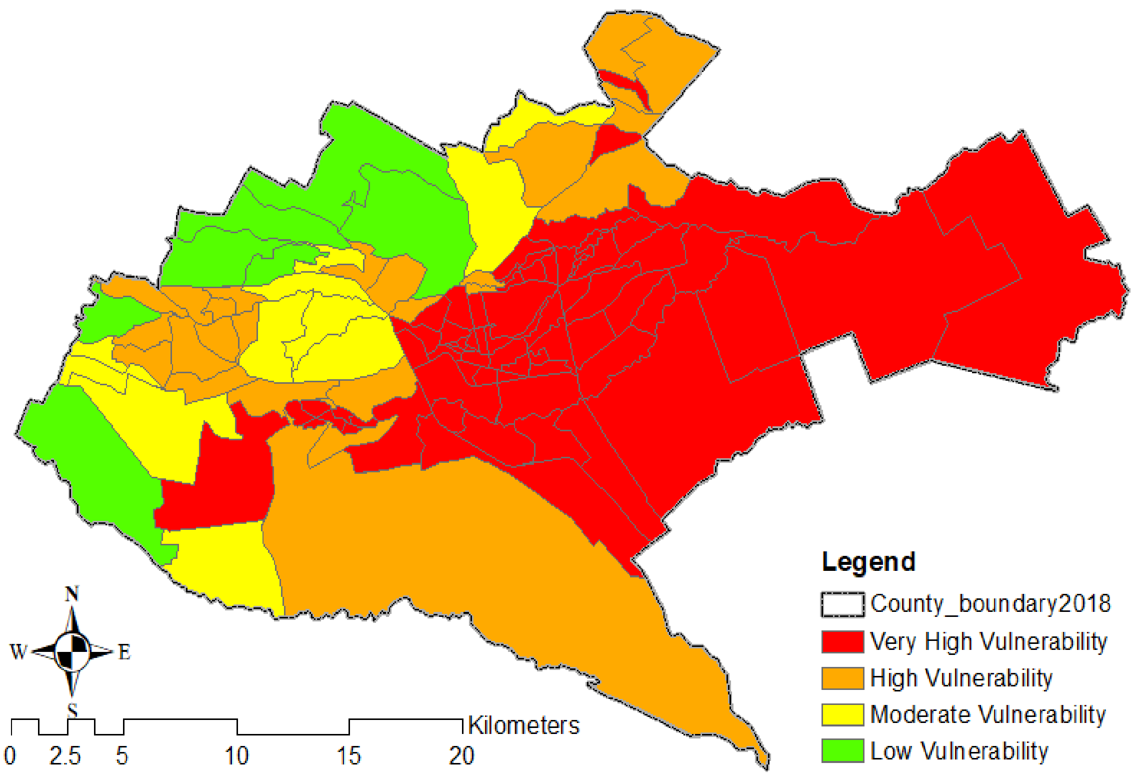


Figure 4.48: Sublocation Vulnerability Based on Normalized Difference Vegetation Index

The climatic vulnerability was based on the climatic parameters of temperature and rainfall. Temperature parameters were Average annual maximum temperature, Average annual minimum temperature, highest annual temperature, and lowest annual temperature. Vulnerability thresholds for temperature were based on the thermal stress indicators proposed by Abdel-Ghany, Al-Helal, and Shady (2013), Matzarakis and Amelung (2008), Matzarakis and Mayer (1996) as ≤ 13℃ for cold stress and ≥ 23℃ for heat stress. Heat stress vulnerability mapping had values above 23℃ considered as high vulnerability.

Nairobi exhibited high and very high vulnerability based on the Average annual maximum temperature at 60 and 52 sublocations, respectively (Table 4.38). Spatially, the vulnerability is concentrated on the central strip increasing southwards (Figure 4.49).

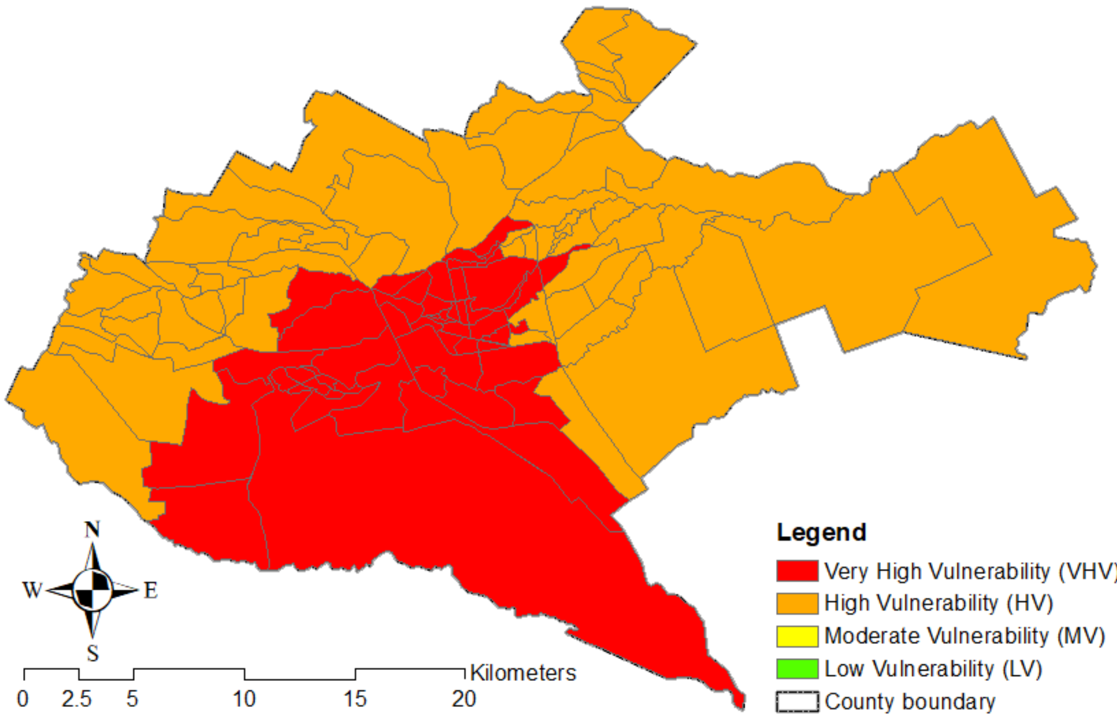


Figure 4.49: Sublocation Vulnerability based on Average annual Maximum Temperature

Nairobi exhibited low vulnerability based on Average annual minimum temperature since all the recorded averages were above the 13 °C threshold. However, the better indicator for thermal stress was the monthly extreme temperatures recorded. These are discussed next under highest annual temperature and lowest annual temperature.

Both highest annual temperature and lowest annual temperature recorded revealed three levels of vulnerability: very high vulnerability, high vulnerability, and moderate vulnerability (Table 4.38). Spatially, highest recorded temperature-based vulnerability increases as you move eastwards (Figure 4.50). On the contrary, the spatial vulnerability of lowest annual temperature increases westwards (Figure 4.51).

The city is predominantly highly vulnerable to rainfall within the context of flood risk. 64% of the sublocations in the city are highly vulnerable followed by 22% exhibiting VHV (Table 4.38). Only 2 sublocations show low vulnerability to rainfall (Figure 4.52).

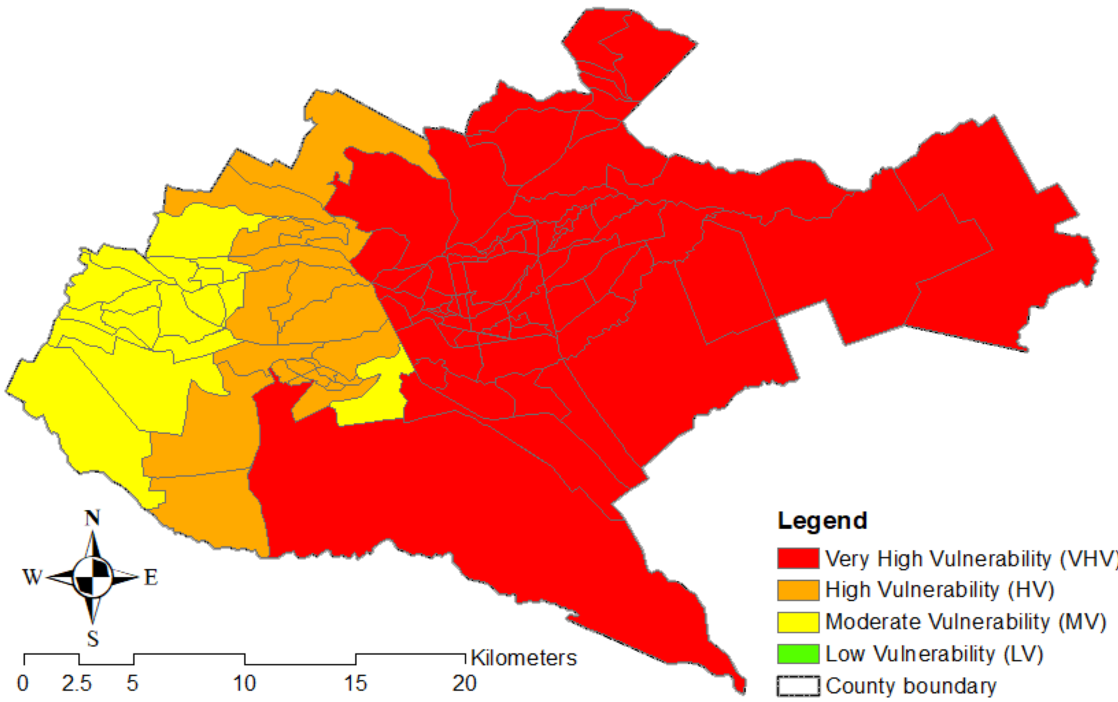


Figure 4.50: Sublocation Vulnerability based on Highest annual Temperature

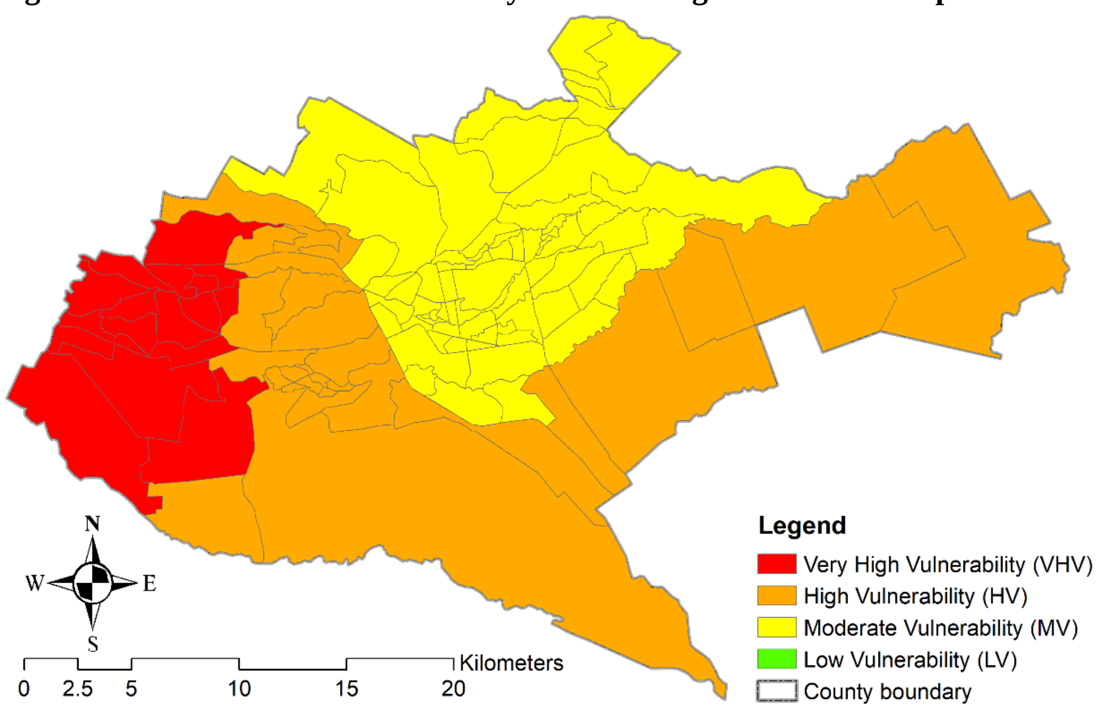


Figure 4.51: Sublocation Vulnerability based on Lowest annual Temperature

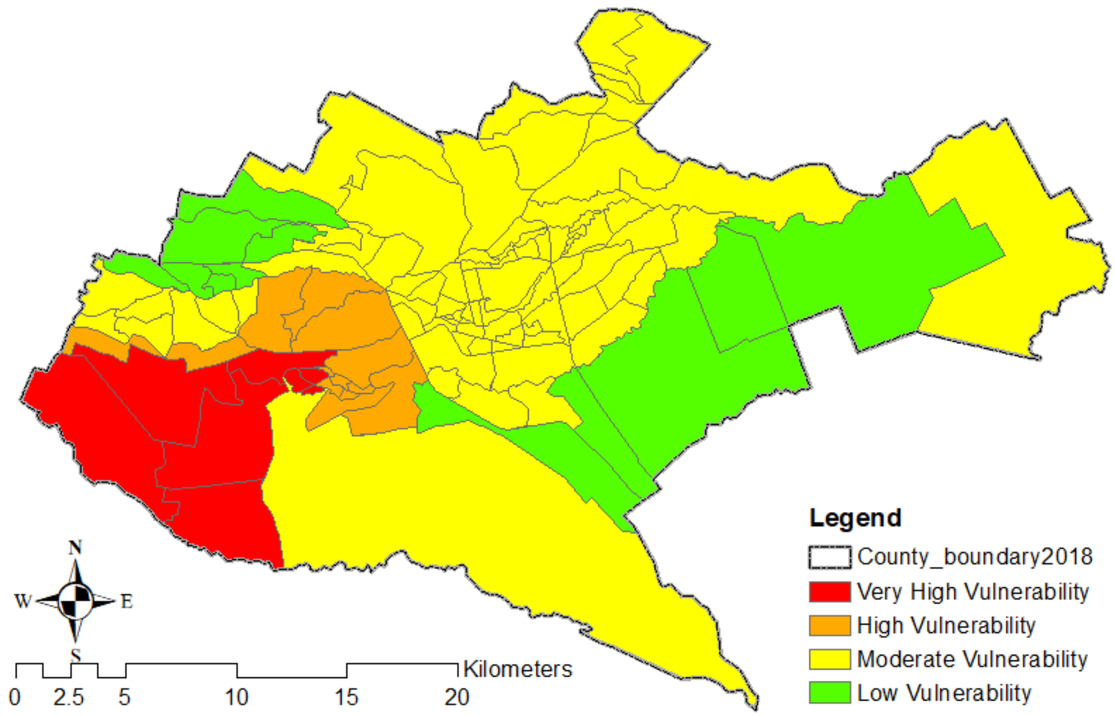


Figure 4.52: Sublocation Vulnerability based on Annual Rainfall

Modelling of the vulnerability based on socioeconomic parameters considered population density, female headed households, population above 64 years, poverty levels and access to services. The high population density means that a higher population is exposed to flood and thermal stress risk compared to low population density areas. The vulnerability scoring for population density covers all the four classes.

The sublocations reveal overall low vulnerability to socio-economic parameters with access to electricity being the lowest at 112 sublocations (Table 4.48). Unlike the rankings, spatial distributions of the vulnerabilities vary. The central zone of the city exhibited moderate vulnerabilities based on population density and the gender of the household head. This switched to the northern and southern western zone for age and poverty (Figure 4.53).

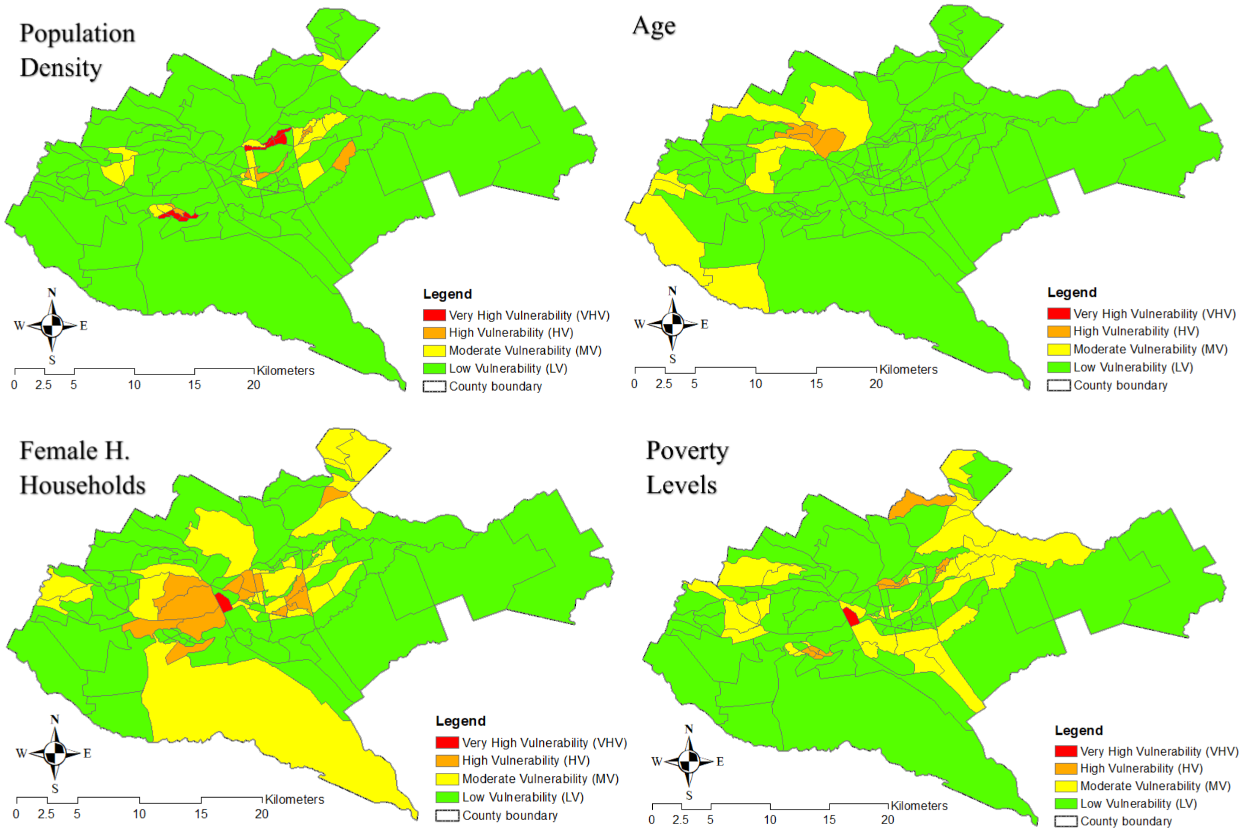


Figure 4.53: Vulnerability Based on Population Density, Age, Gender and Poverty Levels

On access to services, moderate vulnerability was concentrated on the eastern zone of the city for water. It was scattered for both sanitation and electricity access parameters. Highest vulnerability was situated on the easter side of the when analyzed based on source of water.

Access to sanitation and electricity was very good around the entire city county. As a result, a majority of the sublocations exhibited low vulnerability. Cases of moderate and high vulnerability were scattered around the city. However, clusters were noted in the central, western and eastern zones (Figure 4.54).

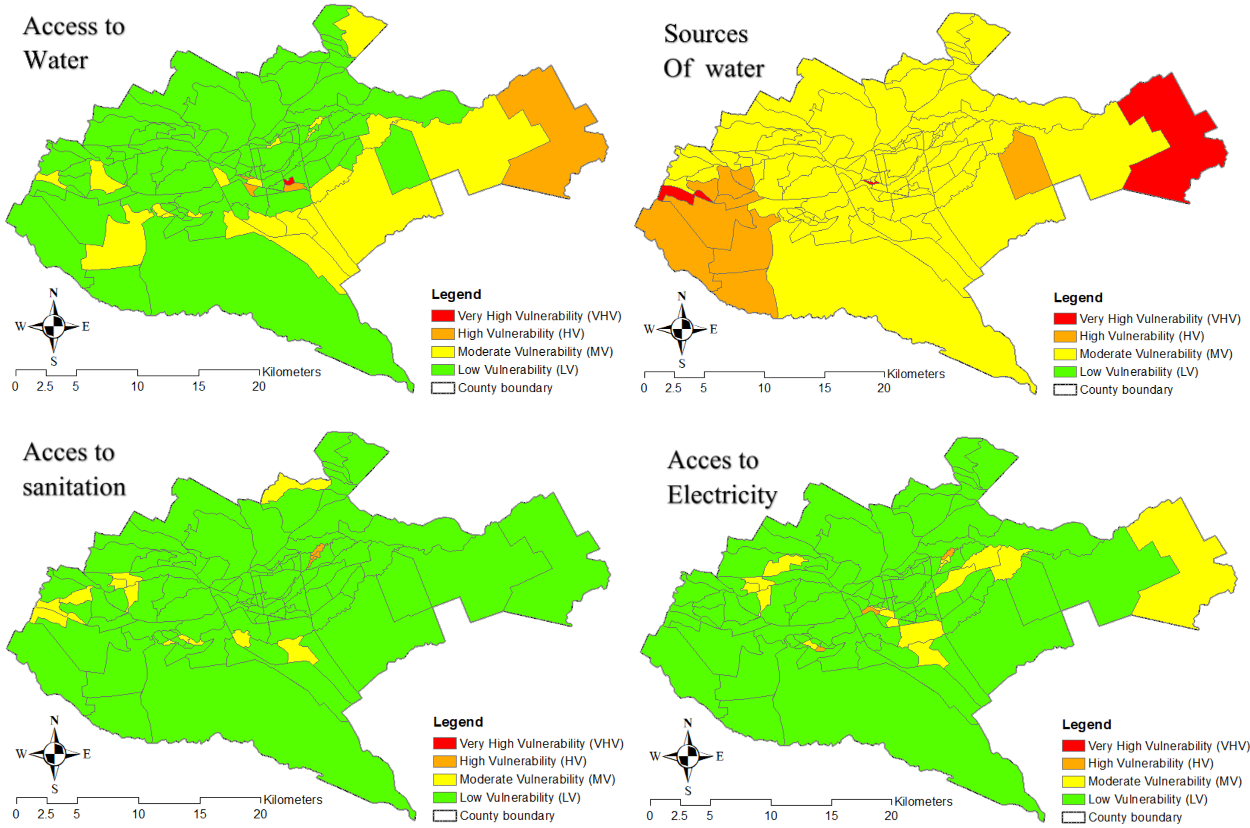


Figure 4.54: Sublocation Vulnerability Based on Access to Services

Table 4.38: Sublocation Vulnerability Levels Per Parameter

Parameter	Very High Vulnerability		High Vulnerability		Moderate Vulnerability		Low Vulnerability	
	No.	%	No.	%	No	%	No	%
Landcover	60	53.57	22	19.64	16	14.29	14	12.50
Elevation	9	8.04	61	54.46	19	16.96	23	20.54
Slope	0	0.00	0	0.00	22	19.64	90	80.36
Flow Accumulation	0	0.00	21	18.75	51	45.54	36	32.14
Soil Drainage Properties	76	67.86	3	2.68	12	10.71	21	18.75
Normalized Difference Vegetation Index	68	60.71	26	23.21	11	9.82	7	6.25
Open Space network	10	8.93	41	36.61	27	24.11	34	30.36
Avg. Monthly Maximum Temp.	52	46.43	60	53.57	0	0.00	0	0.00
Highest annual temperature	74	66.07	22	19.64	16	14.29	0	0.00
Lowest annual temperature	17	15.18	28	25.00	67	59.82	0	0.00
Rainfall	25	22.32	72	64.29	3	2.68	12	10.71
Population Density	9	8.04	7	6.25	17	15.18	79	70.54
Age above 64 years	0		3	2.68	8	7.14	101	90.18
Female headed households	1	0.89	14	12.50	28	25.00	60	53.57
Poverty levels	1	0.89	12	10.71	33	29.46	66	58.93
Access to water	0	0.00	5	4.46	20	17.86	87	77.68
Sources of water	0	0.00	3	2.68	9	8.04	100	89.29

Access to sanitation	0	0.00	3	2.68	12	10.71	97	86.61
Access to electricity	0	0.00	0		0		112	100.00

4.2.5.1 Flood Vulnerability

A regression analysis was conducted to develop the flood vulnerability model. The F and T tests were used to determine the significance of the model and parameters, respectively. Cumulatively, the urban form predictors explain 86.7% of the variance flood vulnerability (Table 4.39). The regression model was significant as F < .10 (Table 4.40). In the model, all the parameters except elevation and slope were significant as t < .10 (Table 4.41).

Table 4.39: Model Summary of Urban Form and Flood Vulnerability Regression

				Change Statistics				
R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
.931[a]	.867	.858	.39339	.867	96.895	7	104	.000

Table 4.40: ANOVA Table of Urban Form Vis a Vis Flood Vulnerability

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	104.968	7	14.995	96.895	.000[b]
	Residual	16.095	104	.155		
	Total	121.063	111			

Table 4.41: Regression Coefficients of Urban Form Vis a Vis Flood Vulnerability

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.229	.413		-2.978	.004
	Landcover	.280	.048	.290	5.826	.000
	Elevation	.052	.055	.045	.946	.347
	Slope	.087	.099	.033	.883	.379
	Flow Accumulation	.275	.059	.194	4.661	.000
	Soil Drainage Properties	.208	.037	.248	5.593	.000
	OSN	.219	.050	.186	4.383	.000
	NDVI	.274	.052	.295	5.227	.000

$$FV = .280_{l} + .052_{e} + .087_{sl} + .275_{fa} + .208_{sd} + .219_{osn} + .274_{n} \quad (5.28)$$

Where:

FV: Flood Vulnerability
l: Landcover
sl: Slope
fa: Flow Accumulation
sd: Soil Drainage properties
osn: Open space network
n: Normalized Difference Vegetation Index

The flood vulnerability map was developed based on the expert rating of the parameters. The parameters and ratings (Table 4.42). It revealed a centrally concentrated Very High Vulnerability of 36 sublocations, High Vulnerability of 33 sublocations, Moderate Vulnerability of 28 and Low Vulnerability of 14 sublocations (Table 4.43).

Table 4.42: Expert Ranking of Parameters' Contribution to Flood Vulnerability

Variables	Vulnerability Parameters	Percentage Contribution to Vulnerability
Urban form	Landcover	9.2
	Elevation	9.2
	Slope	7.7
	Flow Accumulation	9.2
	Soil Drainage Properties	7.7
	Open Space Network	9.2
	NDVI	3.1
Climate	Rainfall	10.8
Socioeconomic	Population Density	5.2
	Age	4.6
	Gender	9.2
	Poverty Levels	9.2
	Access to Water	7.7
	Access to Sanitation	9.2
	Access to Energy	6.7

Table 4.43: Flood Vulnerability Ranking of the Sublocations

Vulnerability Ranking	Sublocations	No.	%
Very High Vulnerability	California, Mbotela, Makongeni, Kaloleni, Shauri Moyo, Muthurwa, Ofafa Maringo, Lumumba, Majengo, Bondeni, Gikomba, Kamukunji, Eastleigh South, Harambee, Umoja, Mlango Kubwa, Mabatini, Mathare, Ziwani/Kariokor, Kongo Soweto, Nairobi South, Huruma, Mathare North, Mathare 4A, Kariobangi South, Dandora A, Korogocho, Nyayo, Gitathuru, City Square, Laini Saba, Silanga, Kibera, Soweto, Lindi, Gatwikira	36	32
High Vulnerability	Mihango, Eastleigh North, Ngandu, Hamza, Kimathi, Air Base, Uhuru, Pangani, Ngara East, Kiwanja, Kahawa West, Kamuthi, Githurai, Zimmerman, Savannah, Kayole, Komarock, Mukuru Kwa Njenga, South C, Land Mawe, Viwandani, Imara Daima, Hazina, Kiamaiko, Mowlem, Njiru, Saika, Dandora B, Kariobangi North, Ruaraka, City Centre, Kenyatta Golf course, Olympic, Makina	33	30
Moderate Vulnerability	Embakasi, Gatina, Gichagi, Hardy, Highridge, Kabiria, Kangemi, Kasarani, Kawangware, Kileleshwa, Kilimani, Kirigu, Langata, Maziwa, Mugumoini, Muthangari, Mwiki, Nairobi West, Ngando, Ngara West, Njathaini, Riruta, Roysambu, Ruai, Spring Valley, Upper Parklands, Utalii, Woodley	28	25
Low Vulnerability	Bomas, Garden, Karen, Karura, Kitisuru, Kyuna, Lenana, Loresho, Mountain View, Muthaiga, Mutuini, Ruthimitu, Uthiru, Waithaka	15	13

Spatially, the distribution of vulnerability levels revealed discernible patterns (Figure 4.55). Very high vulnerability is concentrated in the central zone of the city. This is surrounded by a belt of high vulnerability except for some scattered section to the extreme north and east. low vulnerability zone is located to the western and southern edges of the city.

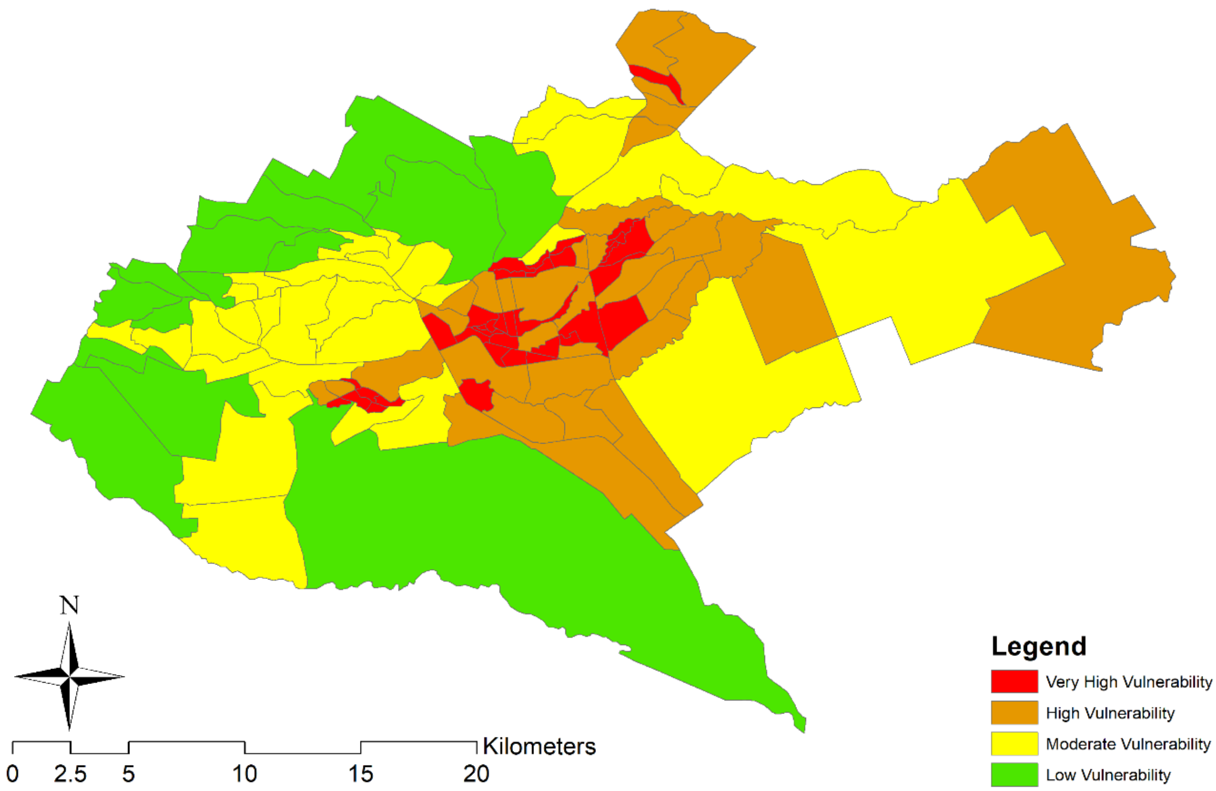


Figure 4.55: Nairobi County's Flood Vulnerability Map

4.2.5.2 Thermal Stress Vulnerability

A regression analysis was conducted to develop the flood vulnerability model. The F and T tests were used to determine the significance of the model and parameters, respectively. Cumulatively, the urban form predictors explain 78.3% of the variance in thermal stress vulnerability (Table 4.44). The regression model was significant as F < .10 (Table 4.45). In the model, all the parameters except elevation, and flow accumulation were significant as t < .10 (Table 4.46).

Table 4.44: Model Summary of Urban Form and Thermal Stress Vulnerability Regression

R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
				R Square Change	F Change	df1	df2	Sig. F Change
.885[a]	.783	.768	.42260	.783	53.528	7	104	.000

Table 4.45: ANOVA Table of Urban Form Vis a Vis Thermal Stress Vulnerability

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	66.918	7	9.560	53.528	.000[b]
	Residual	18.573	104	.179		
	Total	85.491	111			

Table 4.46: Regression Coefficients of Urban Form Vis a Vis Thermal Stress Vulnerability

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.055	.443		.123	.902
	Landcover	.384	.052	.473	7.443	.000
	Elevation	-.045	.059	-.046	-.760	.449
	Slope	.003	.106	.001	.029	.977
	Flow Accumulation	.085	.063	.071	1.338	.184
	Soil Drainage Properties	.124	.040	.175	3.092	.003
	Open Space Network	.177	.054	.179	3.291	.001
	Normalized Difference Vegetation Index	.216	.056	.276	3.830	.000

$$TSV = .384_l - .045_e + .003_{sl} + .085_{fa} + .124_{sd} + .177_{osn} + .216_n \qquad (5.29)$$

Where:

TSV: Thermal Stress Vulnerability
l: Landcover
sl: Slope
fa: Flow Accumulation
sd: Soil Drainage properties
osn: Open space network
n: Normalized Difference Vegetation Index

The heat vulnerability map was developed based on the expert rating of the parameters. The parameters and ratings (Table 4.47) resulted in the vulnerability rankings of the sublocations as shown in Table 4.48. It exhibited a centrally concentrated Very High Vulnerability of 30 sublocations, High Vulnerability of 46 sublocations, Moderate Vulnerability of 29 and Low Vulnerability of 7 sublocations.

Table 4.47: Expert Ranking of Parameters' Contribution to Heat Vulnerability

Variables	Vulnerability Parameters	Ranked contribution to vulnerability (%)
Climate	Average annual maximum temperature	8.8
	Average annual minimum temperature	8.8
	Highest annual temperature	8.8
	Lowest annual temperature	8.8
Urban Form	Landcover	7.4
	Elevation	5.0
	Slope	5.0
	Open space network	6.3
	Normalized Difference Vegetation Index	6.3
	Population Density	5.0
Socio economic	Age	7.4
	Gender	5.0
	Poverty Levels	6.3
	Access to Water	2.2
	Access to Sanitation	2.2
	Access to Energy	6.3

Spatial distribution of thermal stress vulnerability revealed three patterns (Figure 4.56). Very High Vulnerability is concentrated at the central zone of the city. High Vulnerability runs on an east-west axis with patches to the north. Moderate vulnerability is concentrated on the northern, southern, and western zones of the city.

Table 4.48: Thermal Stress Vulnerability Ranking of the Sublocations

Vulnerability Ranking	Sublocations	No	%
Very High Vulnerability	City Square, Dandora A, Eastleigh North, Eastleigh South, Gatwikira, Gitathuru, Huruma, Kaloleni, Kamukunji, Kariobangi South, Korogocho, Laini Saba, Lindi, Lumumba, Mabatini, Majengo, Makina, Makongeni, Mathare, Mathare 4a, Mathare North, Mlango Kubwa, Muthurwa, Nairobi South, Nyayo, Ofafa Maringo, Shauri Moyo, Silanga, Soweto, Ziwani/Kariokor	30	27
High Vulnerability	Air Base, Bondeni, California, City Centre, Dandora B, Embakasi, Gatina, Gikomba, Githurai, Hamza, Harambee, Hazina, Imara Daima Kahawa West, Kariobangi North, Kawangware, Kayole, Kenyatta, Golf course, Kiamaiko, Kibera, Kileleshwa, Kilimani, Kimathi, Komarock, Kongo Soweto, Land Mawe, Mbotela, Mihango, Mowlem, Mukuru Kwa Njenga, Ngandu, Ngara East, Njathaini, Njiru, Olympic, Pangani, Ruai, Ruaraka, Saika, Savannah, South C, Spring Valley, Uhuru, Umoja, Viwandani, Zimmerman	46	41
Moderate Vulnerability	Bomas, Gichagi, Hardy, Highridge, Kabiria, Kamuthi, Kangemi, Kasarani, Kirigu, Kiwanja, Kyuna, Langata, Maziwa, Mountain View, Mugumoini, Muthangari, Mutuini, Mwiki, Nairobi West, Ngando, Ngara West, Riruta, Roysambu, Ruthimitu, Upper Parklands, Utalii, Uthiru, Waithaka, Woodley.	29	26
Low Vulnerability	Garden, Karen, Karura, Kitisuru, Lenana, Loresho and Muthaiga	7	6

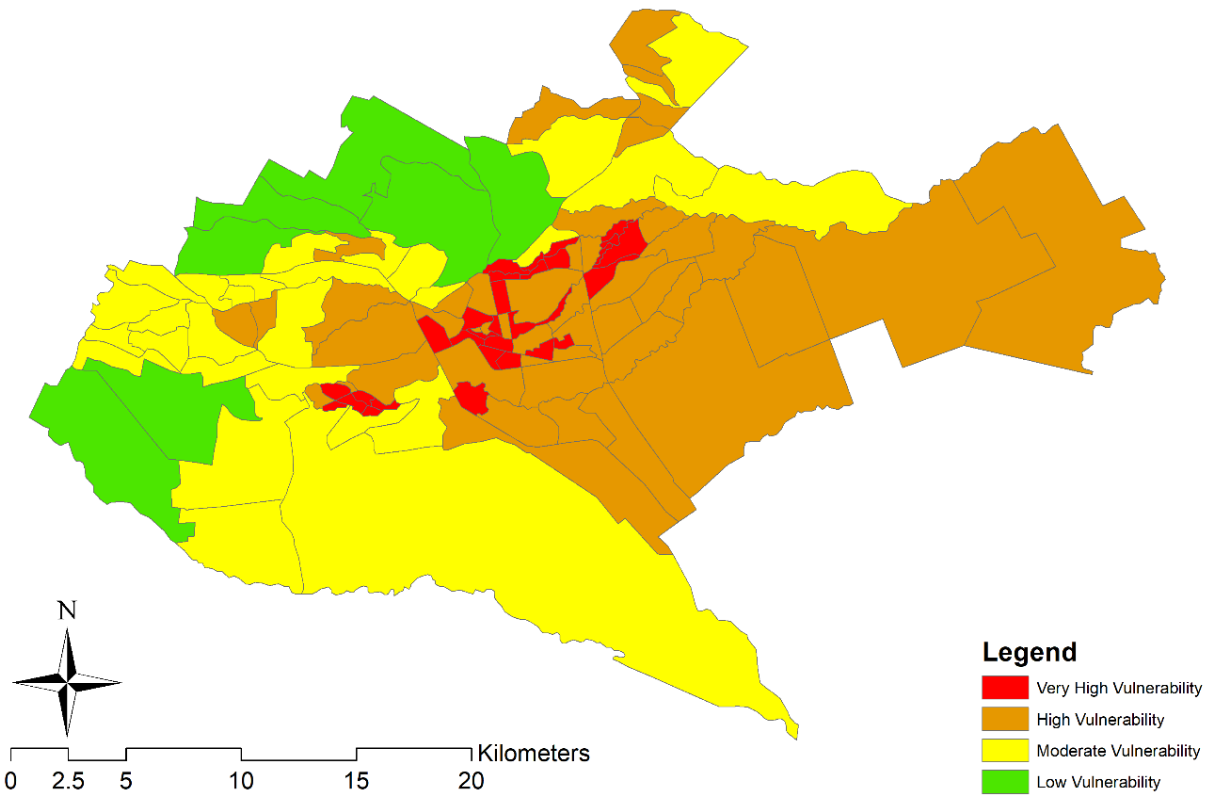


Figure 4.56: Nairobi County's Thermal Stress Vulnerability Map

4.2.5.3 Overall Vulnerability

The correlations between urban form parameters of landcover, elevation, flow accumulation, soil drainage properties, open space network and NDVI and overall vulnerability were statistically significant (Table 4.49). Cumulatively, the urban form predictors explain 97% of the variance in the vulnerability of the city to climate (Table 4.50).

Table 4.49: Correlation Matrix of Urban Form and Vulnerability

	LC	E	S	FA	SDP	OSN	NDVI	OV
Landcover	1	.476**	.101	.369**	.323**	.377**	.669**	.786**
Elevation	.476**	1	.248**	.357**	.457**	.217*	.603**	.581**
Slope	.101	.248**	1	.066	.150	-.065	.216*	.164
Flow Accumulation	.369**	.357**	.066	1	.373**	.377**	.394**	.503**
Soil Drainage Properties	.323**	.457**	.150	.373**	1	.390**	.487**	.601**
Open Space Network	.377**	.217*	-.065	.377**	.390**	1	.389**	.565**
Normalized Difference Vegetation Index	.669**	.603**	.216*	.394**	.487**	.389**	1	.780**
Overall Vulnerability	.786**	.581**	.164	.503**	.601**	.565**	.780**	1

Note: * Correlation is significant at the 0.05 level (2-tailed) and ** Correlation is significant at the 0.01 level (2-tailed).

LC is Landcover, E is Elevation, S is Slope, FA is Flow Accumulation, OSN is Open Space Network, NDVI is Normalized Difference Vegetation Index and OV is Overall Vulnerability

Table 4.50: Model Summary of Urban Form and Overall Vulnerability Regression

				Change Statistics				
R	R Square[b]	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
.985[a]	.970	.968	.40674	.970	478.066	7	105	.000

Note: a. Predictors: Normalized Difference Vegetation Index, Soil Drainage Properties, Slope, Land Use Land Cover, Open Space Network, Elevation, Flow Accumulation

Table 4.51: ANOVA Table of Urban Form Vis a Vis Overall Vulnerability

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	553.629	7	79.090	478.066	.000[c]
	Residual	17.371	105	.165		
	Total	571.000[d]	112			

The model (Equation 5.8) derived from the regression coefficients table (Table 4.52) was statistically significant at 99% confidence interval. The model was significant as F < .10 (Table 4.50). In the model, landcover, slope, soil drainage properties, open space networks and Normalized Difference vegetation Index were significant as t < .10 (Table 4.52)

Table 4.52: Regression Coefficients of Urban Form Vis a Vis Vulnerability

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	Landcover	.373	.050	.355	7.505	.000
	Elevation	.057	.056	.068	1.017	.311
	Slope	-.082	.047	-.139	-1.760	.081
	Flow Accumulation	.074	.059	.104	1.261	.210
	Soil Drainage Properties	.171	.038	.168	4.504	.000
	Open Space Network	.175	.049	.233	3.583	.001
	Normalized Difference Vegetation Index	.231	.053	.242	4.319	.000

$$CV = .373_l + 0.057_e - .082_{sl} + .074_{fa} + .171_{sd} + .175_{osn} + .231_n \qquad (5.8)$$

Where:

CV: Climate Vulnerability
l: Landcover
sl: Slope
fa: Flow Accumulation
sd: Soil Drainage properties
osn: Open space network
n: Normalized Difference Vegetation Index

The overall vulnerability was an aggregation of the flood and thermal stress vulnerability parameters on a contribution scale of 58.4% and 41.6% respectively. The experts believed that flooding contributes to vulnerability more than thermal stress. This resulted in 39 Very Highly vulnerable, 39 Highly Vulnerable sublocation and 24 Moderately vulnerable sublocations. Only 10 sublocations exhibited Low Vulnerability. The specific sublocations are displayed in Table 4.53.

Table 4.53: Overall vulnerability ranking of the sublocations

Vulnerability Ranking	Sublocations	No	%
Very High Vulnerability	Eastleigh North, California, Mbotela, Makongeni, Kaloleni, Shauri Moyo Muthurwa, Ofafa Maringo, Lumumba, Majengo, Bondeni, Gikomba, Kamukunji, Eastleigh South, Harambee, Umoja, Mlango Kubwa, Mabatini, Mathare, Ziwani/Kariokor, Kahawa West, Kongo Soweto, Nairobi South, Huruma, Mathare North, Mathare 4A, Kariobangi South, Dandora A, Korogocho, Nyayo, Gitathuru, City Square, Laini Saba, Silanga, Makina, Kibera, Soweto, Lindi, and Gatwikira	39	34
High Vulnerability	Mihango, Ruai, Ngandu, Hamza, Kimathi, Air Base, Uhuru, Embakasi, Pangani, Ngara East, Kiwanja, Kamuthi, Githurai, Zimmerman, Savannah, Kayole, Komarock, Mukuru Kwa Njenga, South C, Land Mawe, Viwandani, Imara Daima, Hazina, Njathaini, Kiamaiko, Mowlem, Njiru, Saika, Dandora B, Kariobangi North, Ruaraka, Spring Valley, City Centre, Kenyatta Golf course, Olympic, Kilimani, Kawangware, Gatina, and Kileleshwa	39	35
Moderate vulnerability	Bomas, Roysambu, Hardy, Langata, Utalii, Mwiki, Kasarani, Upper Parklands, Highridge, Ngara West, Nairobi West, Mugumoini, Uthiru, Ruthimitu, Waithaka, Kyuna, Riruta, Ngando, Maziwa, Muthangari, Gichagi, Kangemi, Mountain View and Woodley.	25	22
Low vulnerability	Garden, Karen, Karura, Muthaiga, Lenana, Mutuini, Kirigu, Kabiria, Kitisuru, Loresho	10	9

Spatially, the distribution revealed a pattern closely like the patterns of flood and thermal stress vulnerability albeit with minor differences. Very high vulnerability is concentrated in the central zone with patches to the north. Moderate vulnerability is on an east-west central belt with patches to the north. low vulnerability is concentrated in the northwestern and western edges of the city (Figure 4.57).

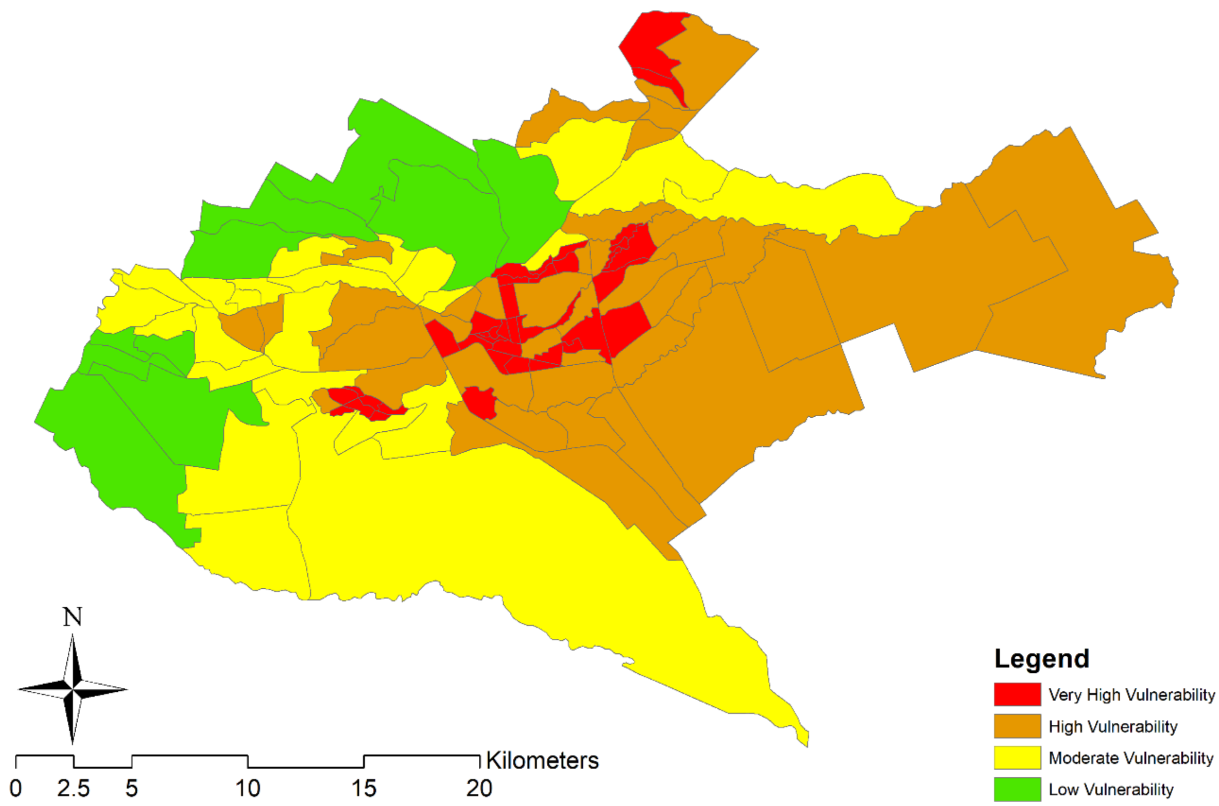


Figure 4.57: Nairobi County's Overall Vulnerability Map Based on Sublocations

All the climatic and some of the urban form parameters changed over time. These changes occurred at both weather station sublocation level and city-wide level. The urban parameters that remained static were soil drainage properties, slope, flow accumulation and elevation. Those that evolved were Built-Up Area, Forest, and Normalized Difference Vegetation Index.

Among the changing urban form parameters, built-up area increased while the forest, Open Space Networks and Normalized Difference Vegetation Index reduced between 1988 and 2018. Climatic parameters exhibited both change and variation. Average annual minimum temperature exhibited a sustained increase while the rest of the parameters exhibited variability between 1988 and 2018.

At both the city-wide and sublocation levels, there were statistically significant relationships between urban form and climate as reflected by the regression models. The urban form parameters in order of strength of relationship was Normalized Difference Vegetation Index (NDVI), Forest cover and Built-Up Area in descending order. These relationships led to different levels of vulnerability at the sublocation levels. The central, north-eastern, and eastern zones of the city that had low NDVI and forest cover and high built-up area exhibited very high vulnerability to both flooding and thermal stress. On the contrary, the north-western, and western zones that had low built-up area, high forest cover and NDVI showed low vulnerability to flooding and thermal stress.

4.3 Discussion

4.3.1 Nairobi's Urban Form Evolution

The first objective sought to analyse the evolution of urban form in Nairobi between 1988 and 2018. Five aspects emerged from the urban form evolution analysis. Nonetheless, the overarching conclusion was that Nairobi's urban form has evolved with remarkable changes in all the landcover typologies over the years.

First, the geographic elements of urban form such as soil drainage properties, elevation, and flow accumulation remained the same through the period under study. However, the evolution of other elements such as landcover affected the functionality of soils drainage properties. The changes in topography due to infrastructural developments such as roads led to flooding hotspots. This was either in the form of obstructions or alterations on the natural flow systems. One of the most affected zones was the Nairobi-Thika highway according to multiple newspaper reports on 1st December 2019 (Ruto, 2019; Wako, 2019). Therefore, these increased the vulnerability of infrastructure developments and their immediate surroundings to floods.

Second, the build environment features evolved; some in consistent patterns and others in fluctuating patterns. Built-up area increased consistently, Open Space Network and Forest reduced consistently while waterbody increased in 1998 then dropped. The increase in water bodies can be attributed to the 1998 El Niño phenomenon that led to conspicuous increase in precipitation (Reliefweb, 1998). The consistent increase in built-up area can be attributed to sustained urbanization. This translated to increased surface sealing that led to increased land surface temperatures, increased surface runoff and reduced stormwater percolation. In addition, the consistent reduction in grassland and forest covers implied reduced benefits from ecosystems services in climate amelioration. This increased the occurrence of higher land and surface temperatures and an exacerbated urban Heat Island as argued by Oke (1987).

Third, the most impacted growth zones were sublocations with informal settlements, road networks and urban forests. These sublocations exhibited the highest population densities. For instance, Silanga and Mlango Kubwa sublocations had population densities 1800% higher than the average of the city: a pattern echoed by Anyamba in NASA, (2016).

The patterns show exponential increase in built-up area along Nairobi-Thika highway and Mombasa Road, and sublocations hosting Silanga and Mlango Kubwa informal settlements. It also showed corresponding reduction in forest cover over the years. Oyugi and K'Akumu, (2007) agrees and add that together with the increasing rural-urban migration, Nairobi is experiencing urban sprawl. The sprawl followed main infrastructural arteries such as the eastern bypass, Nairobi-Thika highway, Mombasa Road and Waiyaki way.

The encroachment and uncontrolled extraction of urban forest resources into urban forests initially affected both Ngong and Karura forests as evident in Figure 4.3. This peaked in the 1995 to 2002 period (Oyugi, Odenyo, & Karanja, 2017). It contributed to the conspicuous reduction in Nairobi's vegetation cover as noted by Ogega, Wanjohi, and Mbugua (2019). In the later years (the 2018 landcover map), only Ngong forest was affected since the Kenya Forestry Service had fenced Karura forest to prevent encroachment (Kenya Forestry Service, 2014).

Reduction in forest cover reduced the city's ability to regulate the higher temperature extremes by minimizing evapotranspiration and shading ability. Its replacement by built-up area increased the impermeable surface thereby increasing the stormwater runoff. This increased the flood vulnerability in the eastern lower elevations of the city (Figure 4.55).

Fourth, the evolution of Nairobi's urban form appears to have followed the racially segregated historical planning of the city pointed out by Anyamba, (2011). For instance, the well-drained soils in the western high elevations which were zoned for white settlements majorly became low-density high-income neighbourhoods. The eastern low elevations of poorly drained zones that were demarcated as African settlements became high-density low-income neighbourhoods. As a result, the city was characterized by densely built-up areas in the central and eastern zone of the city (Figure 4.3). The densely built-up areas exhibited increasing temperature (Figure 4.56) commensurate with Chang, Saha, Castro-Lacouture, and Yang (2019) and Oke (1987) suppositions. This translated to higher thermal and flood vulnerability.

Fifth, the close relationship between some urban form elements. This relationship was reflected in the statistically significant correlations between all the changing parameters of urban form (Table 4.9). Some of the northern and southwestern patches showed low vulnerability because of an ideal balance between forest, open space, and built-up coverage (Figure 4.3). All the urban form parameters were significantly very highly correlated at 99% confidence interval. This high correlation signified the impact that any landcover changes had on all the others. In addition, it revealed the possible multiplier effect of changing any landcover on the vulnerability of the sublocations. This correlation is grounded in Gill, Handley, Ennos, and Pauliet (2007) arguments on the positive and negative impacts of changes in urban form elements.

The 2048 projections of landcover parameters of Open Space Network (OSN), population density, forest and built-up area forecast a worsening of the environmental situation in the city in a no-action scenario (Table 4.10). The increase in built-up area signifies increased surface sealing and exacerbated Urban Heat Island. Based on Lyu, Zhang, Xu, and Li,

(2018) and Palomo (2017) suppositions, the reduction in OSN and forest cover implies reduced ecosystem services derived from vegetation such as temperature amelioration and stormwater management.

4.3.2 Nairobi's Climatic Trends and Patterns

The second objective sought to evaluate the climatic trends and patterns for the city between 1988 and 2018. In general, the climatic parameter of rainfall showed variability while those of temperature showed both variability and change. The dominant changes were in the minimum values of temperature.

First, rainfall fluctuated between 1988 and 2008 and thereafter consistently increased in four of the five observed weather stations. The fluctuations between 1988 and 2008 can be attributed to the 1998 El Niño phenomenon that tremendously increased the rainfall volumes. This trend of increase from 2008 is in agreement with other projections by Ogega et al., (2019) and Giugni et al., (2015) who mention increased variability followed by marginal increase in rainfall in the East African region. This increase heightened the exposure and sensitivity elements of vulnerability with a higher probability of flooding in the latter years.

Second, the Average annual Maximum Temperature (AAT_x) showed high variability as opposed to change. Observations at the station level showed a consistent pattern of decrease and increase for all the stations except Dagoretti. The study therefore argues that there is a 10-year cyclic pattern in the AAT_x variability. The variability in the AAT_x makes it challenging to determine the overall thermal vulnerability based on this parameter alone.

Third, the Average annual Minimum Temperature (AAT_n) consistently increased between 1998 and 2018 by about 1℃. The increase in the minimum values is echoed by Makokha and Shisanya, (2010). The findings were within the projections by Giugni et al., (2015) who projects a range of 1℃ to 2℃. The notable dip in temperatures in 1993 (Figure 4.22) is a unique phenomenon since there was neither an El Niño nor La Niña phenomena. As such, other than the 1993 outlier, it can be argued that the AATn underwent change. Even though the observed change inferred an increased probability of thermal heat stress the temperature ranges still fell within Abdel-Ghany, Al-Helal, and Shady (2013), Matzarakis and Amelung (2008), Matzarakis and Mayer (1996) thermal thresholds of between 13℃ and 23℃.

Fourth, the consistent changes in Highest annual Temperature (HAT) and Lowest annual Temperature (LAT) occurred in two ways; an increase in the minimum values and increase in the ranges. The consistent increase over the 30-year period of observation can be argued to signal change and not variability. As such, the city got warmer and this increased the probability of thermal heat stress especially since the ranges here fell outside the heat stress thresholds of between 13℃ and 23℃ proposed by Abdel-Ghany, Al-Helal, and Shady (2013), Matzarakis and Amelung (2008), Matzarakis and Mayer (1996).

4.3.3 The relationship between urban form and climate in Nairobi.

The third objective sough to establish the relationship between urban form and climate. Spatial modelling revealed discernable patterns. For instance, the temperature increases in the central belt of the city, adjusting to the North-Eastern side, follows other patterns of urban form such as the increase in built-up areas, and the decrease in Normalized Difference Vegetation Index (NDVI). These correlations were also realized by Scott et al., (2017) where temperatures in the informal settlements of Kibera were higher than those at Wilson Airport weather station. Another study by Ochola et al., (2020) revealed a strong correlation between landcover and the Urban Heat Island (UHI) effect within the city.

The average annual minimum temperature exhibited a negative rate of change against Normalized Difference Vegetation Index (NDVI). As the NDVI reduced, the average annual minimum temperature increased. This finding is supported by the arguments of the role played by vegetation in temperature amelioration (Oke, 1988; Coutts, Tapper, Beringer, Loughnan, & Demuzere, 2012). Increase in built-up area was noted to correlate with the average annual minimum temperature positively; as built-up area increased, the temperature increased as well. This correlation supported the role of built-up area in influencing urban temperatures through aspects of thermal reflectivity, loading and emissivity as forwarded by Xiao, Li, and Wang, (2011). The relationship between Built-Up Areas and temperature in Nairobi agrees with Oke, Mills, Christen, and Voogt, (2017), Ningrum, (2018); and Ward, Lauf, Kleinschmit, and Endlicher, (2016) on the contribution of built-up area to high urban temperatures through surface geometry, materials and density modifications.

The regression models revealed three urban form parameters to be significant predictors of the variations in the different climatic parameters (Table 4.54). The predictors were Normalized Difference Vegetation Index (NDVI), Forest and Built-Up Area (BUA). However, the relationship between urban form and climate at the city scale is cognizant of the contributions made by regional and global climatic and geographic trends and patterns.

Table 4.54: Summary of the Urban Form Elements in the Regression Models

Sample	Climate	Normalized Difference Vegetation Index				Forest				Built-Up Area			
		2018	2008	1998	1988	2018	2008	1998	1988	2018	2008	1998	1988
At the weather station sublocation level	AATx	-	-	-	-	-	-	-	-	-	-	-	-
	AATn	-	X	-	-	-	-	-	-	-	-	-	-
	HAT	-	X	-	-	-	-	-	-	-	-	-	-
	LAT	-	X	-	-	-	-	-	-	-	-	-	-
	Rainfall	-	-	-	X	-	-	-	-	-	-	-	-
At the city-wide level of 112 sublocations	AATx	X	X	-	-	-	-	-	-	-	-	-	X
	AATn	X	X	X		-	-	X	X	-	-	-	X
	HAT	X	X	X	X	-	-	X	X	-	-	-	X
	LAT	X	X	-		-	-	X			X	-	-
	Rainfall	-	-	-	-	X	-	-	-	-	-	-	-

Note: AATx is Average annual Maximum Temperature, AATn is Average annual Minimum Temperature, HAT is Highest annual Temperature and LAT is Lowest annual Temperature

4.3.3.1 Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) is an index used to measure vegetation status and ecosystem changes (Pei et al., 2019). It emerged as the dominant predictor of the variations in the climatic parameters except rainfall. In the study, it was used to measure the availability, type, and status of vegetation. The type and status were inferred from the index based on whether the vegetation was evergreen or deciduous and in good health.

The results indicated a significant correlation between NDVI and temperature parameters of climate. This finding supports the arguments by Pei et al., (2019) and Morakinyo and Lam (2016) on the role played by vegetation in ameliorating urban climate. The amelioration is achieved through increased evapotranspiration and shading that influence the urban energy balance by reducing air and surface temperatures, respectively.

In Nairobi, these ecosystem services were compromised: the trees either shed leaves or turned brown at the dry and hot season peaks in January and February. In areas where the vegetation was either totally lacking or in a poor state, the evapotranspiration and shading abilities were reduced. Where the vegetation was present, it was either brown or had shed leaves due to the dry season thereby reducing their evapotranspiration capacities. The reduction in evapotranspiration reduced the cooling abilities.

4.3.3.2 Forest

The study demonstrates a correlation between forest and the climatic parameters of temperature and rainfall. The influence of forest on temperature parameters of average annual minimum, highest annual and lowest annual increased between 1988 and 1998. Forests did not significantly influence any climatic parameter in 2008. In 2018, it influenced rainfall. As the forest cover reduced, the average annual minimum, highest and lowest annual temperatures increased.

The influence of forests on climatic parameters in Nairobi emanates from the role played by trees in ameliorating urban temperatures through evapotranspiration and shading. This role is demonstrated by Lindén, Fonti, and Esper, (2016) in their Germany experiment where urban trees provided significant cooling. For instance, in Eastern China, a 10% increase in forest cover resulted in 0.83℃ temperature reduction (Kong, Yin, James, Hutyra, & He, 2014).

Other than the general urban cooling, urban forests are noted to be more effective in regional level cooling and climate moderation compared to other smaller open spaces (Zhang, Murray, and Turner II, 2017). This supposition can be argued as the reason the influence of forests on temperature parameters increased to 1998 then stopped. According to Oyugi, Odenyo, and Karanja, (2017) the encorachment in to the Karura and Ngong forests peaked between 1995 and 2002 and then it was controlled through forest management approaches such as fencing. This implied that post 2002, the forest cover remained moderatelly constant. As such, other parameters influenced the variations in climate.

The influence of urban forests on rainfall in 2018 is a unique situation. The influence of large forest cover on precipitation is well documented. However, the influence of urban forests on urban precipitation patterns is lacking. The other literature that doscussed urbanization and rainfall revealed that rain often falls between 20-50 Km downwind of the city (Liu & Niyogi, 2019). As sch, the scenario in Nairobi warrants further investigation.

The management of climatic challenges posed by NDVI and Forest changes major on vegetation selection and distribution. Global approaches that have been used in the management of the elements measured under the NDVI include green open space planning, careful selection and increase of street vegetation and park trees and the infusion of green roofs and walls in urban areas.

Green spaces planning and allocation needs to consider distribution and content. In the Arizona experiment, Zhang, Murray, and Turner II, (2017) argues that the distribution should favour small to medium sized green open spaces spread around the city as opposed to large, centralized ones. This ensures an even spread in the temperature regulation services of green open spaces. This position is supported by Kong, Yin, James, Hutyra, and He (2014) who studied parks in Eastern China. The green open spaces should have majority tree canopy cover. This is proposed by Middel, Chetri, and Quay (2015) who argue that it enhanced cooling by up to 0.14℃.

The City County of Nairobi has large green open spaces such as Uhuru Park, Central Park, Uhuru Gardens, Nairobi National Park and Karura Forest. These open spaces can aid in the regional cooling of the city. Nonetheless, localized cooling is lacking. Management of local level temperature and stormwater runoff should focus on clustered open spaces within the affected sublocations such as Kibera and Lindi. Nonetheless, they should be smaller scattered green open spaces with more that 50% tree cover comprising a mix of evergreen and deciduous trees (Figure 4.58).

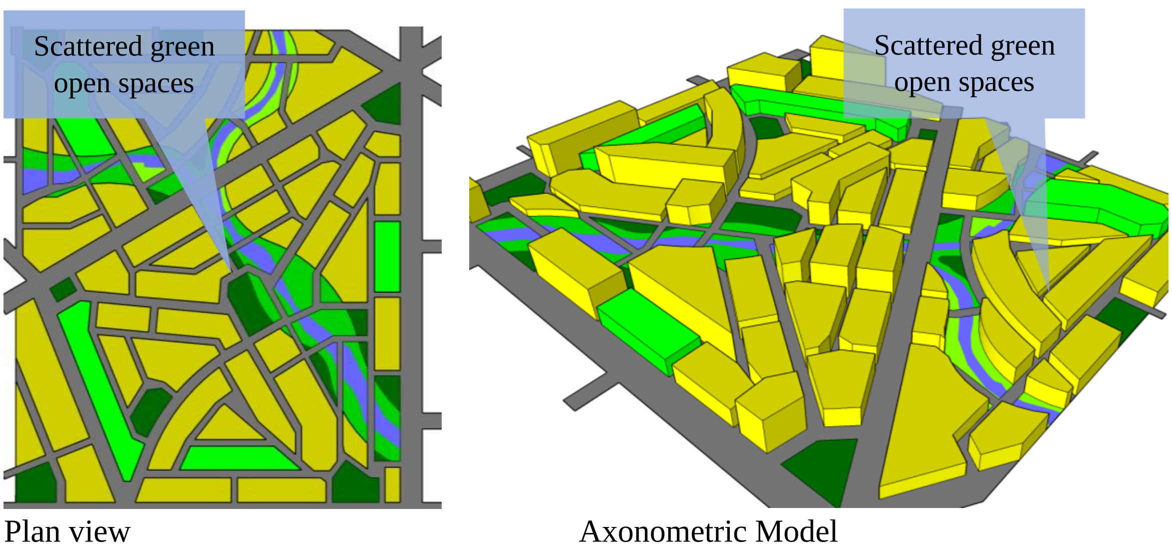


Figure 4.58: Distribution of Smaller Green Open Spaces in Flood and Thermal Stress Vulnerability Zones

Street vegetation also offers ecosystem services critical to the management of NDVI and Forest challenges recorded in Nairobi. The proposed incorporation of street vegetation as a mechanism for managing urban temperatures in Nairobi borrows from the Faro and London experiments (Kabisch, Korn, Stadler, & Bonn, 2017) . In these experiments, the street vegetation cooled distances of 400 m by up to 4℃. As such, incorporation of street vegetation (Figure 4.59) in the high and medium vulnerability sublocations in the city will supply both the shading effect and evapotranspirative cooling necessary in regulating urban temperatures.

Figure 4.59: Street Vegetation Implementation in High and Medium Density Zones

Even though the informal settlements and low-income neighbourhoods in Nairobi have extensively built-up areas and high densities, street vegetation and park trees can be incorporated. These can be implemented through the Kenya Slum Upgrading Programme and Nairobi Regeneration Program. The planning and development of these projects can incorporate street trees in infrastructural layouts and planning of neighbourhood parks and green open spaces.

The effectiveness of the street vegetation and park trees can be enhanced by using trees with short trunks and wide canopies (Kong et al., 2017). A further mix of deciduous and evergreen trees can also assist in ensuring tree canopy cover during all seasons. Further effectiveness can be achieved by linking the vegetation to water bodies (Yu, Guo, Jørgensen, & Vejre, 2017). Taking advantage of this locally will be possible primarily in informal settlements such as Kibera and Mukuru since most are near riparian areas.

4.3.3.3 Built-Up Area

The Built-Up Area (BUA) correlated with climatic parameters of temperature. It influenced the average annual maximum, average annual minimum, highest annual and lowest annual temperatures in 1988 and 2018. As the BUA increased, the temperatures of the city also increased. This analysis supports the theory that built-up areas store and conduct solar radiation and heat thereby affecting the urban temperatures and exarcebating the urban heat island effect (Oke, 1995).

The influence of the Built-Up Area (BUA) on climate was pronounced in 1988, and emerged again in 2018. This can be attributed to the concentrated density at the central zone of the city that allowed for inter station comparison. As the years progressed, sprawl occurred and therefore reduced the differences at the inter station level. However, the sharp increase in BUA between 2008 and 2018 reinforced the earlier difference noted in 1988.

Even though the BUA influence was not as pronounced as that of the Normalized Difference Vegetation Index (NDVI) and Forest, there were significantly very strong correlations at the urban form level. This interconnected nature of urban form elements implies interconnected management mechanism as well. However, an approach that is unique to the BUA element is surface albedo. It functions through changing the reflectivity of urban surfaces. This reduces the amount of heat absorbed, reducing the urban surface temperatures and the air temperatures (Wang & Akbari, 2014; Oke, 1987). It can be applied at the building and paving levels.

This is one of the cheapest ways of regulating urban temperatures since it can be as simple as painting surfaces. Informal settlements such as Korogocho, Mathare 4A, Lindi, Gatwikira and the Central Business District sublocation of City Square which are among the most vulnerable to heat can utilize this approach by painting the roofs and walls of buildings with high reflectivity colours.

A mechanism that can manage the challenges posed by NDVI, forest cover and Built-Up Area are cool roofs and walls. Cool roofs and walls can ameliorate the local temperatures and reducing stormwater surface runoff. The effectiveness depend on the typology of planting which can be either intensive or extensive (Poórová & Vranayová, 2020; Lee, Kim, & Lee, 2013; EPA, 2008a). Extensive cool roofs and walls can be applied to existing flat and low pitch roofs since they are light. Intensive cool roofs that are more effective in managing climate can be implemented in new developments with proper structural considerations.

The City's Central Business District and upcoming high-density nuclei such as Westlands and Upper Hill areas can utilize cool roofs and walls (Figure 4.60). They can be implemented alongside street vegetation. Since these locations are likely to have high densities that can limit space for green open spaces on the ground plane, the cool roofs and walls can replace the ecosystem services lost at the ground plane.

Cool roofs and walls have a cooling effect of up to 0.3°C in residential settlements (Middel, Chhetri, & Quay, 2015). Therefore they can also be implemented in medium-density medium-income neighbourhoods such as Lavington and Kileleshwa that are experiencing infill development and replacement of single dwelling units with high-rise buildings.

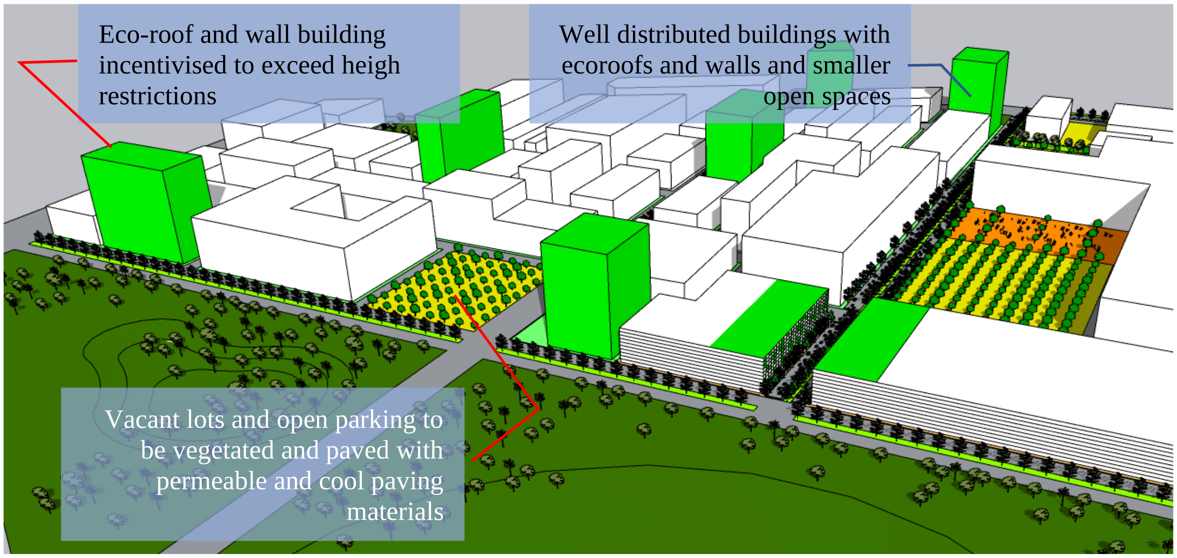


Figure 4.60: Climate Adaptation at the Building, and Open Space Levels Within High Density Neighbourhoods and the Central Business District

Cool and/ porous paving is one adaptation mechanism that can mitigate each of the vulnerabilities independently or both comprehensively. They function through albedo reduced heat loading and percolation to control heat and floods respectively (Cheshmehzangi & Butters, 2017). Their success in flood management is dependent on their location in tandem with soil drainage properties (Figure 4.61).

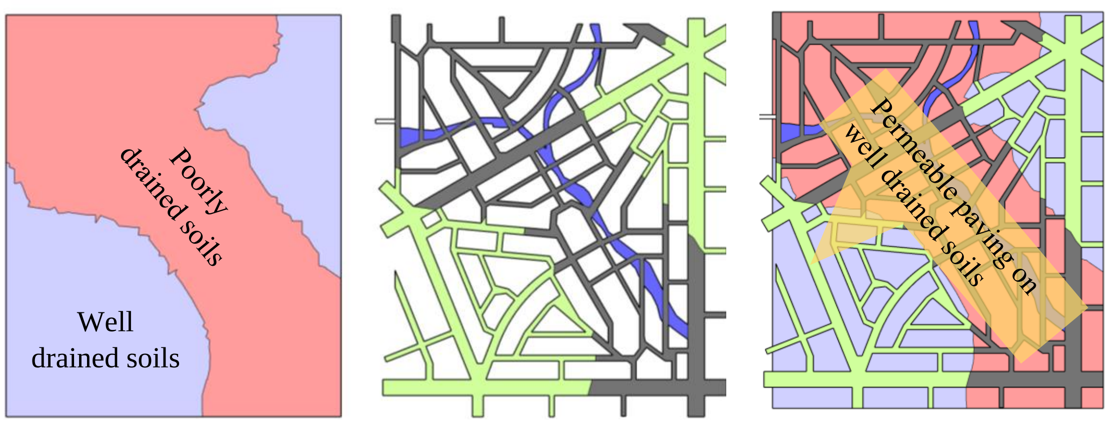


Figure 4.61: Distribution of Permeable Paving on Well Drained Soils

Cases where cool paving has been used for urban heat and runoff management include Faro in Portugal and Chicago in the USA. In Faro, they reduced urban temperatures and runoff (Noro & Lazzarin, 2015). Chicago's Green Alley Programme revealed that porous paving functioned well in reducing runoff but for it to be effective in cooling the urban areas, it needed to retain a portion of the runoff in the voids (Coseo & Larsen, 2015).

Implementation of cool and porous paving is possible in both residential neighbourhood streets and major connecting roads. Streets in low- and medium-income neighbourhoods such as Kasarani and Zimmerman are being paved and recarpeted. Similarly, there are large road infrastructure projects such as Ngong Road. Both can incorporate cool and porous paving alongside other approaches to manage urban temperatures and flooding vulnerability.

The relationship between urban form and climate creates differing vulnerability pattens from sublocation to sublocation. From the exposure parameters of temperature and rainfall, the possible vulnerabilites within the city were thermal stress and flooding.

4.3.3.4 Thermal stress and Flood Vulnerability

The thermal and flood vulnerability are not unique to the City County of Nairobi only. For instance in Asian inland cities, they are associated with built-up landcover, high urban density and low Open Space Networks (Alam, Lee, & Sawhney, 2018).

According to Di Ruocco et al., (2015), the changes in urbanization patterns and climate are influencing the spatial distribution, intensity, and frequency of climate hazards in African urban areas. This is the case in Nairobi where different sublocations show different vulnerability patterns to both thermal stress and flooding (Figure 4.55 and 5.56).

The relationship between urbanization, climate and vulnerability emanates from the landcover effects of urbanization. Built-Up Areas that replace green open spaces seal urban surfaces and increase stormwater runoff. They also increase heat loading, storage, emissivity, and reflectivity. The reduced green systems also compromise ecosystem services such as temperature amelioration (Oke, Mills, Christen, & Voogt, 2017: Ningrum, 2018; Ward, Lauf, Kleinschmit, & Endlicher, 2016).

In Nairobi, vulnerability to flooding can be attributed to landcover typology, flow accumulation characteristics, elevation, and soil drainage properties. The mostly built-up landcover impedes stormwater percolation. The disconnected flow accumulation character leads to a longer delay time before stormwater reaches drainage systems thereby heightening the flood risk. This is further exacerbated by the disconnected, inadequate, and poorly maintained drainage systems. The paved drainage systems also rush water down the watershed thereby increasing the flood risk. In cases where open spaces exist, soil drainage properties reduce the percolation rates. The lower elevations of the city function as recipients of the upper elevation stormwater runoffs that are not drained into rivers.

The case studies of the Climate Change Urban Vulnerability in Africa (CLUVA) project in Dar es Salaam pointed to flood risk related to either riverine flooding or flooding as a result of changes in landcover conversion to built-up landcover (Jalayer, De Risi, Kyessi, Mbuya, & Yonas, 2015). Nairobi exhibited similar scenarios where the most vulnerable sublocations are either the high-density informal settlements next to rivers or the extensively built-up areas such as city square sublocation.

The extremely high overall vulnerability is attributed to five aspects namely: the intensively built-up landcover, high population densities, lack of green open spaces and appropriate vegetation; poverty levels and lack of access to services. The built-up area and housing materials increase the heat loading effect. The lack of green open spaces limits the cooling effects of urban vegetation through shading and/or evapotranspiration. The poverty levels and lack of access to services minimize the residents' adaptive capacity.

The highest vulnerability in informal settlements within Nairobi is supported by Cobbinah and Addaney's (2019) argument that the current housing stock in African urban areas is created and modified informally and illegally and this enhances their vulnerability to climate-related hazards.

Flooding vulnerability can be managed by storm water infiltration, harvesting or delay (Chang, Lu, Chui, & Hartshorn, 2018; Saraswat, Kumar, & Mishra, 2016). The delay mechanisms are the same ones proposed for urban form elements. The infiltration and harvesting mechanisms include flood parks, detention ponds, bioswales, rain gardens and infiltration ponds.

Stormwater management mechanisms in Nairobi can be as varied as the characteristics of the different locations, nature of development or type of infrastructure. For instance, sublocations with poorly drained soils can focus on water harvesting and detention while those with green open spaces and well-drained soils can consider infiltration and detention (Figure 4.62).

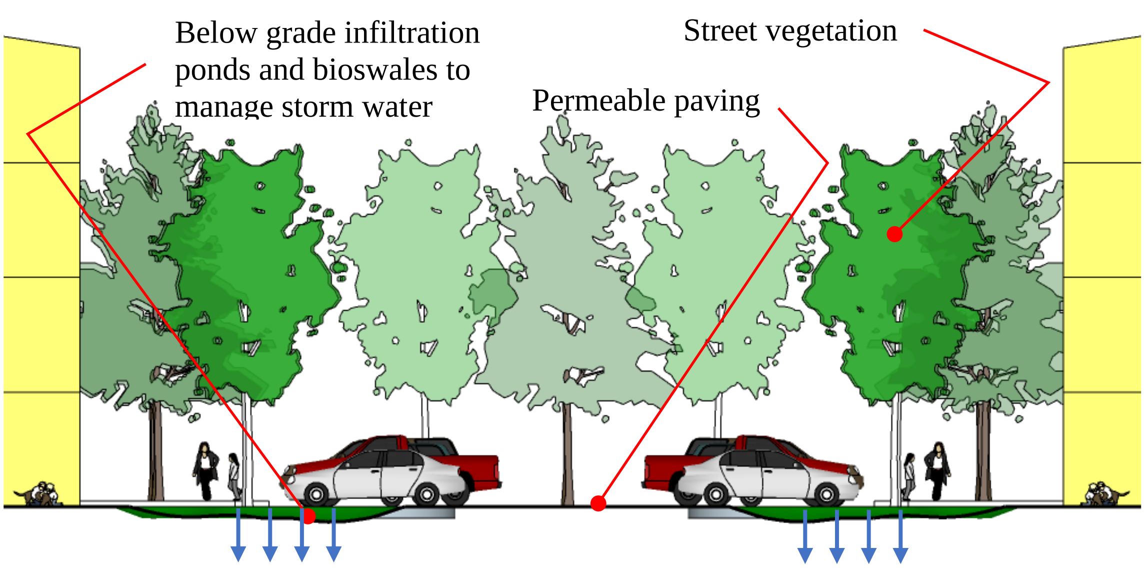


Figure 4.62: Below Grade Bioswales, Retention and Infiltration Ponds in Medium Density Neighbourhoods

Rain gardens and infiltration ponds would be most effective in zones with well-drained soils that are concentrated on the northern strip with patches to the west of the City County of Nairobi (Figure 4.63). The southern part of the city with imperfectly drained soils can utilize bioswales to control the speed of water and increase percolation time.

These mechanisms can be applied in existing and proposed projects. For instance, in existing drainage infrastructure in zones with well-drained and imperfectly drained soils, the paved drainage channels can be unpaved and planted with vegetation. Similarly, road medians strip grade can be graded lower than the road levels and used for infiltration ponds. This can also apply to the trees and other vegetated strips in high-density locations such as the city's CBD.

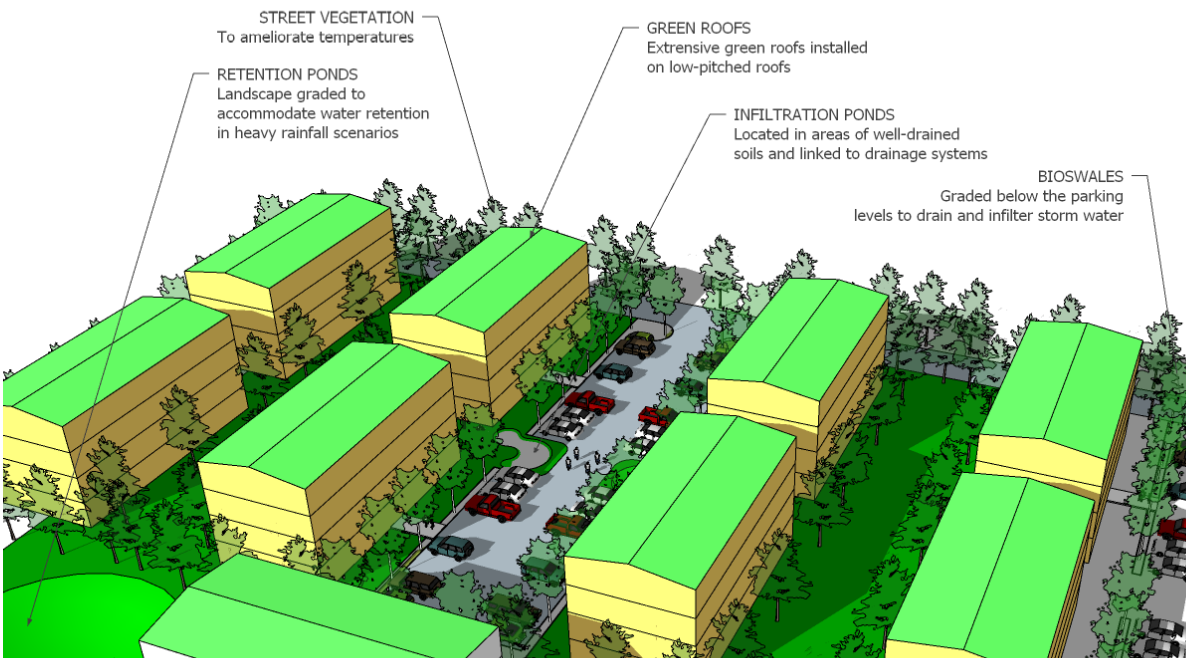


Figure 4.63: Climate Adaptation through Bioswales, Green Roofs, Retention, and Infiltration Ponds at the Medium Density Residential Neighbourhoods

Flood parks are open spaces designed to temporarily accommodate excess Stormwater alongside their normal functions such as recreation. Detention ponds function as flood parks, the difference is they are solely dedicated to flood management. They minimize flood risk in other urban spaces. In Rotterdam Netherlands for instance, the city has planned water squares in low-lying public spaces that can be used for the temporary storage of water during heavy precipitation (Rotterdam Climate Initiative, 2018).

Locally, this approach (Figure 4.64) can either be implemented in new developments or during the rehabilitation of existing urban open spaces. The city's CBD has plazas and green open spaces such as Kenyatta International Conference Centre Square and Jevanjee gardens respectively that can be redesigned and graded to become flood parks alongside their current functions. In upcoming nuclei such as Westlands and Upper Hill, the design of new open spaces can consider this concept.

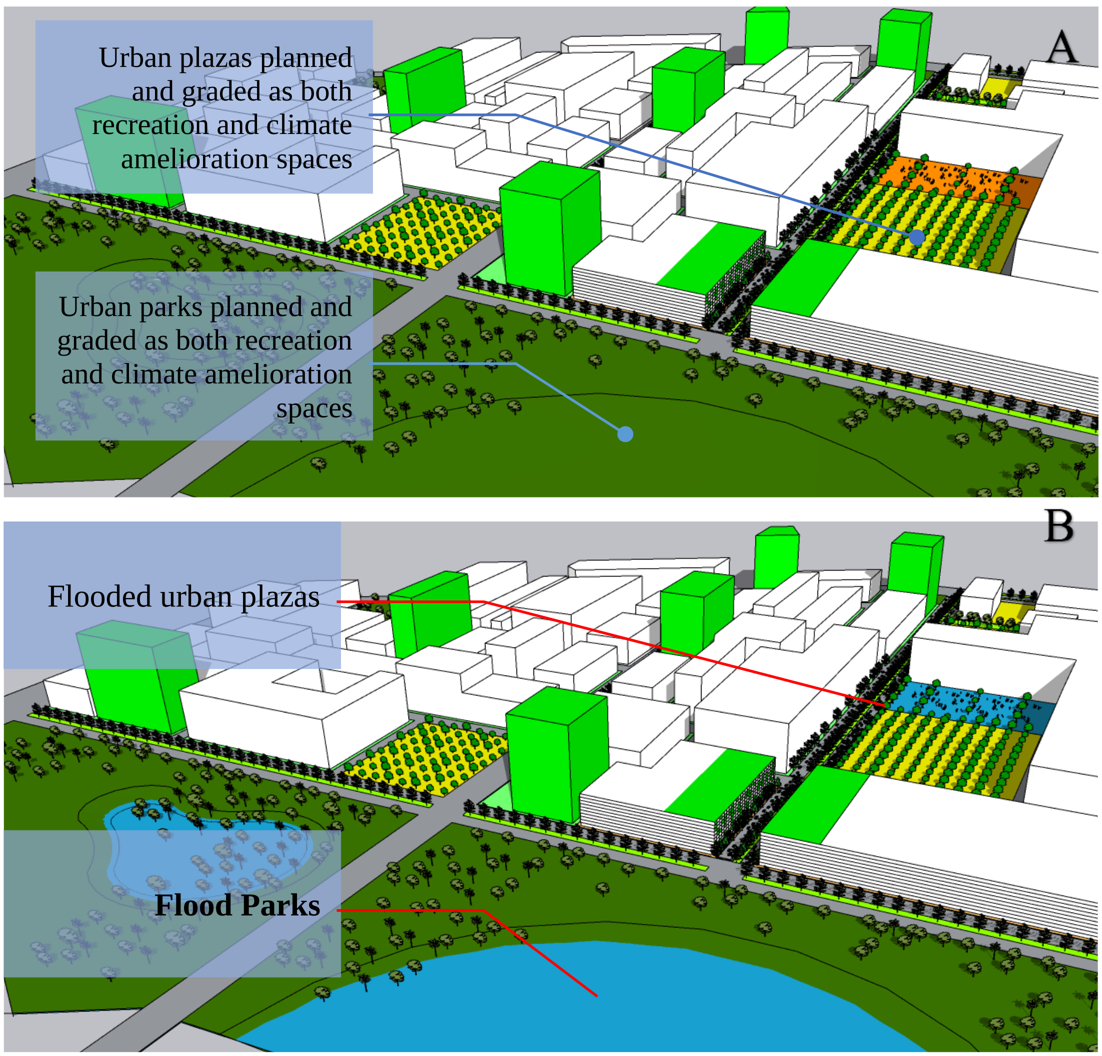


Figure 4.64: Parks and Plazas Graded Planned and Designed as Potential Flood Parks in High Rainfall Scenarios

With most of the informal settlements in Nairobi being along riparian areas, introduced flood parks can also function as recreation spaces and flood buffer zones (Figure 4.65). The utilization of river systems for flood management has been applied in cities such as Dar es Salaam, Addis Ababa, and Lilongwe (ICLEI & CBC, 2017).

Globally, stormwater harvesting has helped in the management of floods in cities such as Malmo (Sweden), Tokyo (Japan), Nanjing (China) and Ho Chi Minh City (Vietnam) (Villarreal & Bengtsson, 2004; Greater London Authority [GLA], 2015; Cheng & Wang, 2018; VCAPS Consortium, 2013). In Nairobi, Stormwater harvesting can be implemented at the city, neighbourhood, or household levels. At the citywide and neighbourhood level, planning, and design of storage spaces such as retention ponds and storage tanks can be implemented in the open spaces or under existing infrastructure, respectively. In the open spaces, the retention ponds can also function as recreation items.

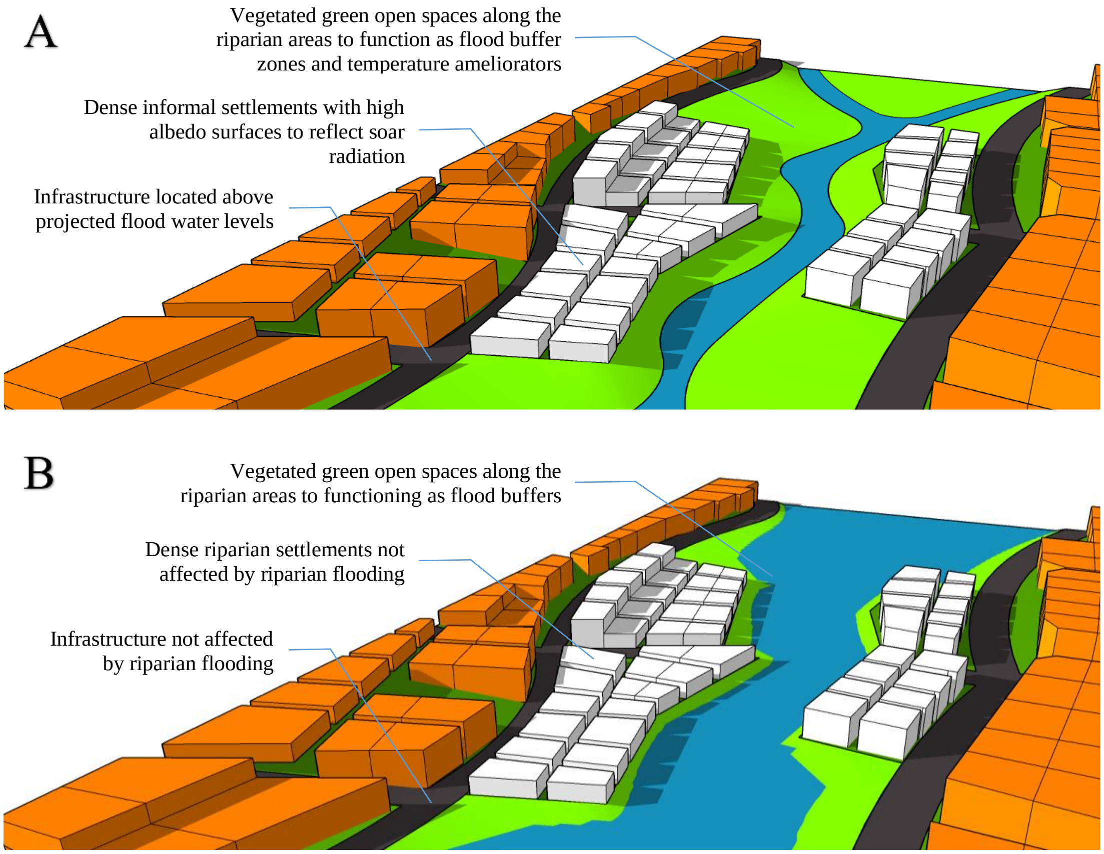


Figure 4.65: Flood and Temperature Amelioration in Dense Informal and Riparian Settlements

Nature-based solutions in managing urban climate challenges is not only clear in adaptation approaches but also the emerging urban planning and design paradigms. Landscape ecological urbanism, sustainable urban planning and green cities concept all consider incorporation of nature-based systems in the planning of the cities (Steiner, 2011; Mostafavi & Doherty, 2010; Beatley, 2012; Tratalos, Fuller, Warren, Davies, & Gaston, 2007). These nature-based solutions are not only contributing to climate change adaptation but also providing other benefits such as the creation of inclusive spaces and the addition of biodiversity to the urban environment (Kabisch et al., 2017).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter covers the conclusion and recommendations. It outlines how the objectives were addressed, the significance and implications of the study, the study's contributions, recommendations, and proposed areas for further research.

5.2 Conclusion

5.2.1 The evolution of Nairobi's urban form between 1988 and 2018

i. The City County of Nairobi's Urban form evolved between 1988 and 2018.
ii. The evolution had non-changing geographic elements such as slope, elevation, and flow accumulation.
iii. The changing elements included landcover parameters such as Built-up Area, Open Space Network, Forest, and Normalized Differential Vegetation Index.
iv. The Dominant evolution of form was evident in sublocations with informal settlements such as Kibera, Soweto, Mukuru Kwa Njenga and Mlango Kubwa.
v. Urban Sprawl followed main infrastructural developments such as the Nairobi – Thika Highway and Mombasa Road.
vi. These was a strong relationship between urban form elements. For instance, an increase in Built-Up Areas corresponded with a decrease in Open Space Networks.

5.2.2 Nairobi's Climatic Trends and Patters between 1988 and 2018

i. Nairobi's climate exhibits both variability and change.
ii. Average Annual Minimum Temperature (AAT_n), Highest Annual Temperature (HAT) and Lowest Annual Temperature (LAT) exhibited consistent change.
iii. Average Annual Minimum Temperature consistently increased by up to 1℃ between 1988 and 2018.

iv. The changes in Highest Annual Temperature and Lowest Annual Temperature manifested as increases in the lower values and ranges.

v. Average Annual Maximum Temperature exhibited variability with a 10-year cyclic pattern.

vi. The city experienced an increasing likelihood of thermal heat stress due to the changes affecting AAT_n, HAT and LAT.

vii. Rainfall fluctuated between 1988 and 2008 then marginally increased in 80% of the stations.

viii. The projected increase of 1.2℃ is in tandem with other global projections.

5.2.3 The relationship between urban form and climate in the City County of Nairobi.

i. AAT_n exhibited a negative correlation against Open Space Network (OSN) and Normalized Differential Vegetation Index (NDVI).

ii. There was a positive correlation between HAT and urban form.

iii. The LAT increased as the OSN, NDVI and Forest cover reduced.

iv. NDVI, Forest and Built-Up Area (BUA) significantly explained most of the changes in climate.

v. NDVI was the dominant explainer of the changes in climate. Followed by Forest and then BUA.

vi. Nairobi's urban form influenced both thermal and flood vulnerability.

vii. Flood and thermal vulnerability were highest at the central zone of the city.

viii. Northern and Western zones showed low flood vulnerability.

ix. Thermal stress vulnerability was highest at the central zone extending Eastwards.

x. The Extremely High Vulnerability was attributed to a climatic, biophysical, and socioeconomic parameters.

xi. Vulnerability in informal settlements was worsened by an extremely low adaptive capacity.

5.3 Significance and Implications of the Study

The study explored two aspects identified in the research gaps: medium scale management of urban climate and vulnerability in inland urban areas. In the medium scale management of climate change and variability, the study revealed that urban form elements of Normalized Difference Vegetation Index, Forest, and Built-Up Area influence climate. Therefore, the management of climate change and variability at the urban form context should adopt a nature or ecosystem-based approach. This proposal borrows from the relationships highlighted by the theoretical frameworks to exist between urban natural and human dimensions (Lynch, 1981, Jorgensen, 1997, Steward, Pickett, Burch Jr, Dalton, and Foresman 1997; Huang & Du, 2010).

The study also revealed that inland urban areas are as vulnerable to climate change as coastal urban areas. Nairobi is experiencing changes in the Average annual Minimum and Extreme Temperature values. The landcover has increased the surface sealing while the soil types have controlled runoff percolation. Combined, the parameters caused thermal and flood vulnerabilities which vary between the sublocations. The documented vulnerabilities are projected to worsen with the projected 2048 urban form and climatic scenario.

5.3.1 Theoretical Implications of the Study

The strong link the study draws between the urban form and climate supports the forwarded theory of Integrated Urban Ecosystems Theory arguments. The theory denotes the significance of natural systems in the survival of and liveability in urban areas (Steward, Pickett, Burch Jr, Dalton, and Foresman 1997; Huang & Du, 2010). This is more critical in the age of climate change which aggravates pre-existing challenges such as the Urban Heat Island. Climate change also poses new challenges such as flooding in hitherto liveable urban areas.

The world lacks global climate change vulnerability indices due to the diverse dynamics of climate and location specificity. However, climate change adaptation funding requires comparative indices and justifications. The findings of this study and vulnerability mapping provides a baseline for the development of climate change vulnerability indices for Nairobi.

5.3.2 Methodological Implications of the Study

The study contributes to three aspects of the methodology. First, the combination of qualitative and quantitative data in vulnerability assessment. Geographic Information Systems data on the assessment of the biophysical and socioeconomic parameters of vulnerability to climate change requires both quantitative and qualitative approaches. The climatic, biophysical, and socioeconomic data is quantitative. However, the determination of their magnitudes in influencing vulnerability: which cannot be equal, can only be determined qualitatively through expert and non-expert ranking.

The second aspect is the impact vulnerability assessments have on the methodology of census data collection. Vulnerability assessment is location specific and highly differentiated. For instance, national assessment can use counties as the unit of assessment. However, if the unit is reduced further to sub-counties, different vulnerability rankings can be revealed within the same county. As such, census data, which are often very comprehensive, can be collected and analysed in as small a unit as possible to enable vulnerability assessments as detailed at the building level. The type of data to be collected can also be expanded to cover information relevant for climate vulnerability analysis.

The third methodological implication is the development of vulnerability indices for the city and country. The study provides baseline data for the establishment of vulnerability indices and subsequent vulnerability assessments. Current global indices cannot be applied uniformly to all nations, cities, and locations due to differences in exposure, sensitivity, and adaptive capacity indicators.

5.3.3 Practical Implications of the Study

The broad practical implications advocate the use of ecosystem or nature-based approaches in managing climate-related challenges within inland urban areas. The main approaches target stormwater and heat management to reduce vulnerability to flooding and thermal stress events. The recommendations impact how urban renewal, regeneration, rehabilitation, and the development of new neighbourhoods in Nairobi should be undertaken to enhance Nairobi's resilience to climate change.

5.4 Recommendations

The management of the city's climate and climate vulnerability must adhere to the general tenets of Sustainable Development Goals (SDGs) 11, 13 and 15 which advocates for sustainable cities and communities, climate action and life on land (UNDESA, 2015). The three SDGs address the challenges posed by reducing Normalized Difference Vegetation Index, dwindling Forest cover, and rapidly increasing Built-Up Area.

They can be realized by reviewing urban planning and development policy to adopt nature and ecosystem-based approaches such as conservation of urban forests, parks, and street vegetation. These actions would impact the urban landcover, the greatest determinant of the interaction between climatic parameters and urban areas.

5.4.1 Strategies for Nature and Ecosystem-based Planning and Development

The first strategy is green open space planning. This should be applied in both existing and proposed developments. It involved incorporation of two scales of green open spaces: small and large scale. In existing developments, green spaces can be realized through acquisition and change from other landuses to conservation and recreation. Further articulation of the green open spaces should borrow from the second and third.

The second strategy is enhanced vegetation in the city. Policy statements should advocate for and incentivize the improvement of vegetation cover in the city. Priority should be given to tree cover. This can be implemented as urban forests, street and park trees, green roofs, and walls.

The third strategy is stormwater management. Sustainable water management practices such as rainwater harvesting, infiltration ponds, bioswales and rain gardens should be encouraged and incentivised to minimize the amount of stormwater runoff and enhance urban cooling. These should be incorporated alongside drainage system's periodic maintenance. Other urban construction materials such as cool and porous paving can also be adopted in place of current paving materials that seal urban surfaces and load heat.

The fourth strategy is expanded climatic data collection. This advocates for the establishment of climatic data collection centres in each sublocation. Such centres can be in public purpose landuses or buildings such as sub-chief's camp for ease of management.

5.4.2 Areas for Further Research

To augment this study, further investigation should be conducted on the appropriate plant species suited to offer optimum ecosystem services such as shading, cooling, and runoff regulation in Nairobi. The study also recommends further detailed study on the seasonal variability of rainfall and temperature and their impacts on flooding vulnerability in the city.

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APPENDICES

Appendix I: Questionnaire for Weighting of Vulnerability Indices

Jomo Kenyatta University of Agriculture and Technology

(JKUAT)

Centre for Urban Studies (CUSt)

Doctor of Philosophy in Urban Planning

DECLARATION: *The information obtained from this questionnaire is confidential and for academic purposes only*

Questionnaire

The Influence of Urban Form on Climate Change Vulnerability in the City County of Nairobi.

The weighting of Climate Change Vulnerability Indicators

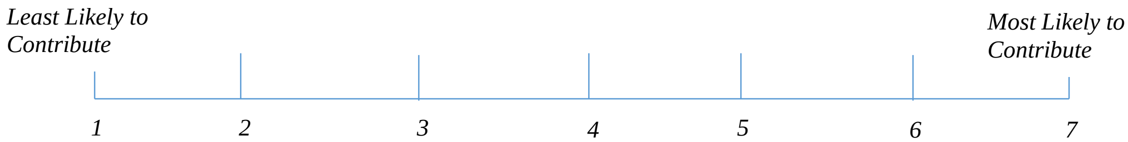
The research is seeking to establish the influence of socioeconomic and biophysical characteristics of urban form on climate change vulnerability. The projected outcome is Climate Change Vulnerability Maps for the County and a Climate Change Adaptation Framework based on the vulnerability status of the various sublocations

To this endeavour, due to your expertise in the Built Environment, you have been selected to assist in developing a weighting mechanism of the different sub variables' contribution to vulnerability. The assumption is that they do not have an equal contribution.

Section A

Part I: Sub-variables for Flood Vulnerability

Using the semantic Difference scale, rank the contribution of the following sub-variable in flood vulnerability. The Scale is as follows:

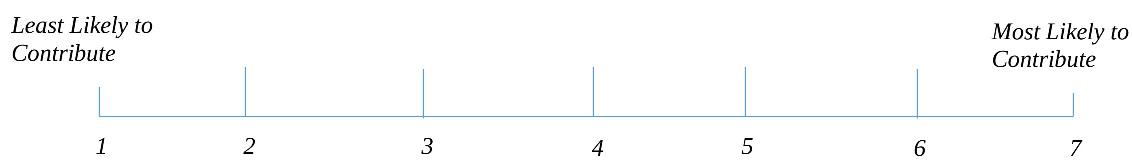


SN	Sub-Variable	Description	Weight
1	Drainage frequency	The ratio of stream number to the total area of the watershed	
2	Drainage density	The ratio of Stream (natural drains) length to the total watershed area	
3	Surface flow length	Distance travelled by water before reaching the stream	
4	Elevation	Height relative to the lowest point within the county	
5	Slope/Slope	The rate of change in the level of the ground	
6	Landcover	The type of structure, material or elements covering the surface of the earth (buildings, paved surfaces, grassland, bare ground, Forest)	
7	Rainfall volume	The average amount of rainfall that falls in one rain event	
8	Flow Accumulation	The accumulation of stormwater as it drains to natural systems	
9	Hydro-lithology	The Soil and geology characteristics that include soil texture and depth of soil	
10	Dwelling type	The material of construction of the dwelling walls and roofs	
11	Population density	Number of people living per Km2	
12	Poverty levels	Percentage of population living below the poverty line	
13	Gender distribution	Percentage of females/Males in the population/Female-headed households	
14	Age	Population below 5 years and above 65 years of age	
15	Access to clean water	Source of water for household use (piped, borehole vendors, river)	

16	Access to electric energy	Use of electric energy for lighting and cooking	
17	Access to a solid waste management system	Solid waste and sewage disposal methods available to residents	
18	Access to Health Services	Percentage of population with access to health services (clinics, health centres)	
19	Road Infrastructure	Percentage of population with access to road networks	
20	Levels of education	Percentage of the population above 25 years of age with O-level education	
21	Communication devices	Ownership of mobile phones, TV, and radio devices	

Part II Sub-variables for Heat Vulnerability

Using the semantic Difference scale, rank the contribution of the following sub-variable in heat vulnerability. The Scale is as follows:



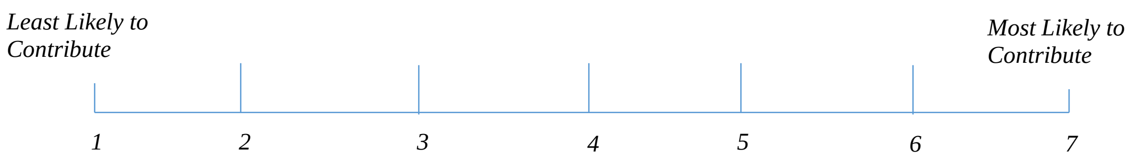
SN	Sub-Variable	Description	Weighting
1	Temperature	The average and temperature extremes	
2	Normalized vegetation Index	The quantification of vegetation using remote sensing	
3	Slope/Slope	The rate of change in the level of the ground	
4	Poverty levels/Income levels	Percentage of population living below the poverty line	
5	Landcover	The type of structure, material or elements covering the surface of the earth (buildings, paved surfaces, grassland, bare ground, Forest)	
6	Population Density	Number of people living per Km2	
7	Dwelling type	The material of construction of the dwelling walls and roofs	
8	Population density	Number of people living per Km2	
9	Poverty levels	Percentage of population living below the poverty line	
10	Gender distribution	Percentage of females/Males in the population/Female-headed households	

11	Age	Population below 5 years and above 65 years of age	
12	Access to clean water	Source of water for household use (piped, borehole vendors, river)	
13	Access to electric energy	Use of electric energy for lighting and cooking	
14	Access to a solid waste management system	Solid waste and sewage disposal methods available to residents	
15	Access to Health Services	Percentage of population with access to health services (clinics, health centres)	
16	Road Infrastructure	Percentage of population with access to road networks	
17	Levels of education	Percentage of the population above 25 years of age with O-level education	
18	Communication devices	Ownership of mobile phones, TV, and radio devices	

Section B: Aggregation of Dimensions of Vulnerability

Aggregation is the determination of the contribution by different sub-variables to the different dimensions of vulnerability.

Using the semantic Difference scale, rank the contribution of the following dimensions of vulnerability to the vulnerability of an area. The Scale is as follows:



Exposure dimension to Vulnerability This is the component of vulnerability that is linked to climate parameters and whether they are present in an area and the magnitude			
SN	**Sub-Variable**	**Description**	**Weight**
1	Flooding Risk	The potential of an area to flood	
2	Thermal stress risk	The potential of the inhabitants to experience thermal stress	

Sensitivity dimension to Vulnerability Sensitivity is the degree to which a system is affected directly or indirectly, either adversely or beneficially, by climate-related stimuli. It is viewed at the level of systems and encompasses both biophysical and social aspects.			
SN	**Sub-Variable**	**Description**	**Weight**
1	Population density	Number of people living per Km2	
2	Poverty levels	Percentage of population living below the poverty line	
3	Gender distribution	Percentage of females/Males in the population/Female-headed households	
4	Age	Population below 5 years and above 65 years of age	
5	Slope	The rate of change in the level of the ground	
6	Landcover	The type of structure, material or elements covering the surface of the earth (buildings, paved surfaces, grassland, bare ground, Forest)	
7	Hydro-lithology	The Soil and geology characteristics that include soil texture and depth of soil	
8	Drainage density	Ratio of Stream (natural drains) length to the total watershed area	
9	Surface flow length		
10	Elevation	Height relative to the lowest point within the county	
11	Flow Accumulation	The accumulation of stormwater as it drains to natural systems	
12	Dwelling Type	The material of construction of the dwelling walls and roofs	

Adaptive Capacity dimension to Vulnerability Adaptive capacity is the ability of a system to adjust to climate change.			
SN	**Sub-Variable**	**Description**	**Weight**
1	Access to clean water	Source of water for household use (piped, borehole vendors, river)	
2	Access to electric energy	Use of electric energy for lighting and cooking	
3	Access to a solid waste management system	Solid waste and sewage disposal methods available to residents	
4	Access to Health Services	Percentage of population with access to health services (clinics, health centres)	

5	Road Infrastructure	Percentage of population with access to road networks	
6	Levels of education	Percentage of the population above 25 years of age with O-level education	
7	Communication devices	Ownership of mobile phones, TV, and radio devices	
8	Poverty Levels	Percentage of population living below the poverty line	
9	Policy Frameworks	Availability of climate action policy frameworks	
10	Disaster preparedness	Availability of early warning systems and emergency services	

Appendix II: Observation Checklist for Ground Truthing

Jomo Kenyatta University of Agriculture and Technology (JKUAT)

Centre for Urban Studies (CUSt)

Doctor of Philosophy in Urban Planning

Observation Checklist for Ground Truthing

The Influence of Urban Form on Climate Change Vulnerability in the City County of Nairobi.

Using the given Global Positioning System Co-ordinates, visit the indicated locations and note the characteristics and parameters given.

		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
Soil	Clay											
	Loam											
	Sandy											
	Paved											
Altitude												
Landcover	Trees											
	Grassland											
	Water											
	Built-Up											
	Bare ground											

Appendix III: Scoring List for Vulnerability Assessment

FID	Name	AAT_x	AAT_n	HAT	LAT	Rainfall	Landcover	Elevation	Slope	Flow Accumulation	Soil Drainage Properties	Open Space Network	NDVI	Population Density	Age >65	FHH	Poverty	Access to Water	Water Source	Access to Sanitation	Access to Energy
0	Mihango	2	2	1	2	2	2	2	3	4	1	3	1	4	4	4	4	4	2	4	4
1	Ruai	2	2	1	2	4	2	1	3	4	3	4	2	4	4	4	4	3	3	4	4
2	Eastleigh North	1	2	1	3	4	1	2	4	2	1	2	2	3	4	2	4	4	3	4	4
3	California	1	2	1	3	2	1	2	4	2	1	2	2	3	4	3	4	4	3	4	4
4	Ngandu	2	2	1	2	2	2	1	4	4	3	4	1	4	4	4	4	2	1	4	3
5	Mbotela	1	2	1	3	2	1	2	3	2	1	2	1	4	4	3	4	4	3	4	4
6	Makongeni	1	2	1	3	2	1	2	4	2	1	2	1	4	4	4	4	4	3	4	3
7	Kaloleni	1	2	1	3	2	1	2	4	2	1	2	1	4	4	3	4	2	3	4	4
8	Shauri moyo	1	2	1	3	2	1	2	4	3	1	2	1	3	4	4	4	3	3	4	3
9	Muthurwa	1	2	1	3	2	1	2	4	3	1	1	2	4	4	3	4	4	3	4	2
10	Ofafa Maringo	1	2	1	3	2	1	2	3	2	1	2	1	4	4	2	4	4	3	4	4
11	Hamza	2	2	1	3	2	3	2	3	2	1	3	1	4	4	3	4	2	3	4	4
12	Lumumba	1	2	1	3	2	1	2	3	2	3	2	1	4	4	2	4	1	3	4	4
13	Majengo	1	2	1	3	2	1	2	4	2	1	3	1	2	4	3	3	4	3	4	4
14	Bondeni	1	2	1	3	2	1	2	4	2	1	3	1	3	4	3	4	4	3	4	4
15	Gikomba	1	2	1	3	2	1	2	4	2	1	2	1	4	4	4	4	4	3	4	4
16	Kamukunji	1	2	1	3	2	1	2	4	2	1	1	1	4	4	4	3	2	1	4	3
17	Kimathi	1	2	1	3	2	1	2	4	3	1	3	2	4	4	3	4	4	3	4	4
18	Eastleigh South	1	2	1	3	2	1	2	4	3	1	3	1	2	4	4	3	4	3	4	4
19	Air Base	1	2	1	3	2	2	2	4	3	1	4	2	4	4	3	4	4	3	4	4
20	Uhuru	1	2	1	3	2	1	2	4	3	1	3	1	4	4	2	4	4	3	4	4
21	Harambee	2	2	1	3	2	1	2	3	2	1	2	1	4	4	2	4	4	3	4	4
22	Bomas	1	2	1	2	2	2	2	4	4	3	4	4	4	4	3	4	4	3	4	4
23	Embakasi	2	2	1	2	3	2	2	3	4	1	4	1	4	4	4	4	3	3	4	4

FID	Name	AAT_x	AAT_n	HAT	LAT	Rainfall	Landcover	Elevation	Slope	Flow Accumulation	Soil Drainage Properties	Open Space Network	NDVI	Population Density	Age >65	FHH	Poverty	Access to Water	Water Source	Access to Sanitation	Access to Energy
24	Umoja	2	2	1	3	2	1	2	3	3	1	2	1	3	4	3	4	4	3	4	4
25	Mlango Kubwa	1	2	1	3	2	1	2	4	3	1	3	1	1	4	3	2	4	3	4	4
26	Mabatini	1	2	1	3	2	1	2	4	3	1	2	2	1	4	4	2	3	3	4	4
27	Mathare	1	2	1	3	2	1	2	4	3	1	3	1	3	4	4	2	4	3	4	4
28	Pangani	1	2	1	3	2	3	2	4	2	1	2	2	4	4	2	4	4	3	4	4
29	Ziwani/Kariokor	1	2	1	3	2	1	2	4	2	1	2	1	4	4	2	4	4	3	4	4
30	Ngara East	1	2	1	3	2	3	2	3	2	3	2	2	4	4	2	4	4	3	4	4
31	Garden	2	2	1	3	2	4	2	4	4	4	4	4	4	4	4	4	4	3	4	4
32	Roysambu	2	2	1	3	2	2	2	4	4	4	2	3	4	4	4	4	4	3	4	4
33	Kiwanja	2	2	1	3	2	2	1	4	3	1	4	2	4	4	3	4	3	3	4	4
34	Kahawa West	2	2	1	3	3	2	1	4	3	1	4	2	4	4	3	3	4	3	4	4
35	Kongo Soweto	2	2	1	3	3	1	1	3	2	1	2	2	4	4	3	4	4	3	4	4
36	Kamuthi	2	2	1	3	3	3	1	4	3	1	3	2	4	4	4	3	4	3	4	4
37	Githurai	2	2	1	3	3	3	1	4	3	1	3	1	3	4	3	3	4	3	4	4
38	Zimmerman	2	2	1	3	3	3	1	4	3	1	3	2	4	4	2	3	4	3	4	4
39	Savannah	2	2	1	3	2	1	2	3	3	3	4	2	4	4	4	3	3	3	4	4
40	Kayole	2	2	1	3	3	1	2	3	4	1	2	1	2	4	4	4	4	3	4	4
41	Komarock	2	2	1	3	3	1	2	3	3	1	4	1	4	4	3	4	4	3	4	4
42	Karen	2	1	3	1	1	4	4	4	4	4	4	4	4	3	4	4	4	2	4	4
43	Hardy	1	1	2	2	1	4	4	3	3	1	4	4	4	3	4	4	4	2	4	4
44	Langata	1	1	2	1	1	4	4	3	4	1	4	3	4	4	4	4	3	2	4	4
45	Mukuru Kwa Njenga	2	2	1	2	2	1	2	4	3	3	3	1	4	4	4	3	3	3	4	4
46	South C	1	2	1	2	2	1	2	4	2	3	4	1	4	4	4	4	3	3	4	4
47	Land Mawe	1	2	1	3	2	1	2	4	2	1	2	2	4	4	4	3	4	3	4	4
48	Viwandani	1	2	1	3	2	1	2	4	2	1	3	2	4	4	4	3	4	3	4	3
49	Imara Daima	1	2	1	3	2	1	2	4	3	3	3	1	4	4	4	3	3	3	3	3
50	Hazina	1	2	1	3	2	1	2	4	3	1	4	2	4	4	4	4	3	3	4	4

FID	Name	AAT_x	AAT_n	HAT	LAT	Rainfall	Landcover	Elevation	Slope	Flow Accumulation	Soil Drainage Properties	Open Space Network	NDVI	Population Density	Age >65	FHH	Poverty	Access to Water	Water Source	Access to Sanitation	Access to Energy
51	Nairobi South	1	2	1	3	2	1	2	4	3	1	2	1	4	4	4	3	4	3	3	4
52	Karura	2	2	2	3	2	4	3	4	4	4	4	4	4	4	4	4	4	3	4	4
53	Njathaini	2	2	1	3	2	1	2	4	3	4	4	3	4	4	4	2	4	3	3	4
54	Huruma	2	2	1	3	2	1	2	4	3	1	2	2	1	4	3	3	4	3	4	4
55	Kiamaiko	2	2	1	3	2	1	2	4	3	3	2	1	4	4	4	4	4	3	4	4
56	Utalii	1	2	1	3	2	3	2	4	2	3	3	2	4	4	4	4	4	3	4	4
57	Mathare North	2	2	1	3	2	1	2	4	2	1	2	1	1	4	4	3	4	3	4	4
58	Mathare 4a	1	2	1	3	2	1	2	4	2	1	2	1	1	4	4	2	4	3	4	4
59	Mowlem	2	2	1	3	2	1	2	3	4	1	4	1	4	4	4	3	4	3	4	3
60	Kariobangi South	1	2	1	3	2	1	2	4	3	1	2	1	3	4	3	4	4	3	4	4
61	Njiru	2	2	1	3	3	1	2	3	3	1	4	2	4	4	4	3	3	3	4	3
62	Saika	2	2	1	3	3	1	2	4	4	1	3	1	4	4	4	3	4	3	4	3
63	Mwiki	2	2	1	3	3	2	1	3	4	3	4	2	4	4	4	3	4	3	4	4
64	Dandora B	2	2	1	3	3	1	2	4	3	1	2	1	3	4	4	3	4	3	4	4
65	Dandora A	2	2	1	3	2	1	2	3	3	1	2	1	3	4	3	3	4	3	4	4
66	Korogocho	2	2	1	3	2	1	2	4	3	1	2	1	2	4	4	2	3	3	2	3
67	Nyayo	2	2	1	3	2	1	2	3	3	1	3	2	2	4	3	2	4	3	2	3
68	Gitathuru	2	2	1	3	2	1	2	3	3	1	3	2	3	4	4	2	3	3	2	2
69	Kariobangi North	2	2	1	3	2	1	2	4	3	1	2	1	3	4	4	4	4	3	4	4
70	Ruaraka	2	2	1	3	2	1	2	4	4	1	3	2	4	4	4	4	4	3	4	4
71	Kasarani	2	2	1	3	3	3	2	4	4	1	3	4	4	4	3	3	4	3	4	4
72	Muthaiga	2	2	1	3	2	4	3	4	4	4	4	4	4	3	3	4	4	3	4	4
73	Lenana	2	1	3	1	1	4	4	4	4	1	4	4	4	4	4	4	4	2	4	4
74	Mutuini	2	1	3	1	1	4	4	4	3	4	4	3	4	3	4	4	4	1	3	4
75	Kirigu	2	1	3	1	1	2	4	4	3	4	4	4	4	3	3	4	3	3	3	4
76	Kabiria	2	1	3	1	1	2	4	4	2	3	4	4	4	4	4	4	4	2	4	4
77	Kitisuru	2	1	2	2	2	4	4	4	4	4	3	4	4	3	4	4	4	3	4	4

FID	Name	AAT_x	AAT_n	HAT	LAT	Rainfall	Landcover	Elevation	Slope	Flow Accumulation	Soil Drainage Properties	Open Space Network	NDVI	Population Density	Age >65	FHH	Poverty	Access to Water	Water Source	Access to Sanitation	Access to Energy
78	Spring Valley	2	1	2	2	2	2	3	4	4	3	2	3	4	2	4	4	4	3	4	4
79	Upper Parklands	2	2	2	2	2	3	3	4	4	1	3	3	4	2	4	4	4	3	4	4
80	Highridge	2	2	1	3	2	3	3	4	4	1	2	3	4	2	4	4	4	3	4	4
81	Ngara West	1	2	1	3	2	3	3	4	3	1	3	3	4	4	4	4	4	3	4	4
82	City Centre	1	2	1	3	2	1	2	4	3	1	2	2	4	4	4	3	4	3	4	4
83	City Square	1	2	1	3	2	1	2	4	2	1	3	3	4	4	1	1	3	3	4	4
84	Nairobi West	1	2	3	2	2	3	3	4	3	1	4	2	4	4	4	4	4	3	4	4
85	Kenyatta Golf	1	2	2	2	1	2	3	4	3	1	2	3	4	4	2	4	4	3	4	4
86	Mugumoini	1	2	2	2	1	3	3	4	4	1	3	2	4	4	2	4	4	3	4	4
87	Laini Saba	1	2	2	2	1	1	3	4	3	1	1	1	1	4	4	2	3	3	3	4
88	Silanga	1	2	2	2	1	1	3	4	3	1	3	1	1	4	4	2	4	3	4	2
89	Olympic	1	1	2	2	1	4	3	4	3	1	3	1	3	4	4	3	3	3	4	4
90	Makina	1	1	2	2	1	1	3	4	4	1	2	1	3	4	4	4	4	3	4	4
91	Kibera	1	2	2	2	1	1	3	4	3	1	3	1	2	4	4	3	4	3	4	4
92	Soweto	1	2	2	2	1	1	3	4	3	1	1	1	2	4	4	2	4	3	3	4
93	Lindi	1	2	2	2	1	1	3	4	4	3	2	1	1	4	4	2	4	3	4	3
94	Gatwikira	1	2	2	2	1	1	3	4	3	1	3	2	1	4	4	3	3	3	3	4
95	Uthiru	2	1	3	1	2	2	4	4	3	4	4	4	4	4	4	3	4	3	4	4
96	Ruthimitu	2	1	3	1	2	2	4	4	4	4	4	4	4	4	3	4	4	3	4	4
97	Waithaka	2	2	3	1	2	2	4	4	4	4	4	3	4	4	3	4	4	3	3	4
98	Loresho	2	1	3	1	2	4	4	4	4	4	4	4	4	4	4	3	4	3	4	4
99	Kyuna	2	1	2	2	2	4	4	4	4	4	3	4	4	4	4	3	4	3	4	3
100	Kilimani	1	2	2	2	1	2	3	4	4	1	2	3	4	4	2	4	4	3	4	4
101	Riruta	2	1	3	1	1	2	4	4	4	4	4	3	4	4	4	3	3	2	4	4
102	Ngando	2	1	3	1	1	3	4	4	3	1	4	3	4	4	4	3	4	2	4	4
103	Kawangware	2	1	3	1	1	1	4	4	4	4	4	1	3	4	4	3	4	2	4	4
104	Gatina	2	1	3	1	1	1	4	4	4	4	4	2	3	4	4	3	4	3	3	3

FID	Name	AAT_x	AAT_n	HAT	LAT	Rainfall	Landcover	Elevation	Slope	Flow Accumulation	Soil Drainage Properties	Open Space Network	NDVI	Population Density	Age >65	FHH	Poverty	Access to Water	Water Source	Access to Sanitation	Access to Energy
105	Maziwa	2	1	2	2	1	2	4	4	4	4	2	4	4	3	3	4	4	3	4	4
106	Muthangari	2	1	2	2	2	4	4	4	3	1	2	4	4	3	3	4	4	3	4	4
107	Gichagi	2	1	3	1	2	3	4	4	3	4	2	3	4	4	4	4	4	3	3	3
108	Kangemi	2	1	3	1	2	3	4	4	4	4	3	2	3	4	4	4	4	3	3	3
109	Mountain View	2	1	3	1	2	2	4	4	3	4	3	4	4	4	4	4	4	3	4	4
110	Kileleshwa	1	1	2	2	1	2	3	4	4	1	3	4	4	4	2	4	4	3	4	4
111	Woodley	1	1	2	2	1	4	4	4	3	1	3	4	4	4	2	4	4	3	4	4

Legend for Parameters

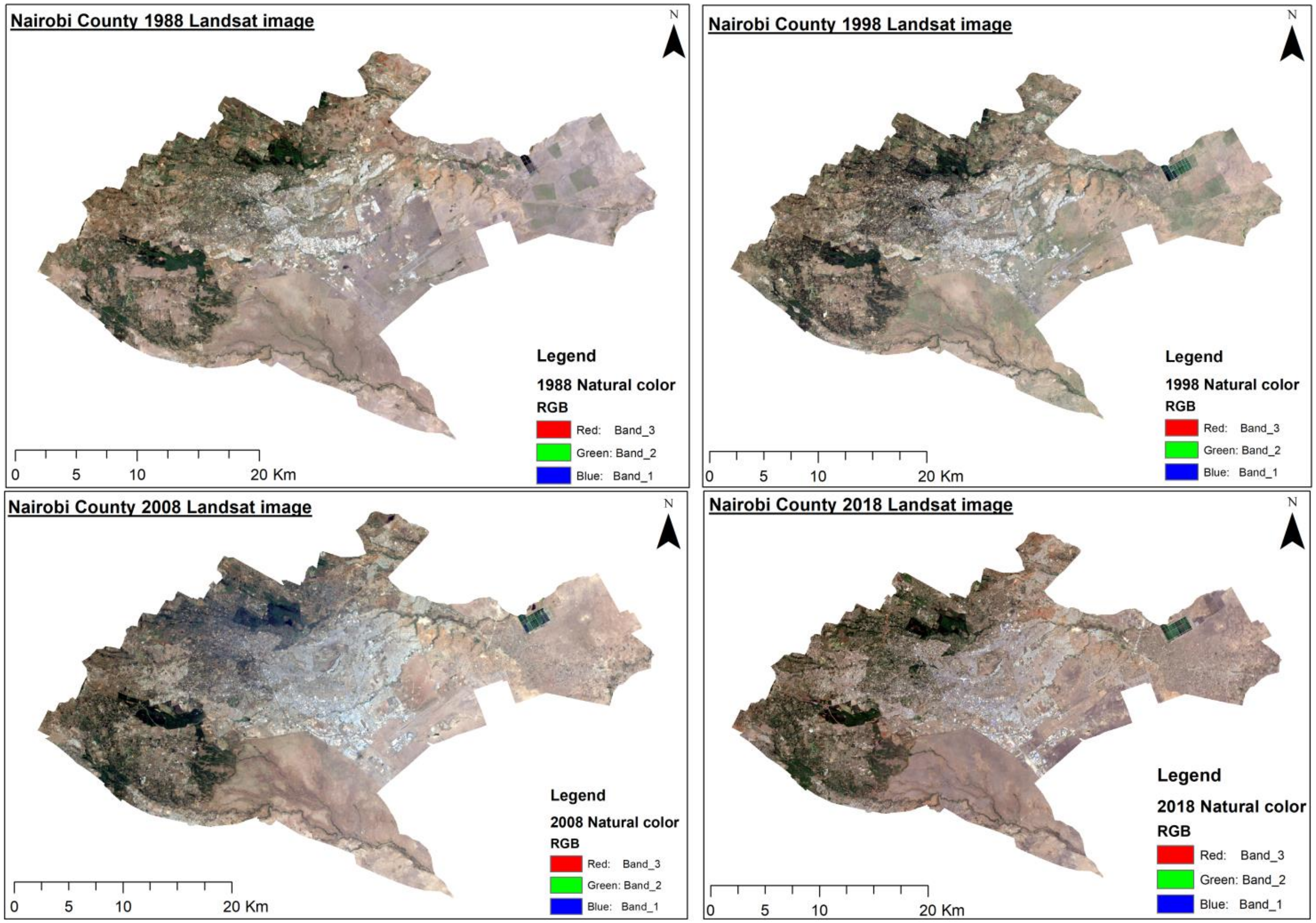
AAT_x	Average annual Maximum Temperature
AAT_n	Average annual Minimum Temperature
HAT	Highest annual Temperature
LAT	Lowest annual Temperature
NDVI	Normalized Difference Vegetation Index
FHH	Female-headed Households

Appendix IV: Expert Ranking of Vulnerability Indicators

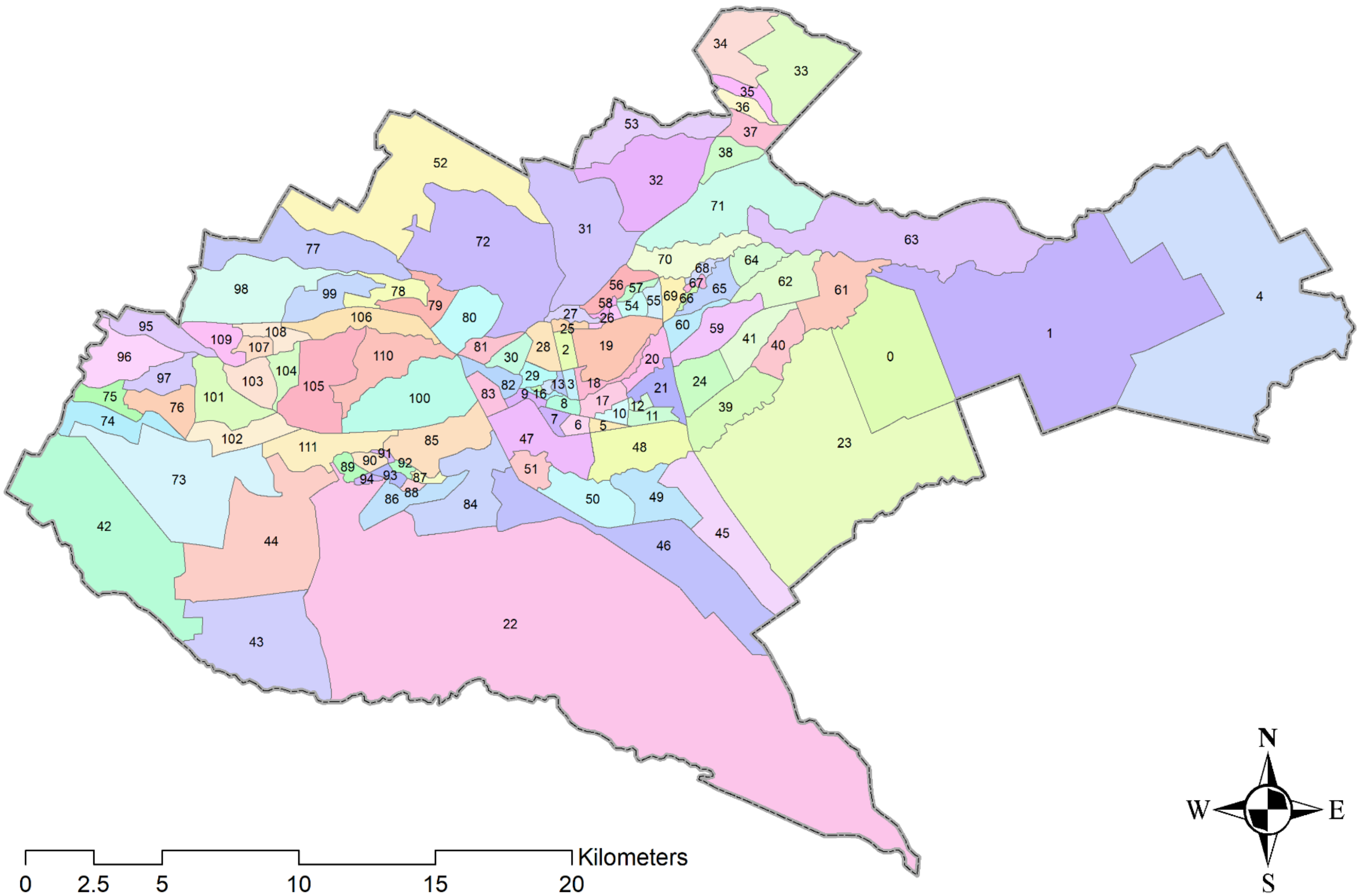
Vulnerability Type	Parameters	Expert Responses												Mean
		A	B	C	D	E	F	G	H	I	J	K	L	
Flood vulnerability	Elevation	5	6	6	5	7	6	6	7	5	7	7	6	6.08
	Slope	5	5	5	5	5	6	7	5	5	6	6	7	5.58
	Landcover	6	7	7	4	6	6	7	6	4	7	7	7	6.17
	Rainfall volume	7	6	6	6	7	6	7	7	6	7	7	7	6.58
	Flow Accumulation	7	6	7	5	7	5	7	7	5	6	6	6	6.17
	Soil drainage Properties	5	4	6	5	4	6	7	4	5	6	6	6	5.33
	Population density	4	5	2	5	3	5	4	3	5	2	2	5	3.75
	Poverty levels	4	4	2	5	3	6	5	3	5	5	5	5	4.33
	Female headed households	2	5	3	2	1	6	3	1	2	5	3	1	2.83
	Age >65	3	2	3	2	2	7	5	2	2	6	5	2	3.42
	Access to clean water	3	2	2	2	2	1	4	2	2	6	6	3	2.92
	Access to electric energy	3	4	4	2	3	5	4	3	2	4	4	1	3.25
	Access to solid waste management	5	3	5	5	3	3	4	3	5	6	6	4	4.33
Heat Vulnerability	Temperature	7	7	7	4	4	6	7	4	7	7	6	6	6.00
	Normalized Difference Vegetation Index	7	6	4	4	3	6	6	3	4	6	6	6	5.08

Vulnerability Type	Parameters	Expert Responses												Mean
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	
	Slope	6	3	4	4	5	6	6	5	4	1	3	4	4.25
	Landcover	6	5	6	4	5	6	5	5	6	6	6	6	5.50
	Population Density	7	5	4	2	4	6	5	4	4	1	3	4	4.08
	Poverty levels	5	5	3	5	7	7	6	7	3	6	6	6	5.50
	Female headed households	4	4	2	2	5	4	5	5	2	6	3	2	3.67
	Age > 65	4	6	4	2	7	6	6	7	5	6	1	1	4.58
	Access to clean water	3	5	1	3	6	2	6	6	1	2	2	2	3.25
	Access to electric energy	5	4	3	4	5	6	5	5	4	2	3	3	4.08
	Access to solid waste	4	4	2	5	4	3	3	4	2	1	1	1	2.83

Appendix V: Nairobi County Landsat Images



Appendix VI: Map of Sublocations in Nairobi County as per the 2009 Population and Housing Census



Appendix VII: Legend to the Sublocations Map

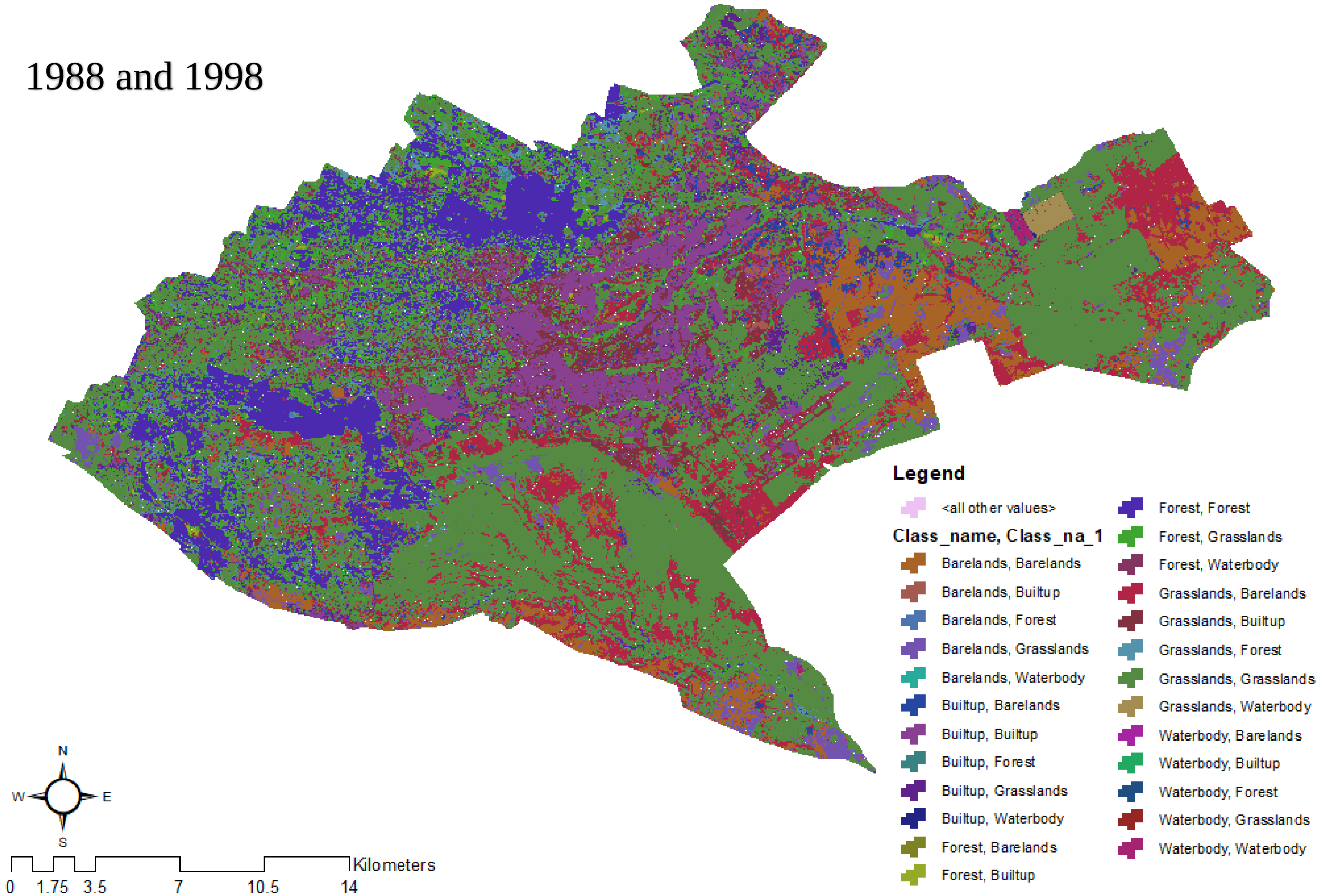
No.	Sublocation
0	Mihango
1	Ruai
2	Eastleigh north
3	California
4	Ngandu
5	Mbotela
6	Makongeni
7	Kaloleni
8	Shauri moyo
9	Muthurwa
10	Ofafa Maringo
11	Hamza
12	Lumumba
13	Majengo
14	Bondeni
15	Gikomba
16	Kamukunji
17	Kimathi
18	Eastleigh south
19	Air base
21	Uhuru
22	Harambee
23	Bomas
24	Embakasi
25	Umoja
26	Mlango Kubwa
27	Mabatini
28	Mathare
29	Pangani

No.	Sublocation
30	Ziwani/Kariokor
31	Ngara east
32	Garden
33	Roysambu
34	Kiwanja
35	Kahawa west
36	Kongo Soweto
37	Kamuthi
38	Githurai
39	Zimmerman
40	Savannah
41	Kayole
42	Komarock
43	Karen
44	Hardy
45	Langata
46	Mukuru kwa Njenga
47	South c
48	Land Mawe
49	Viwandani
50	Imara Daima
51	Hazina
52	Nairobi south
53	Karura
54	Njathaini
55	Huruma
56	Kiamaiko
57	Utalii

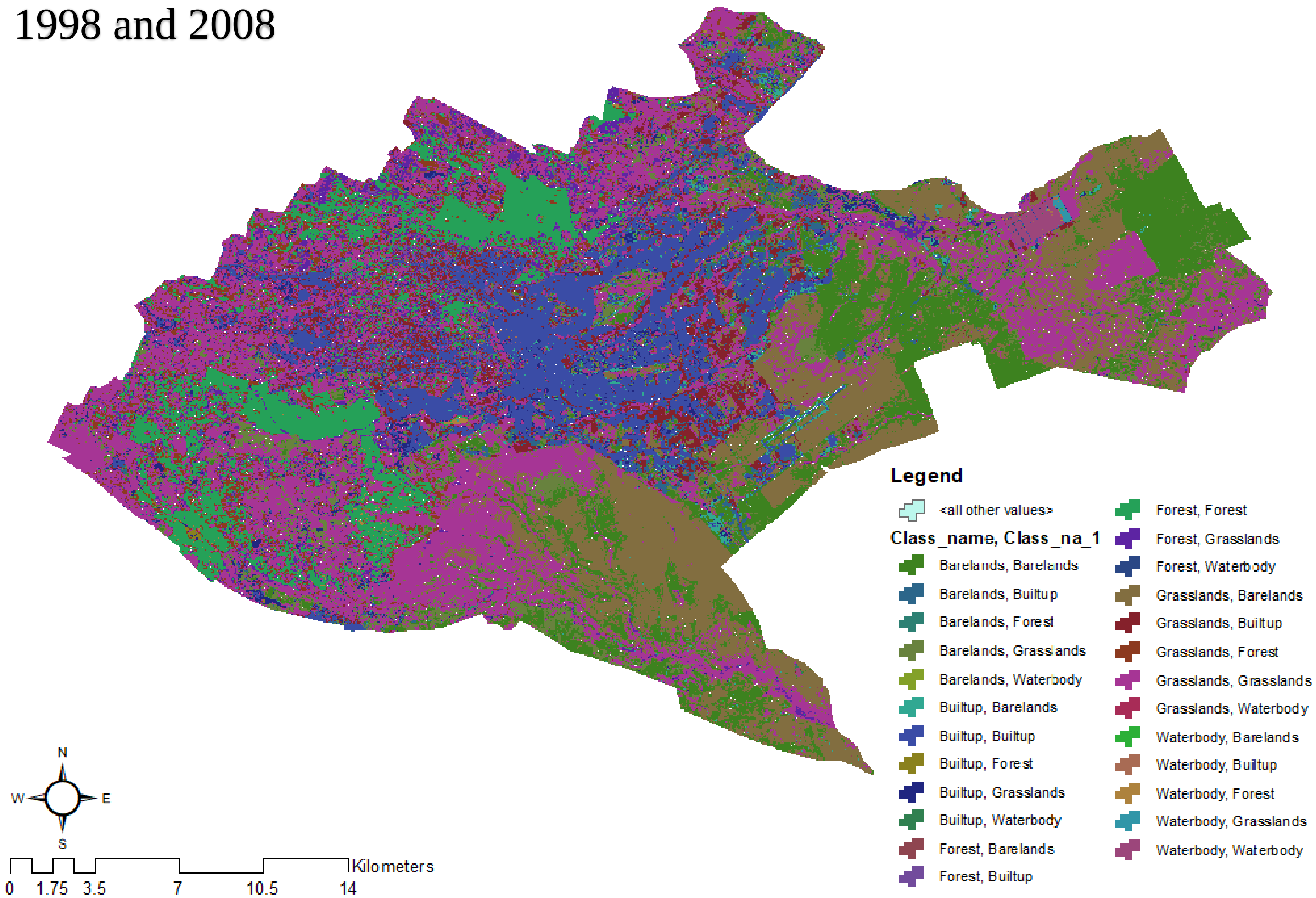
No.	Sublocation
58	Mathare north
59	Mathare 4a
60	Mowlem
61	Kariobangi south
62	Njiru
63	Saika
64	Mwiki
65	Dandora b
66	Dandora a
67	Korogocho
68	Nyayo
69	Gitathuru
70	Kariobangi north
71	Ruaraka
72	Kasarani
73	Muthaiga
74	Lenana
75	Mutuini
76	Kirigu
77	Kabiria
78	Kitisuru
79	Spring valley
80	Upper parklands
81	Highridge
82	Ngara west
83	City centre
84	City square
85	Nairobi west
86	Kenyatta/ Golf C

No.	Sublocation
87	Mugumoini
88	Laini Saba
89	Silanga
90	Olympic
91	Makina
92	Kibera
93	Soweto
94	Lindi
95	Gatwikira
96	Uthiru
97	Ruthimitu
98	Waithaka
99	Loresho
100	Kyuna
101	Kilimani
102	Riruta
103	Ngando
104	Kawangware
105	Gatina
106	Maziwa
107	Muthangari
108	Gichagi
109	Kangemi
110	Mountain view
111	Kileleshwa
112	Woodley

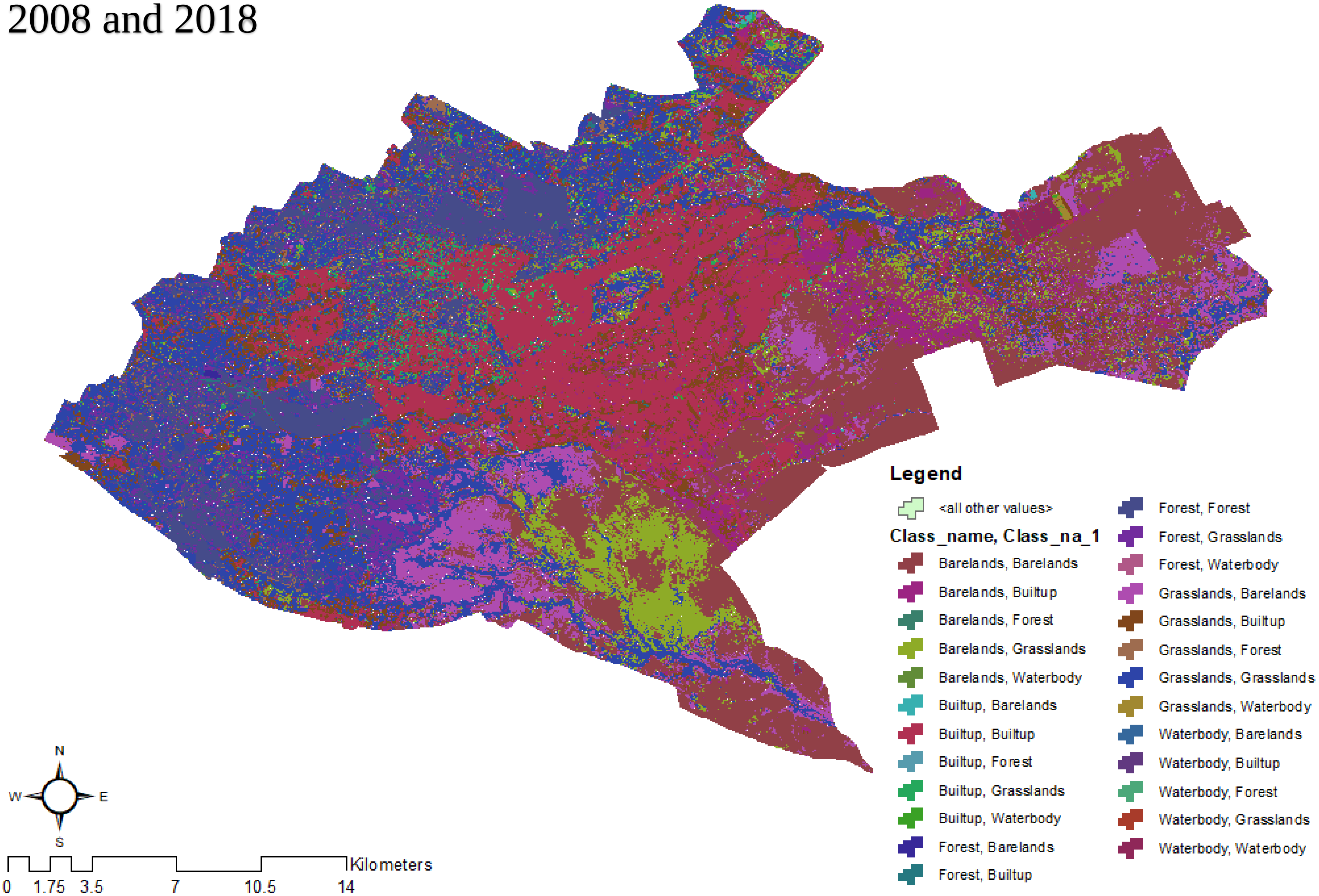
Appendix VIII: Landcover Change Detection between 1988 and 2018



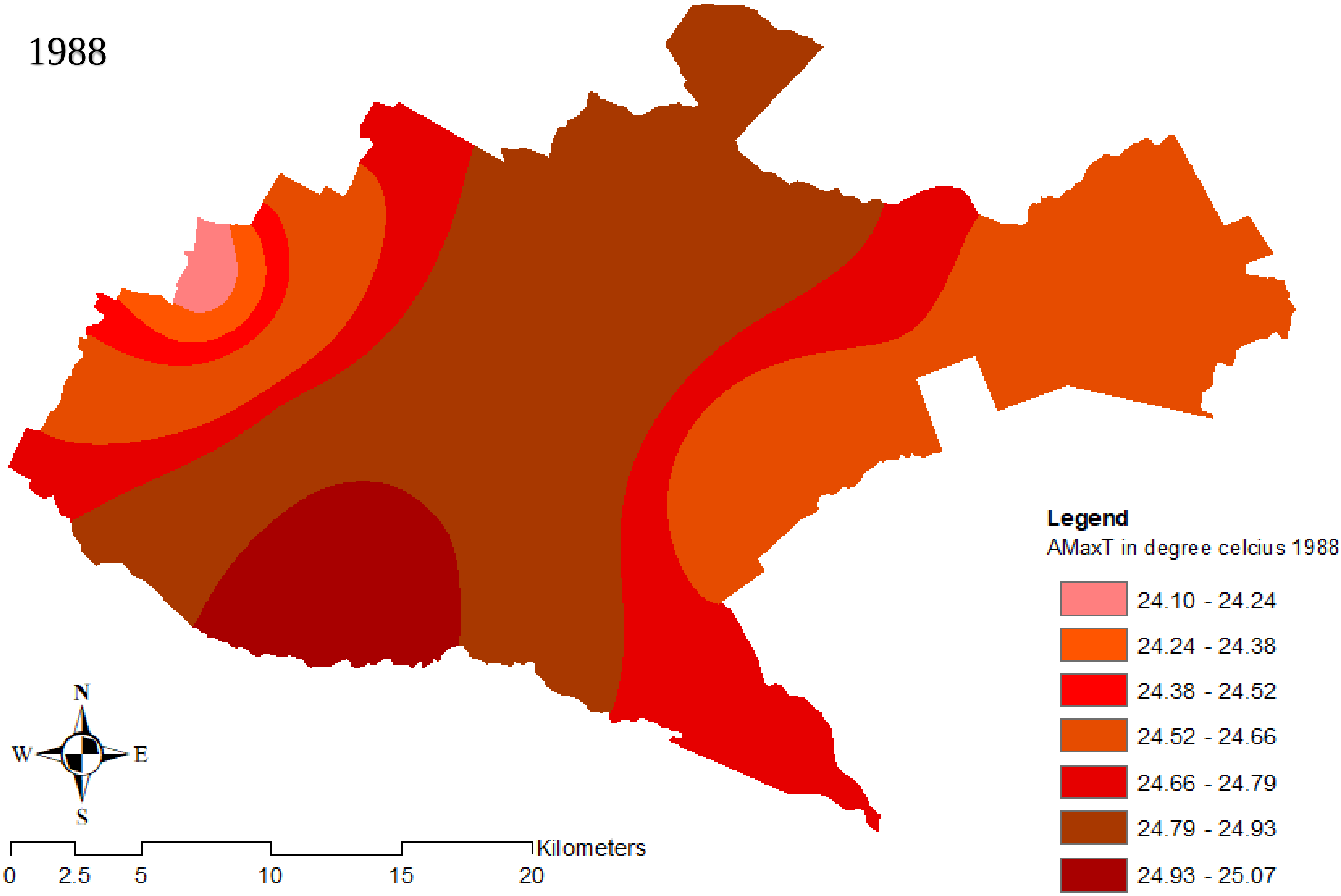
1998 and 2008

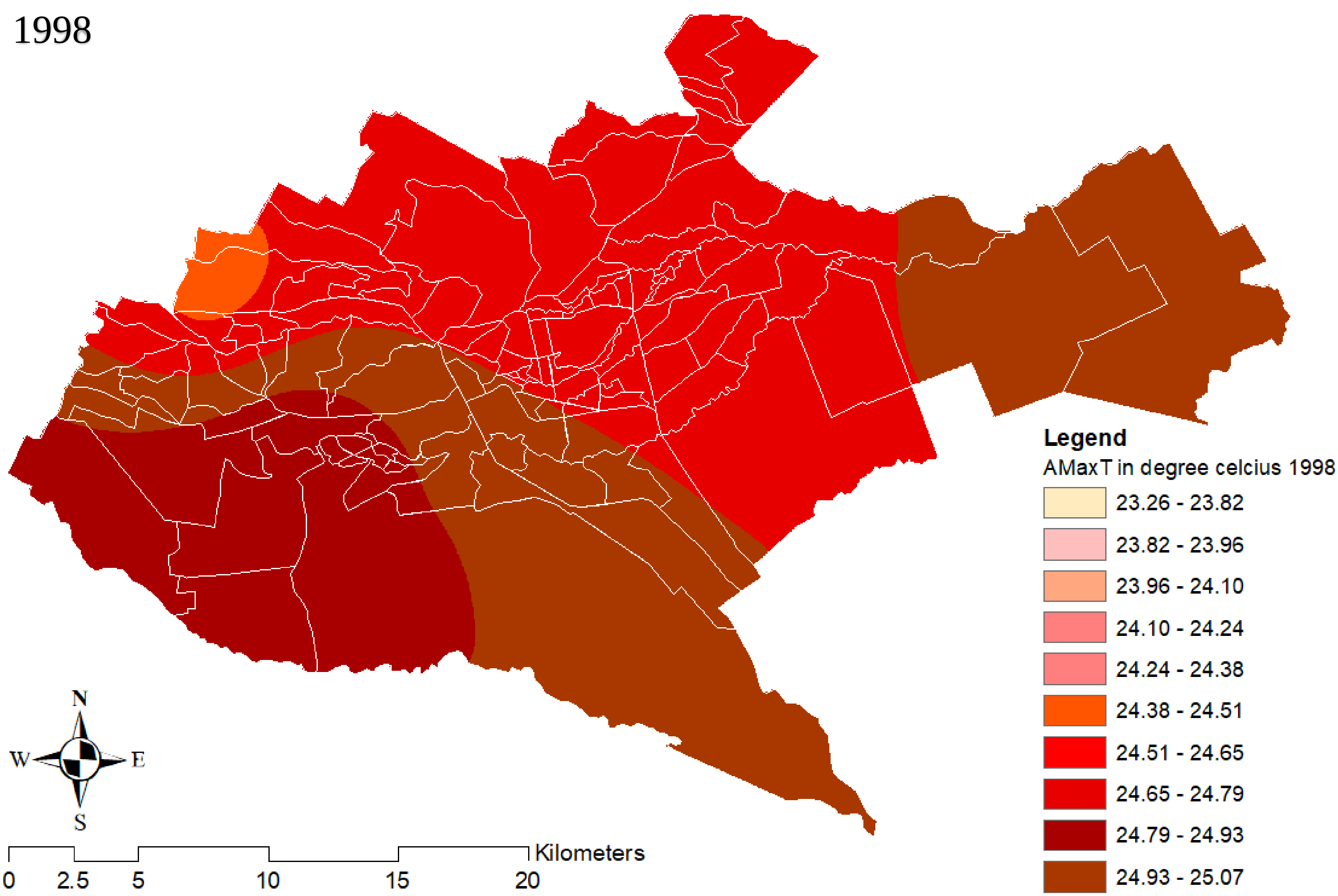


2008 and 2018

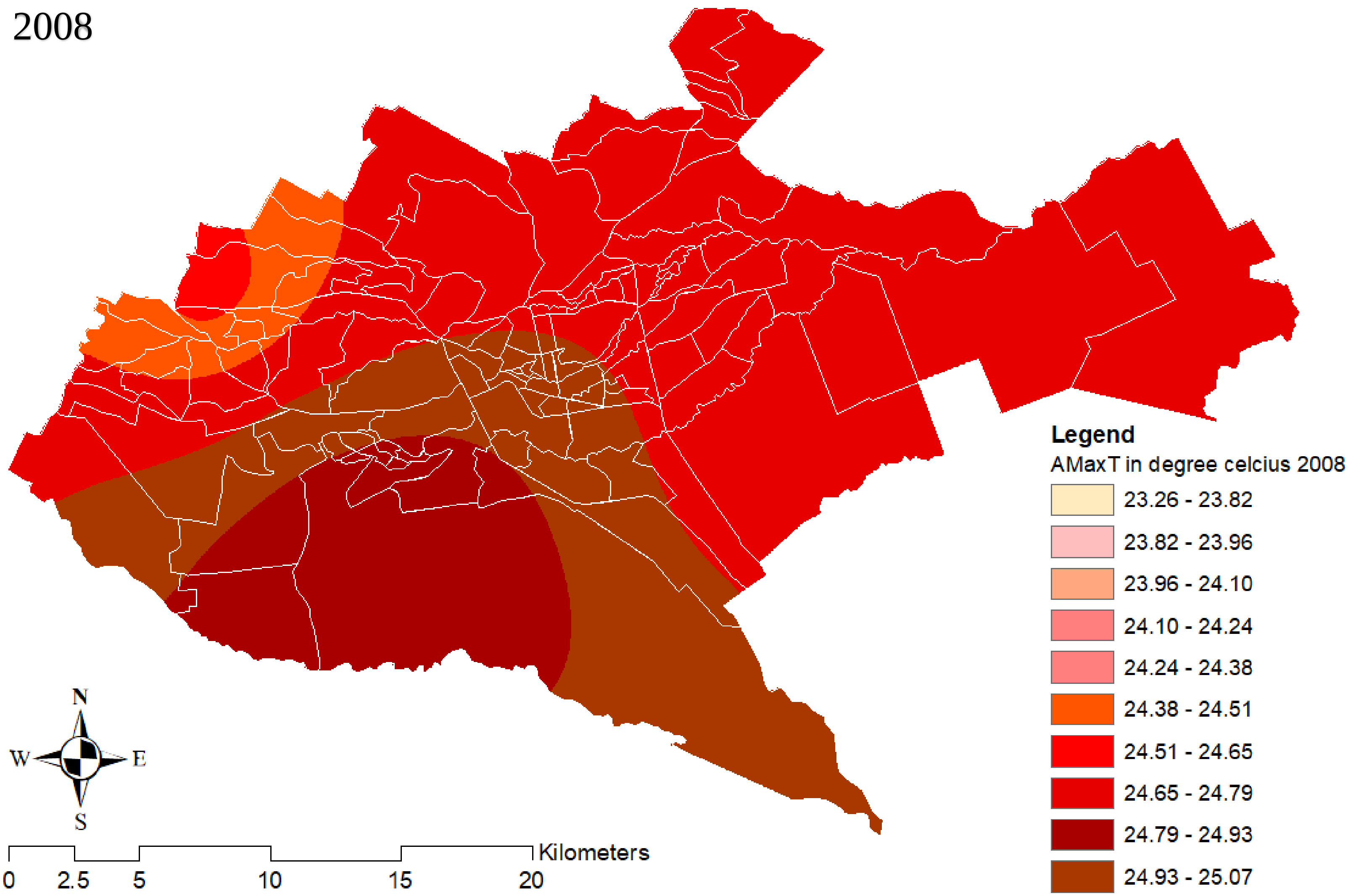


Appendix IX: Average Annual Maximum Temperature for Nairobi between 1988 and 2018

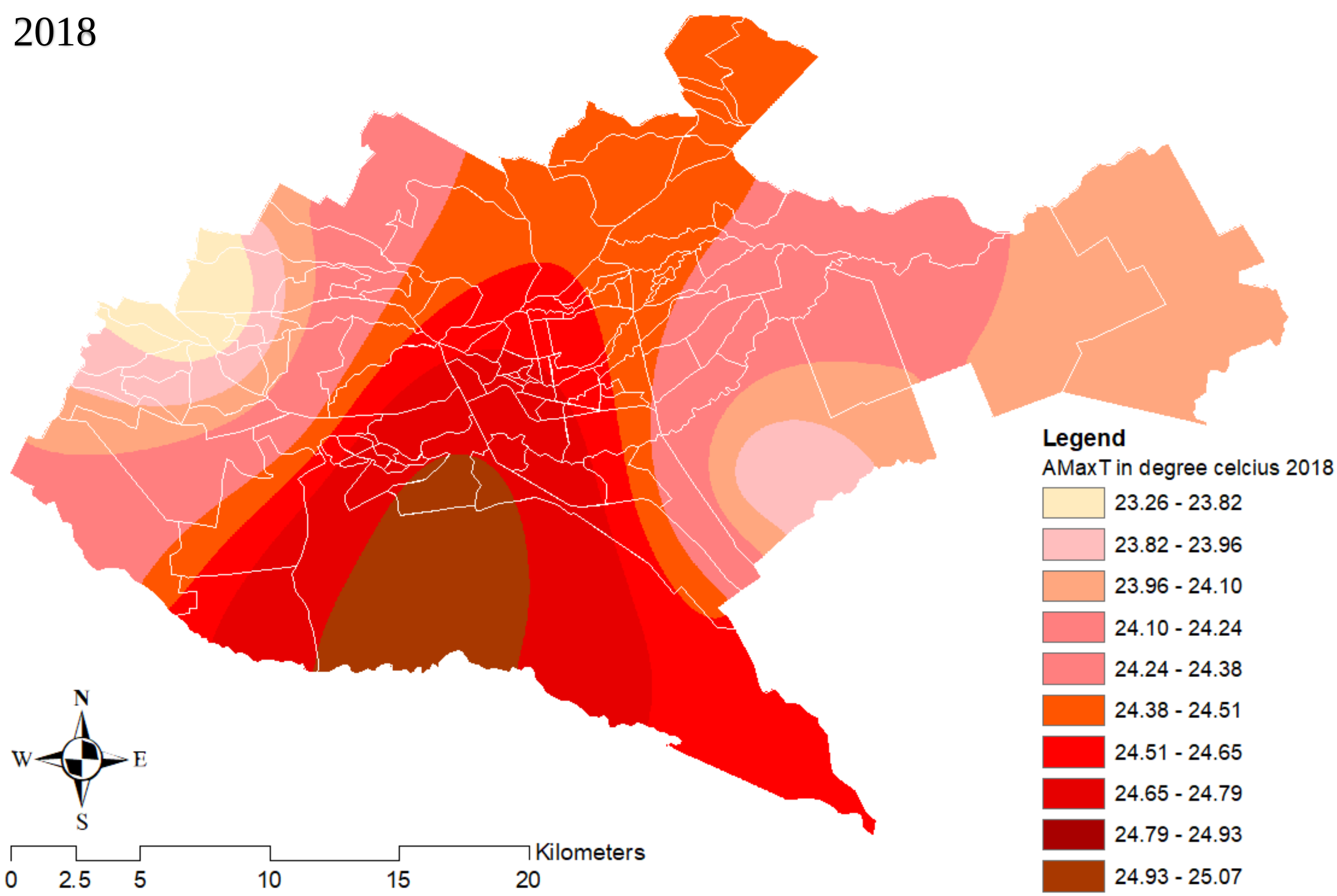



1998
Legend
AMaxT in degree celcius 1998
23.26 - 23.82
23.82 - 23.96
23.96 - 24.10
24.10 - 24.24
24.24 - 24.38
24.38 - 24.51
24.51 - 24.65
24.65 - 24.79
24.79 - 24.93
24.93 - 25.07
N
W
E
S
0
2.5
5
10
15
20
Kilometers

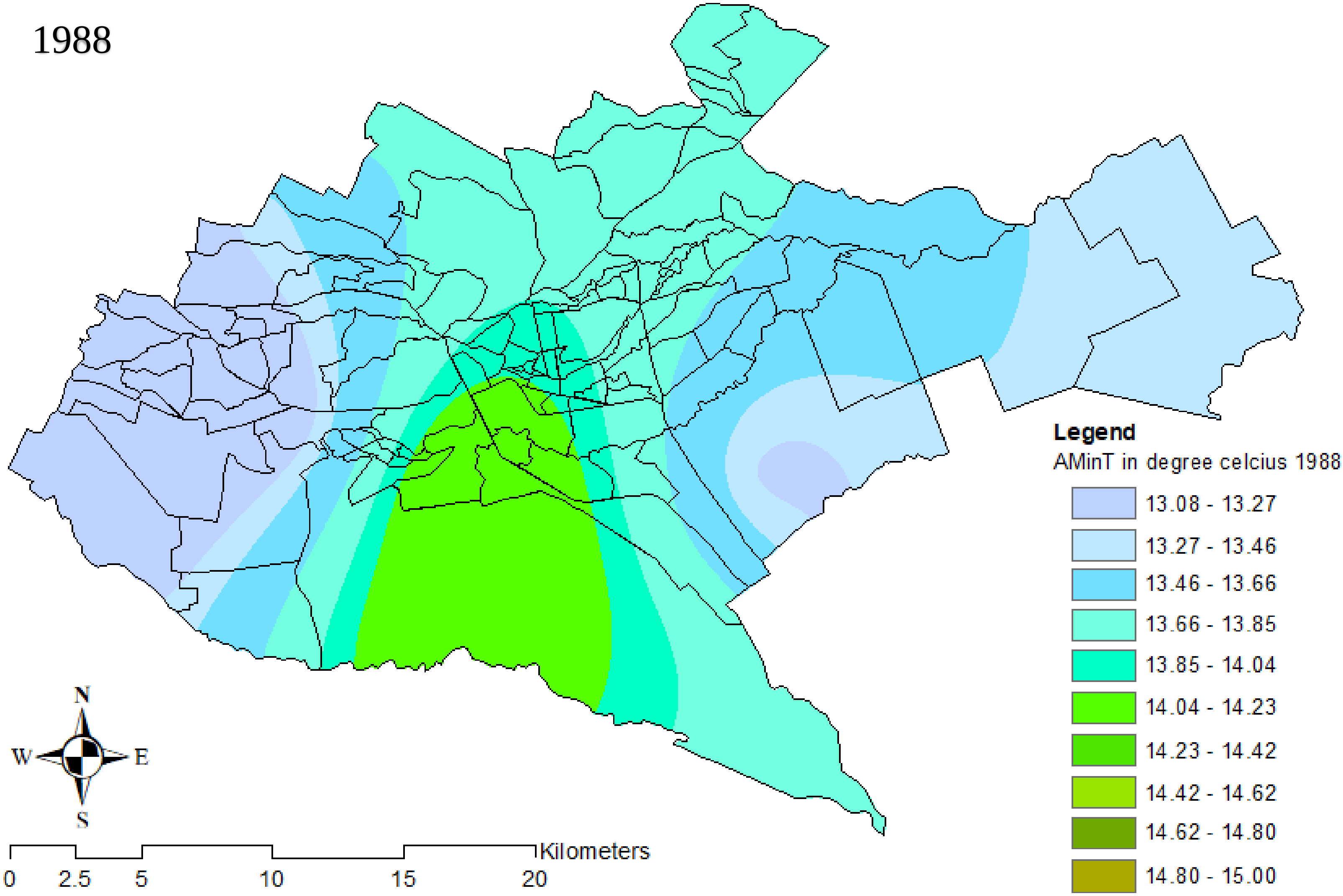
2008



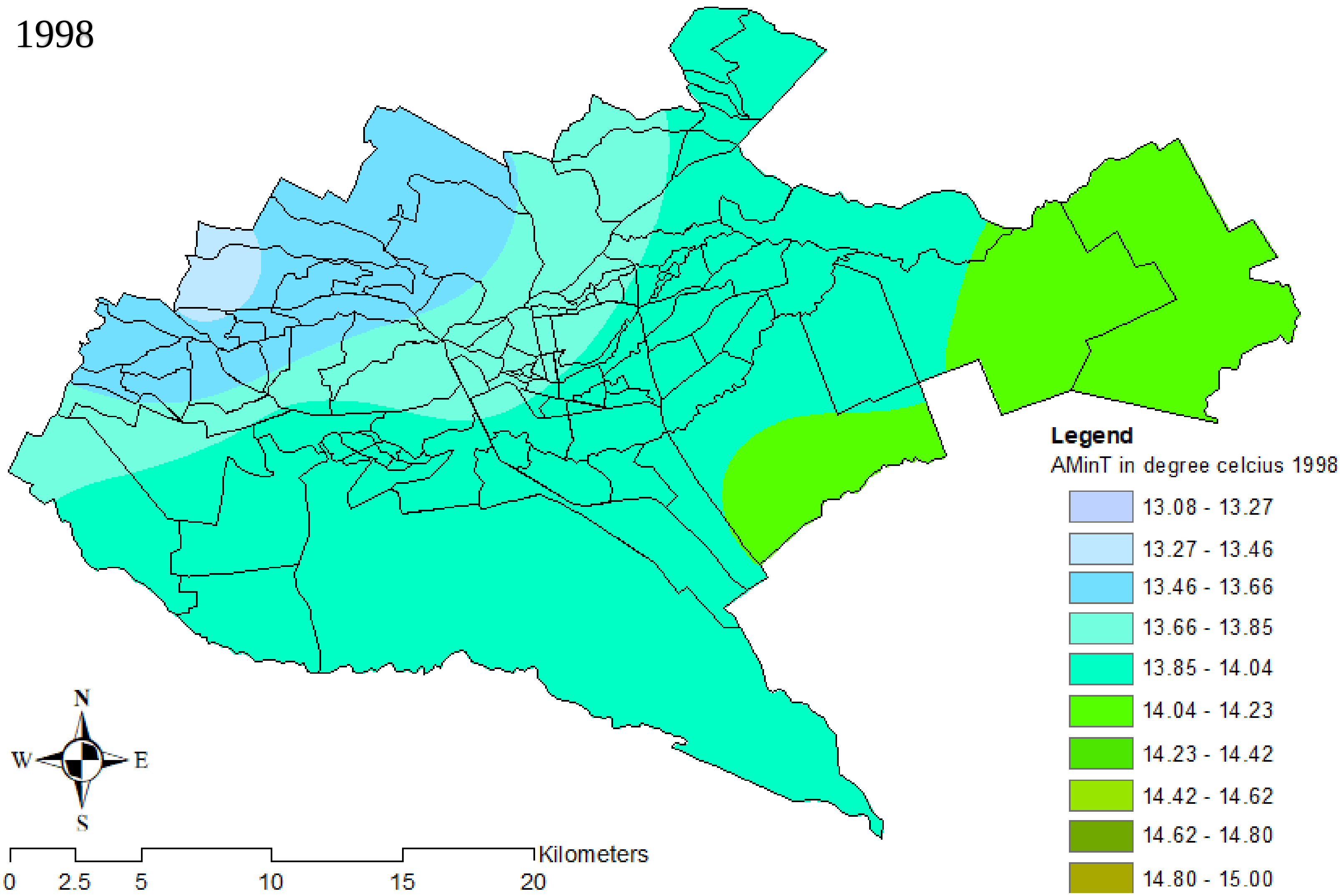
N
W
E
S
0
2.5
5
10
15
20
Kilometers
Legend
AMaxT in degree celcius 2008
23.26 - 23.82
23.82 - 23.96
23.96 - 24.10
24.10 - 24.24
24.24 - 24.38
24.38 - 24.51
24.51 - 24.65
24.65 - 24.79
24.79 - 24.93
24.93 - 25.07

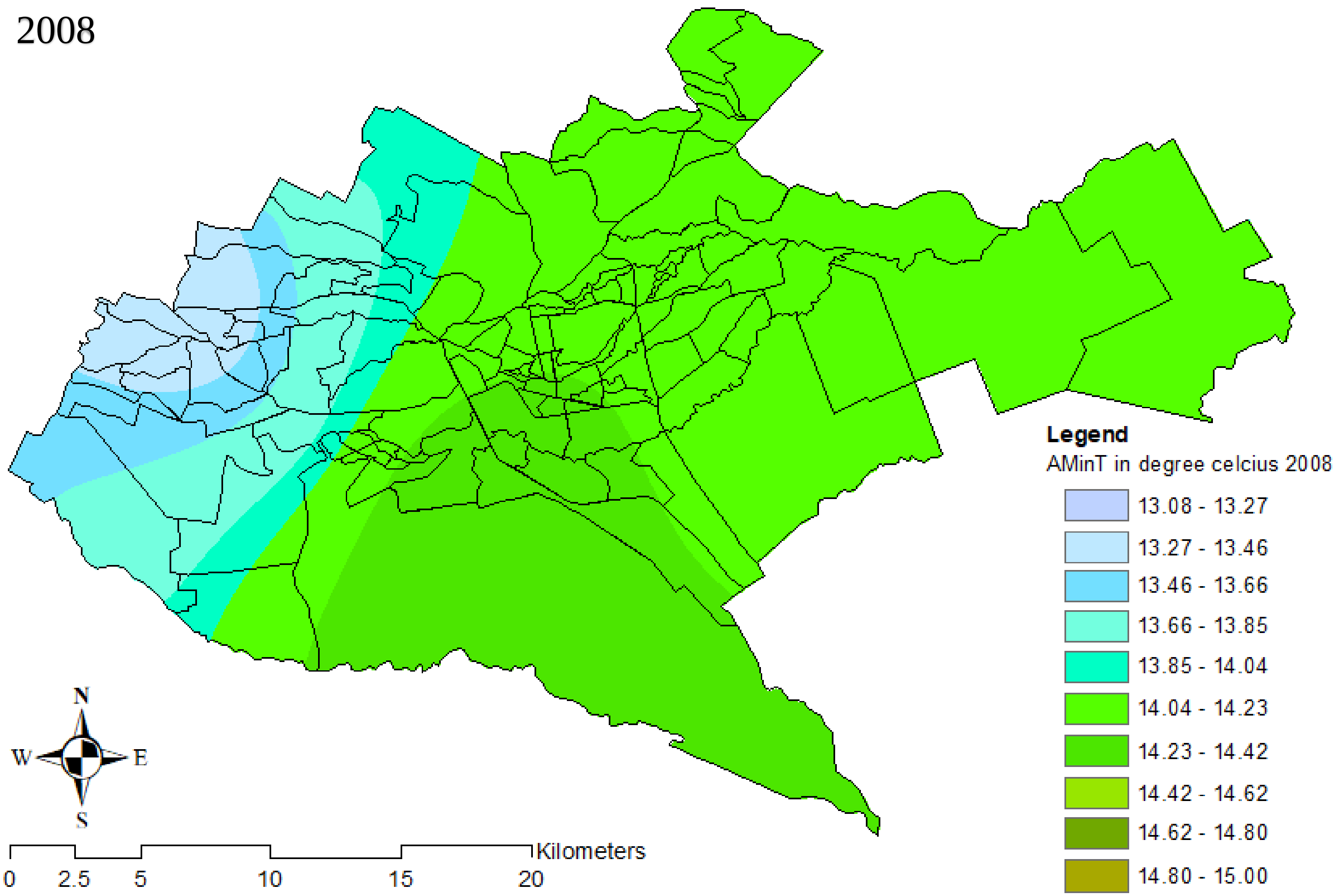

2018
N
W
E
S
0
2.5
5
10
15
20
Kilometers
Legend
AMaxT in degree celcius 2018
23.26 - 23.82
23.82 - 23.96
23.96 - 24.10
24.10 - 24.24
24.24 - 24.38
24.38 - 24.51
24.51 - 24.65
24.65 - 24.79
24.79 - 24.93
24.93 - 25.07

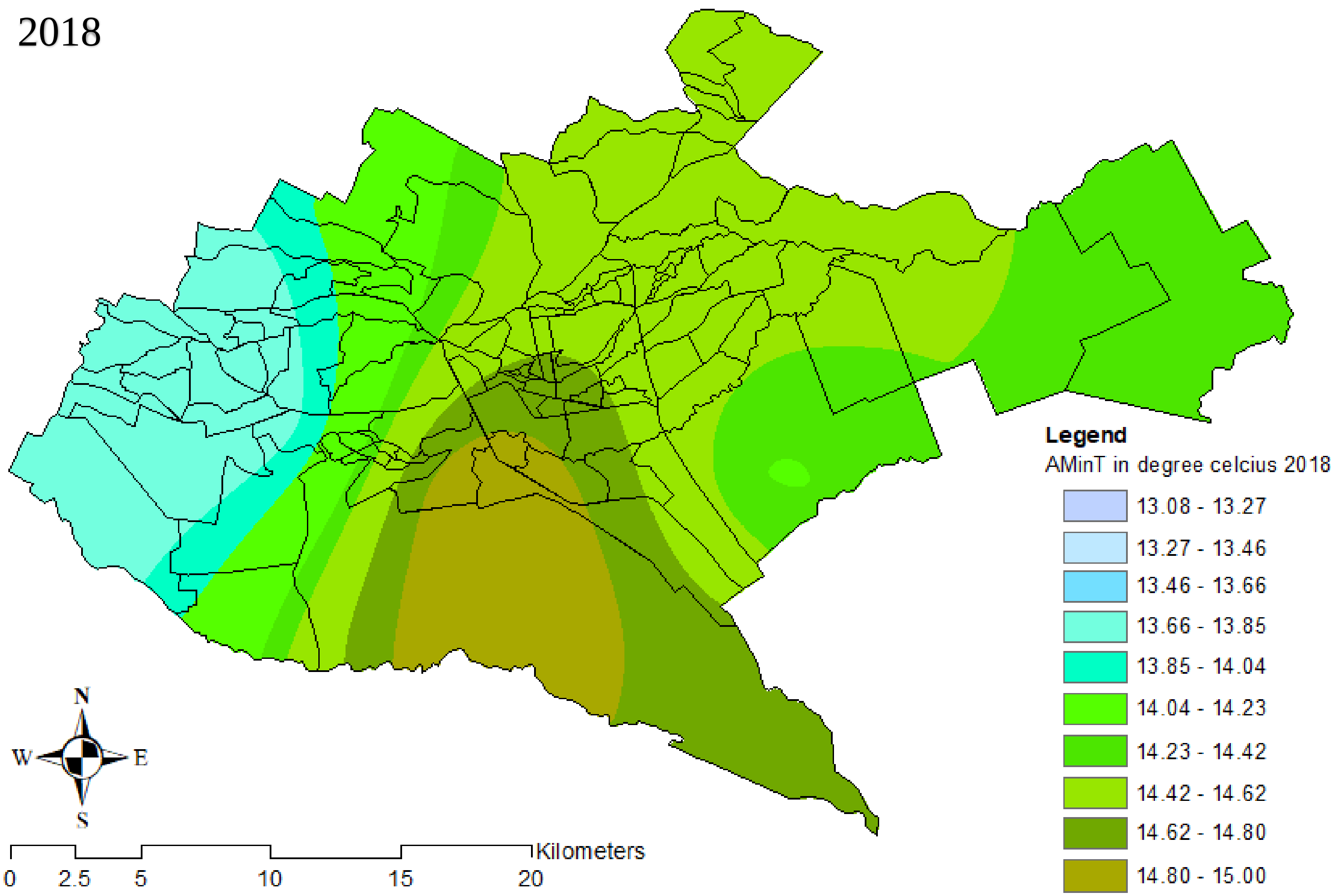
Appendix X: Average Annual Minimum Temperature for Nairobi between 1988 and 2018



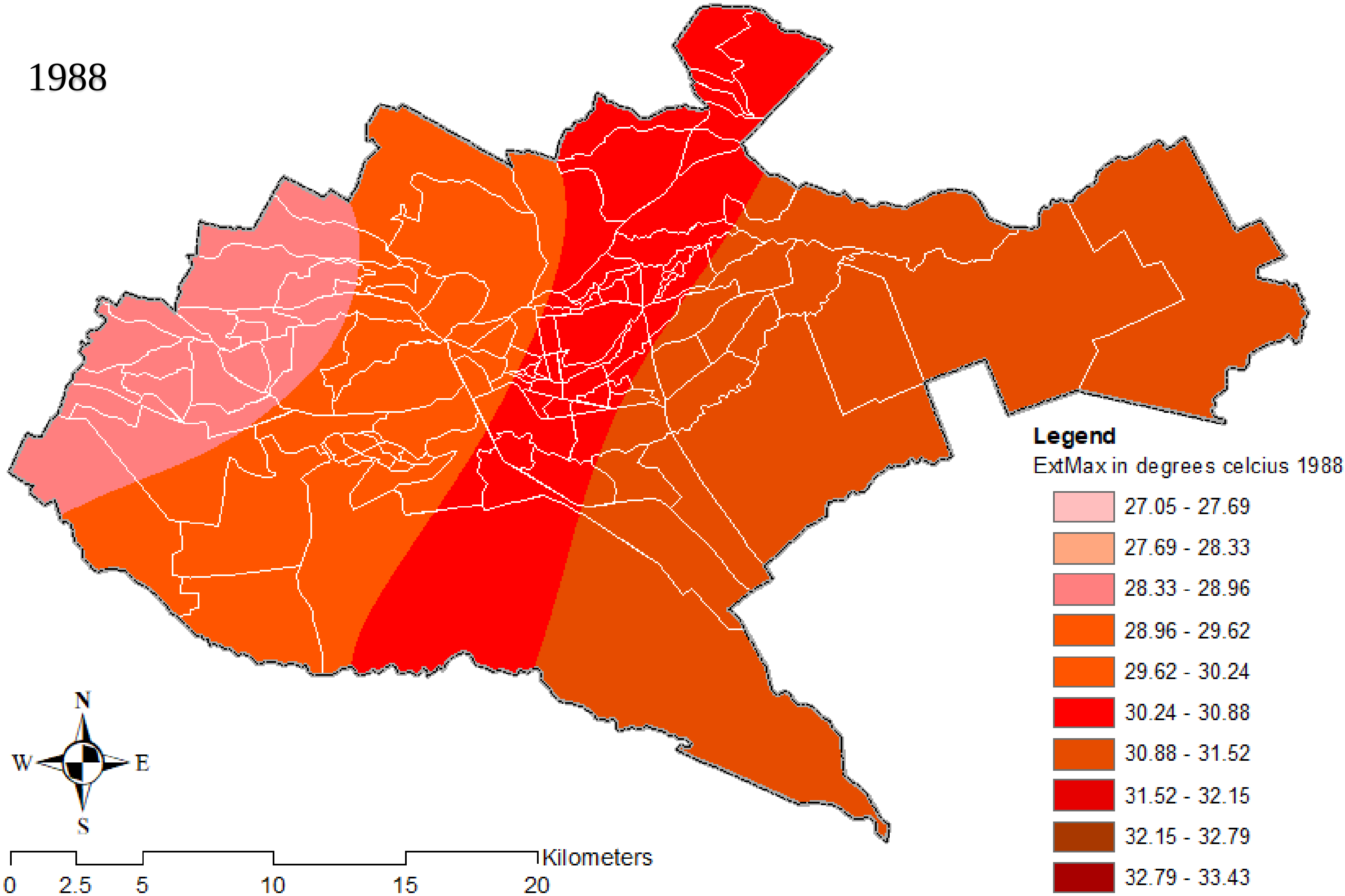
1998


N
W
E
S
0
2.5
5
10
15
20
Kilometers
Legend
AMinT in degree celcius 1998
13.08 - 13.27
13.27 - 13.46
13.46 - 13.66
13.66 - 13.85
13.85 - 14.04
14.04 - 14.23
14.23 - 14.42
14.42 - 14.62
14.62 - 14.80
14.80 - 15.00

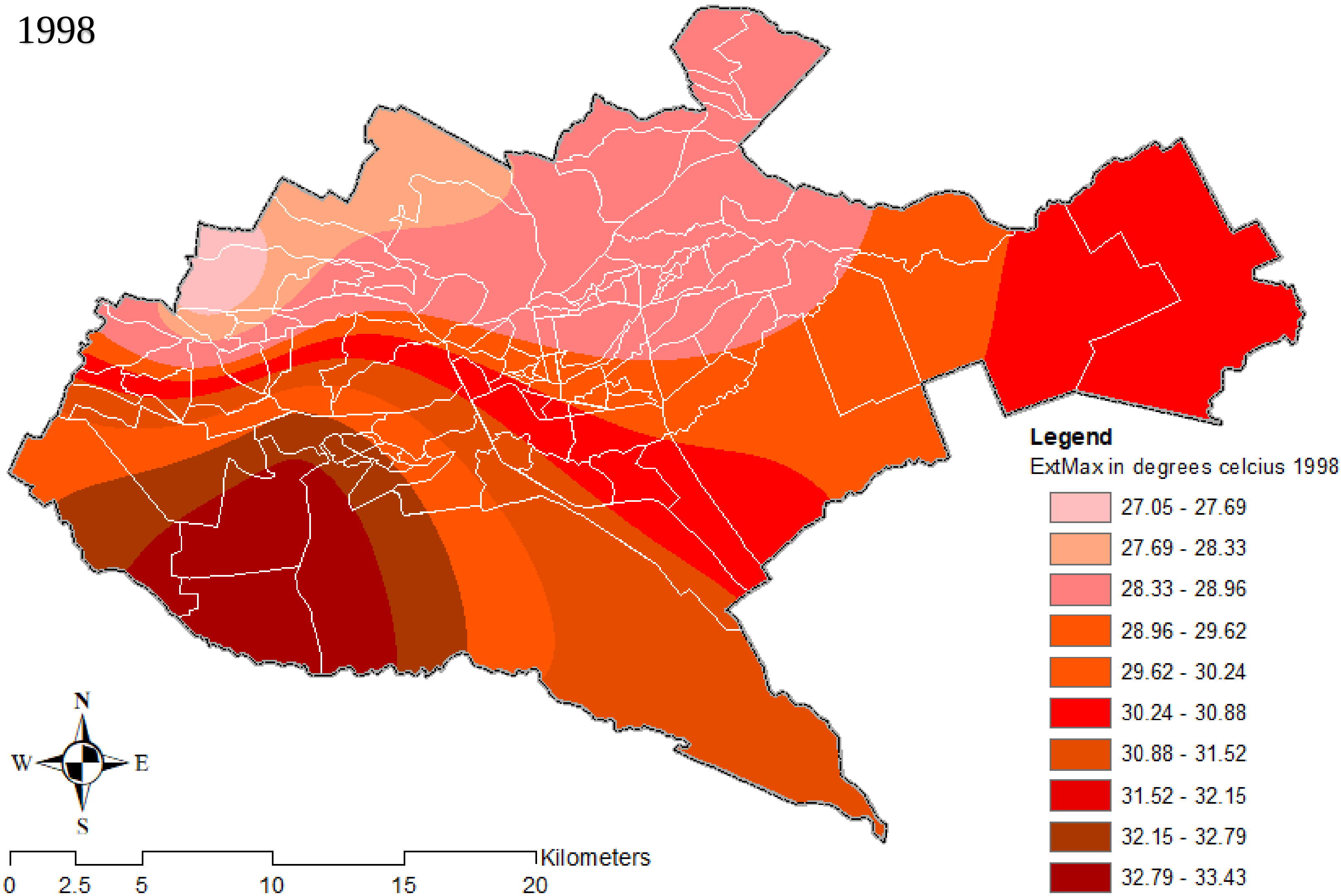

2008
Legend
AMinT in degree celcius 2008
13.08 - 13.27
13.27 - 13.46
13.46 - 13.66
13.66 - 13.85
13.85 - 14.04
14.04 - 14.23
14.23 - 14.42
14.42 - 14.62
14.62 - 14.80
14.80 - 15.00
N
W
E
S
0
2.5
5
10
15
20
Kilometers


2018
N
W
E
S
0
2.5
5
10
15
20
Kilometers
Legend
AMinT in degree celcius 2018
13.08 - 13.27
13.27 - 13.46
13.46 - 13.66
13.66 - 13.85
13.85 - 14.04
14.04 - 14.23
14.23 - 14.42
14.42 - 14.62
14.62 - 14.80
14.80 - 15.00

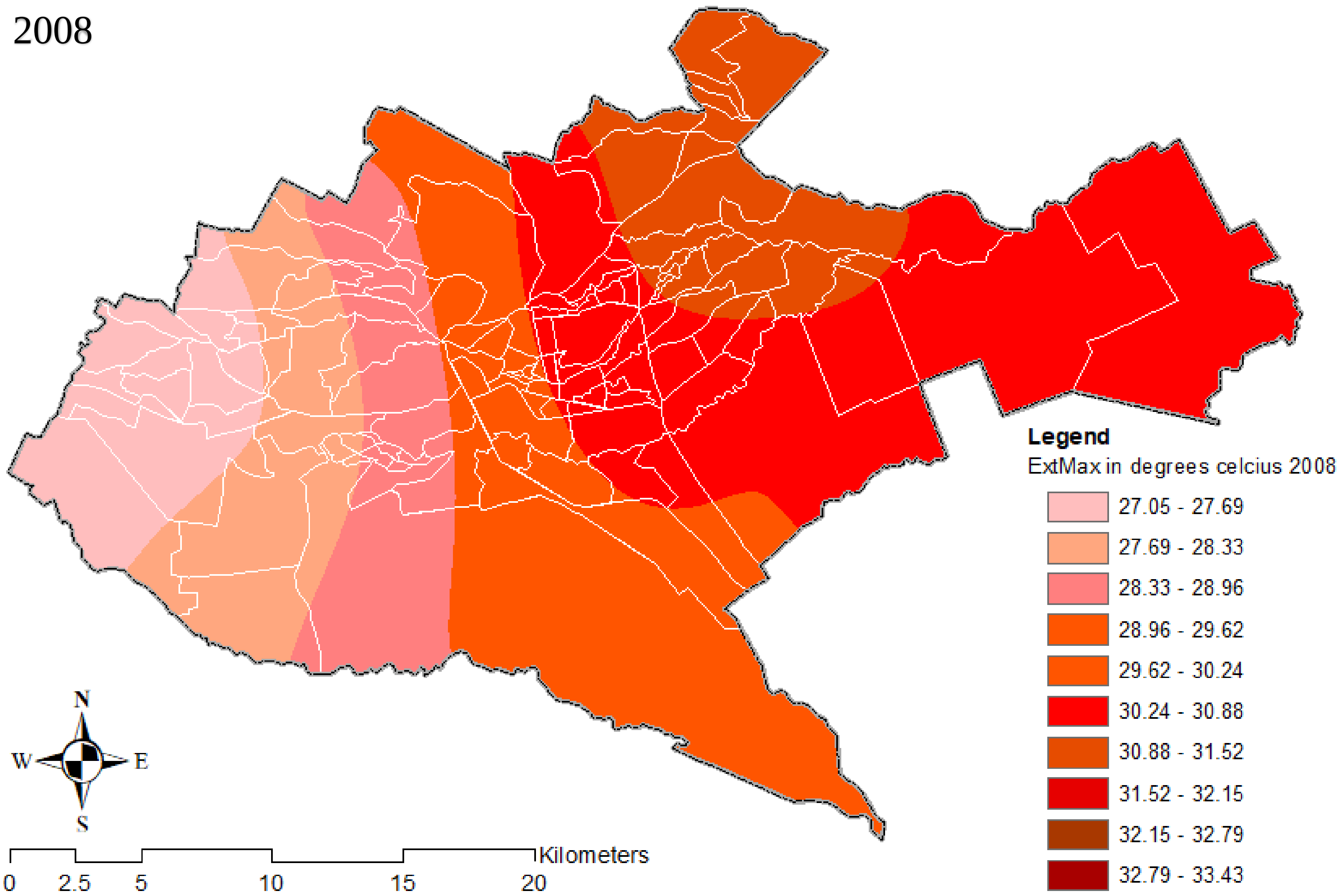
Appendix XI: Highest Annual Temperature for Nairobi between 1988 and 2018



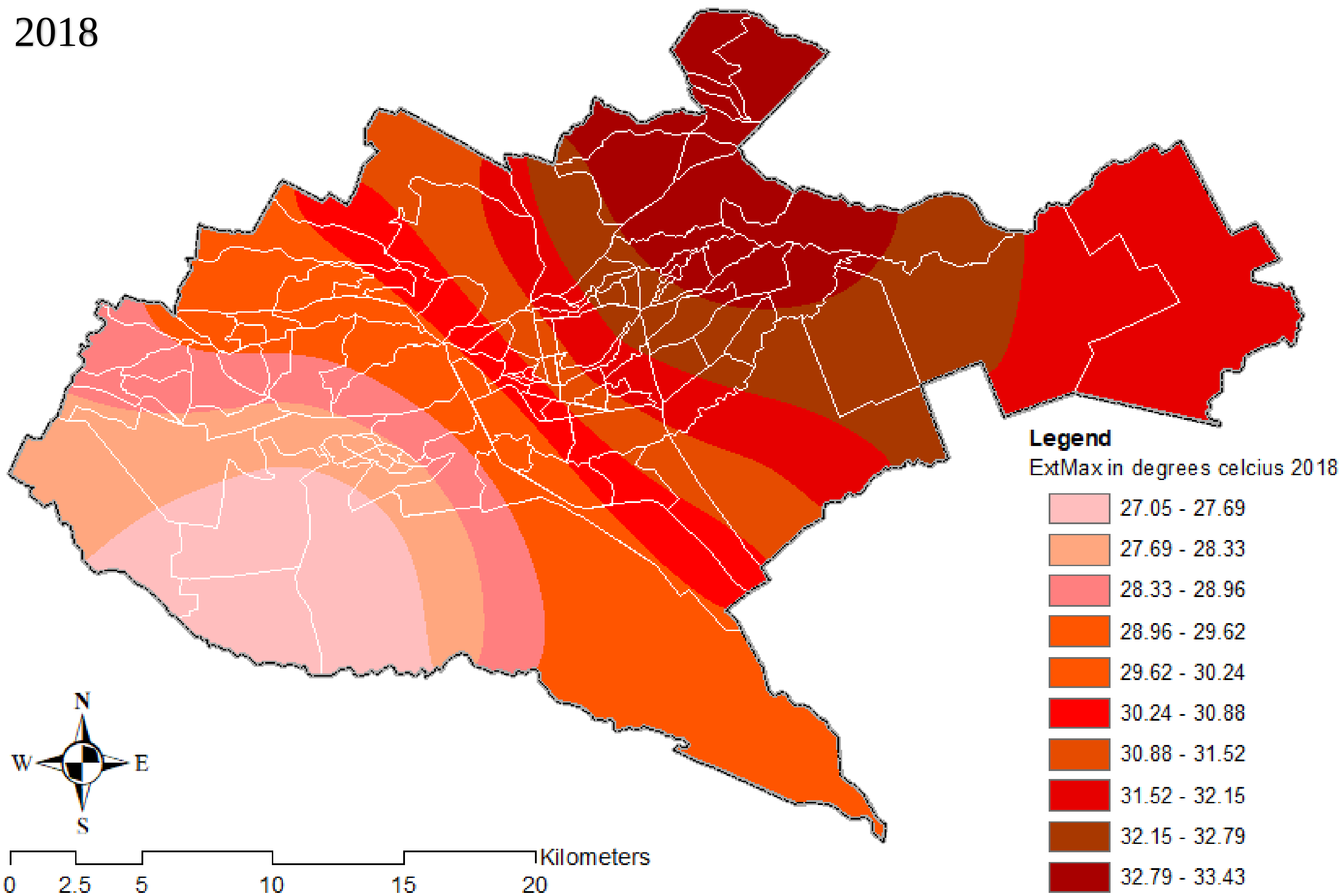
1998



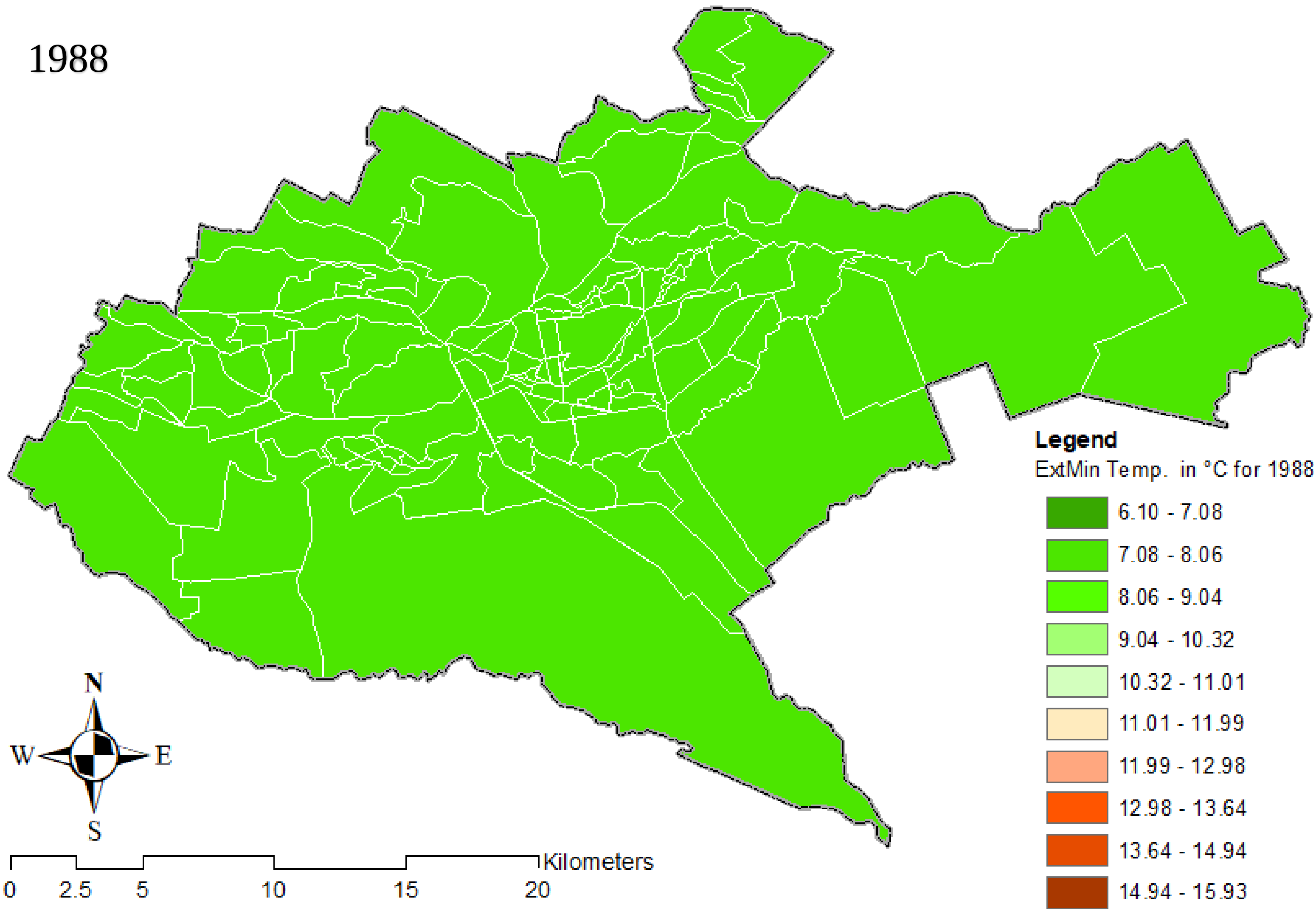
N
W
E
S
0
2.5
5
10
15
20
Kilometers
Legend
ExtMax in degrees celcius 1998
27.05 - 27.69
27.69 - 28.33
28.33 - 28.96
28.96 - 29.62
29.62 - 30.24
30.24 - 30.88
30.88 - 31.52
31.52 - 32.15
32.15 - 32.79
32.79 - 33.43


2008
Legend
ExtMax in degrees celcius 2008
27.05 - 27.69
27.69 - 28.33
28.33 - 28.96
28.96 - 29.62
29.62 - 30.24
30.24 - 30.88
30.88 - 31.52
31.52 - 32.15
32.15 - 32.79
32.79 - 33.43
N
W
E
S
0
2.5
5
10
15
20
Kilometers

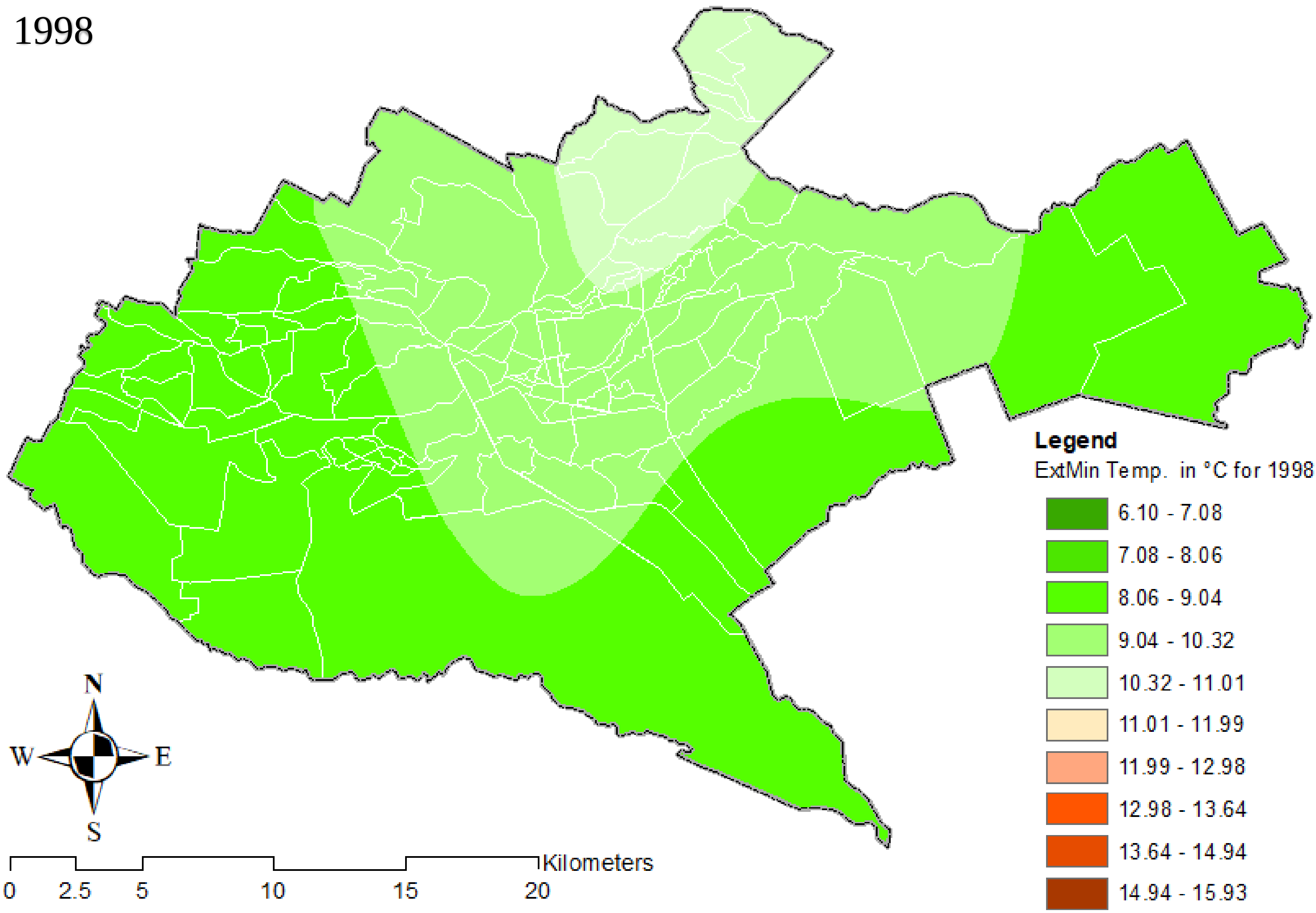
2018


N
W
E
S
0
2.5
5
10
15
20
Kilometers
Legend
ExtMax in degrees celcius 2018
27.05 - 27.69
27.69 - 28.33
28.33 - 28.96
28.96 - 29.62
29.62 - 30.24
30.24 - 30.88
30.88 - 31.52
31.52 - 32.15
32.15 - 32.79
32.79 - 33.43

Appendix XII: Lowest Annual Temperature for Nairobi between 1988 and 2018

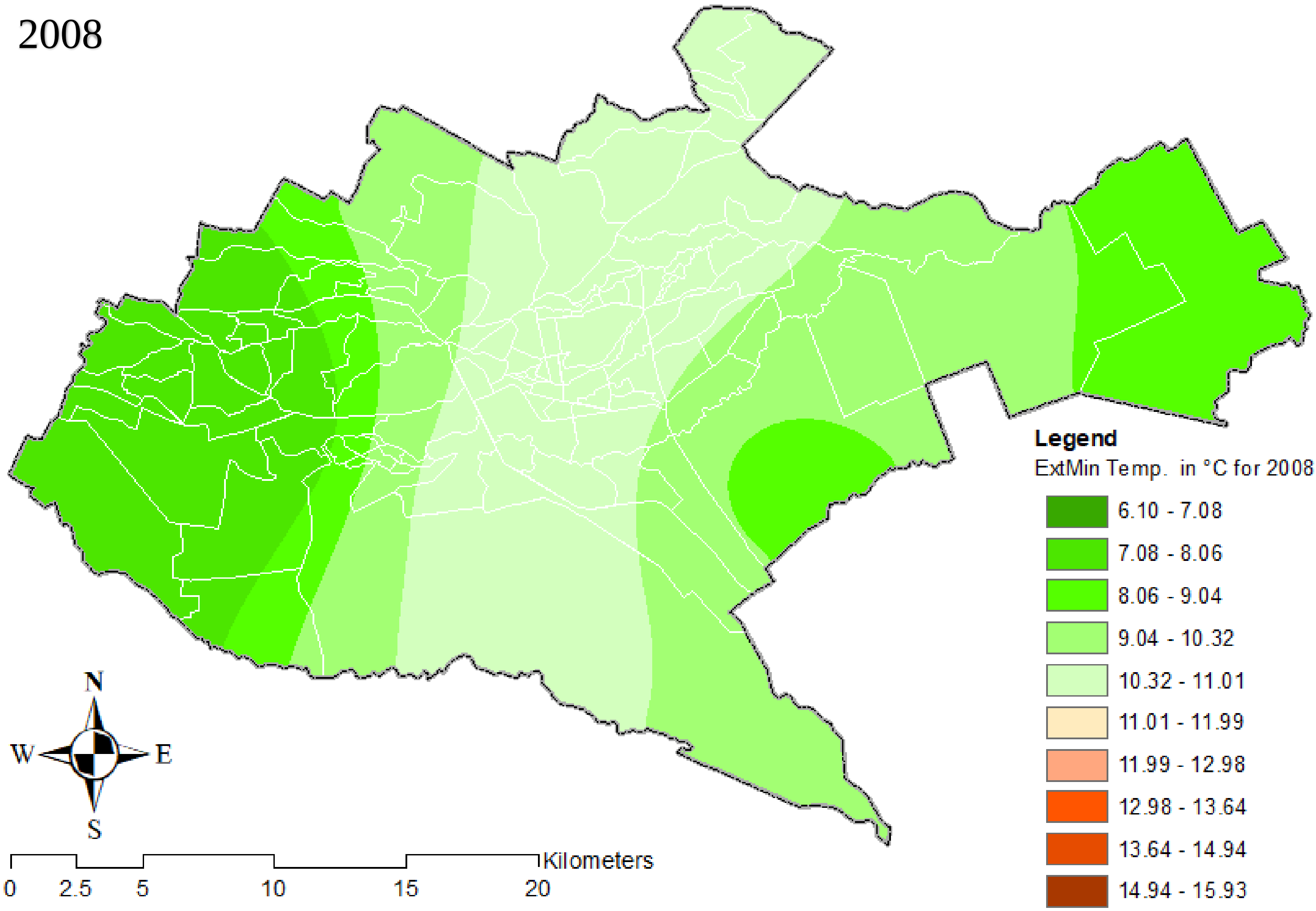


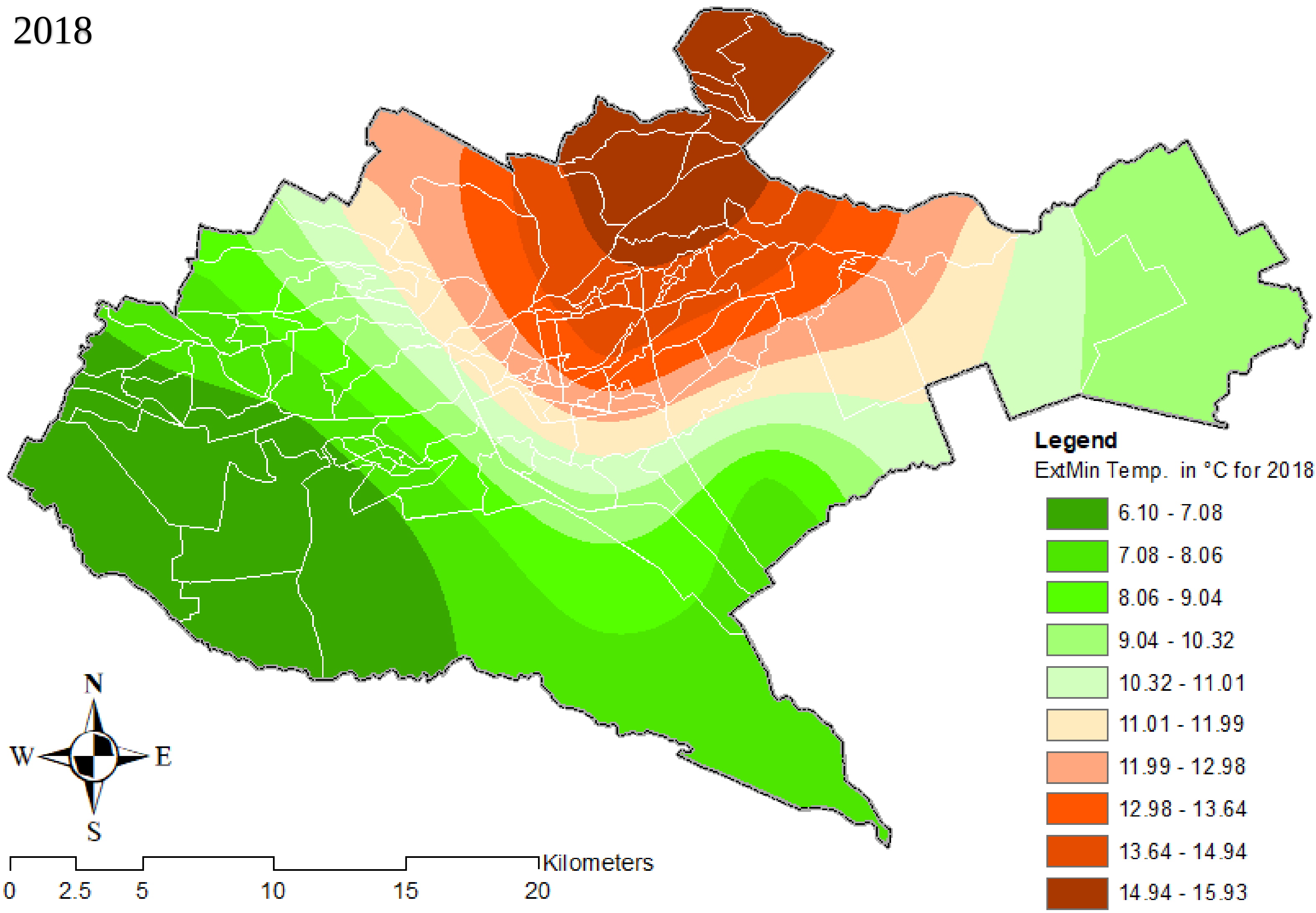
1998



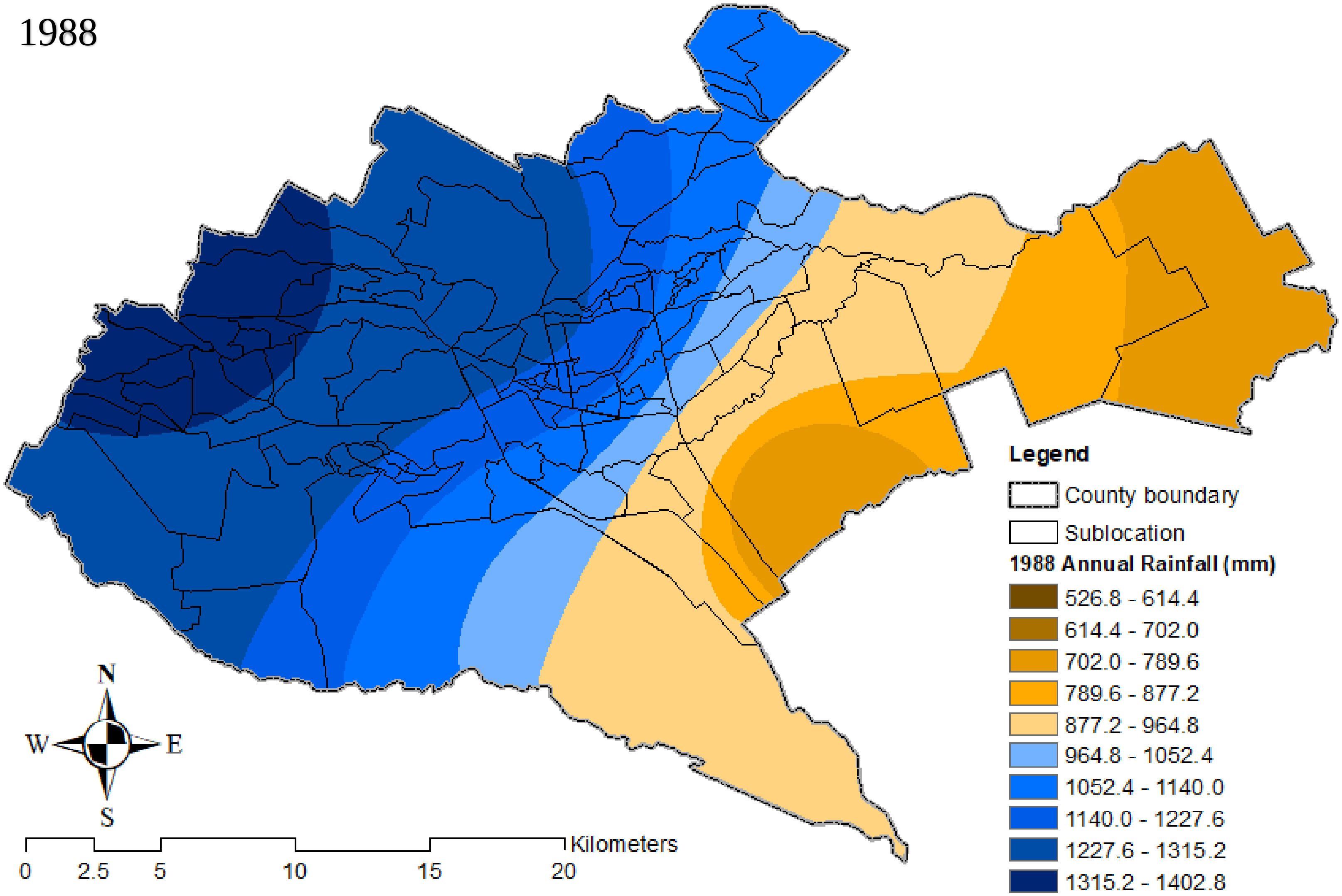
N
W
E
S
0
2.5
5
10
15
20
Kilometers
Legend
ExtMin Temp. in °C for 1998
6.10 - 7.08
7.08 - 8.06
8.06 - 9.04
9.04 - 10.32
10.32 - 11.01
11.01 - 11.99
11.99 - 12.98
12.98 - 13.64
13.64 - 14.94
14.94 - 15.93

2008

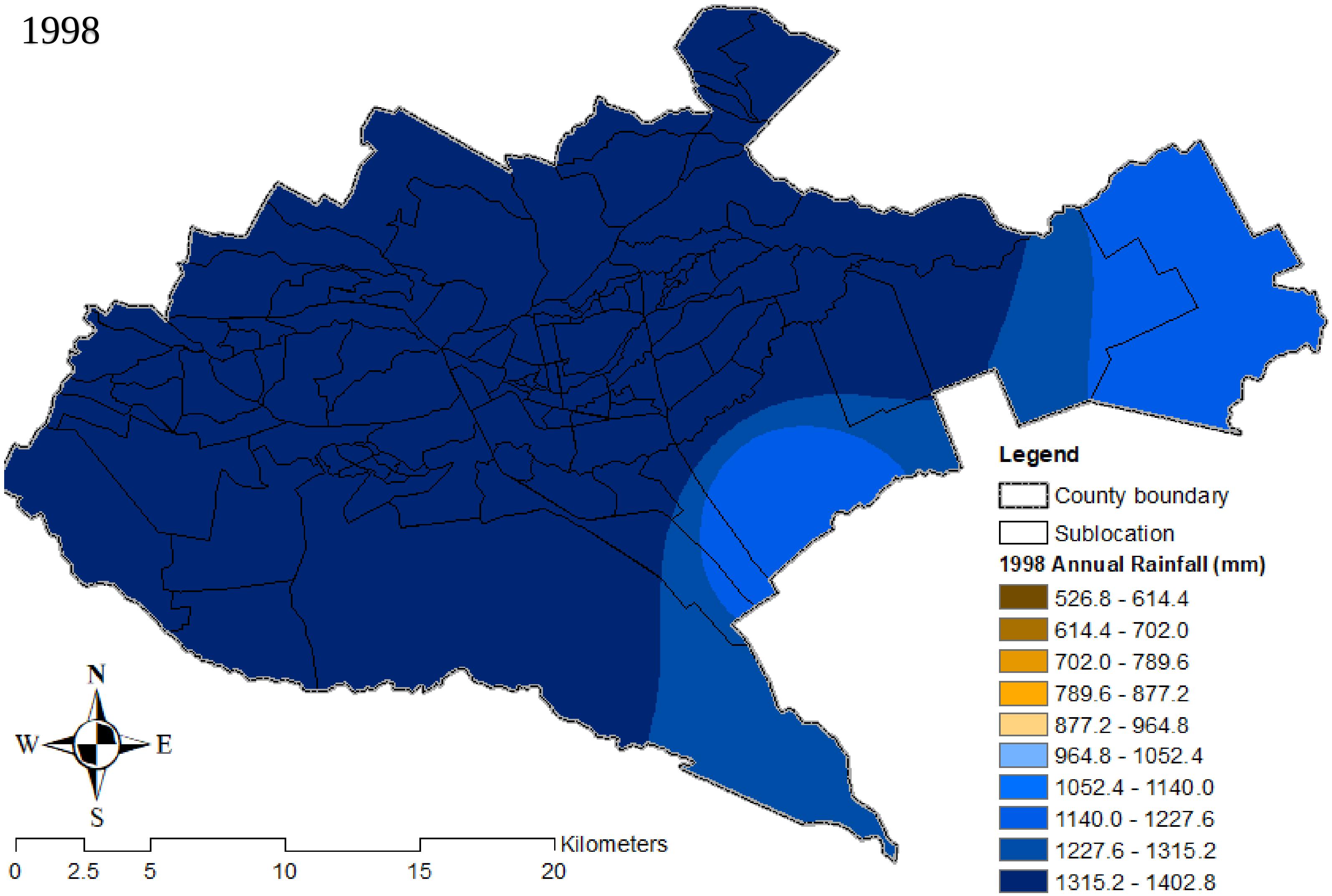

N
W
E
S
0
2.5
5
10
15
20
Kilometers
Legend
ExtMin Temp. in °C for 2008
6.10 - 7.08
7.08 - 8.06
8.06 - 9.04
9.04 - 10.32
10.32 - 11.01
11.01 - 11.99
11.99 - 12.98
12.98 - 13.64
13.64 - 14.94
14.94 - 15.93


2018
Legend
ExtMin Temp. in °C for 2018
6.10 - 7.08
7.08 - 8.06
8.06 - 9.04
9.04 - 10.32
10.32 - 11.01
11.01 - 11.99
11.99 - 12.98
12.98 - 13.64
13.64 - 14.94
14.94 - 15.93
N
W
E
S
Kilometers
0
2.5
5
10
15
20

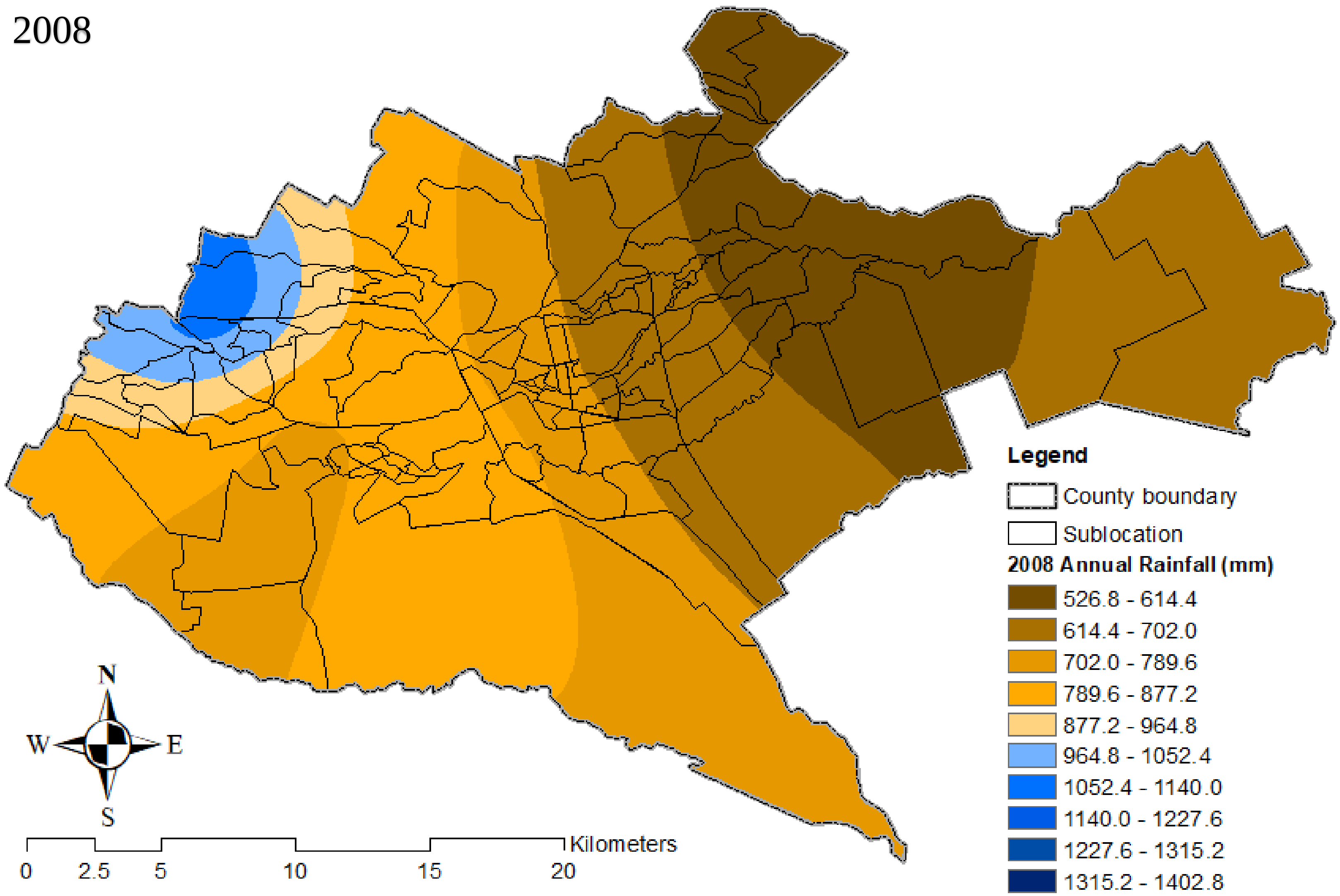
Appendix XIII: Rainfall Distribution Map for Nairobi between 1988 and 2018



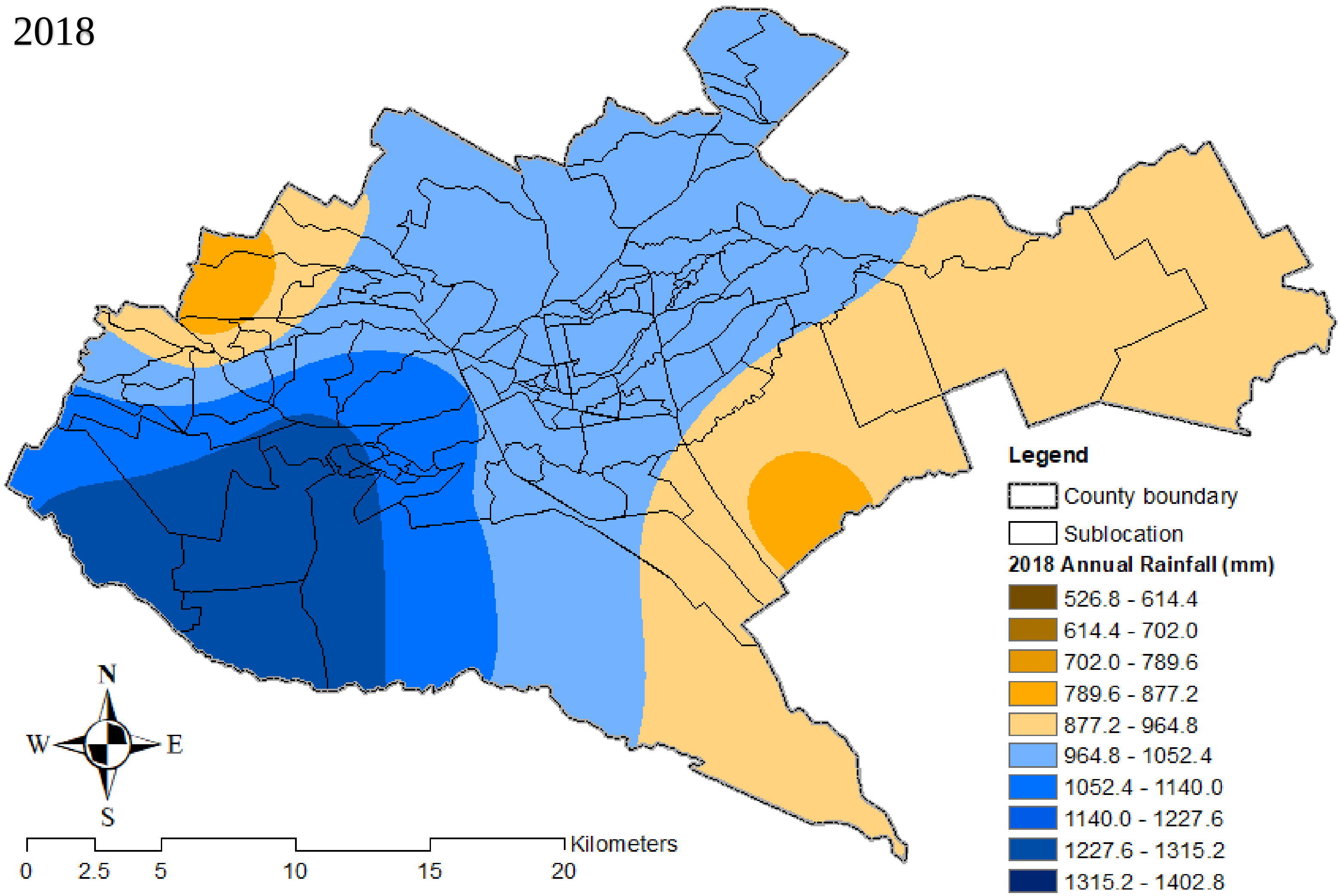
1998


Legend
County boundary
Sublocation
1998 Annual Rainfall (mm)
526.8 - 614.4
614.4 - 702.0
702.0 - 789.6
789.6 - 877.2
877.2 - 964.8
964.8 - 1052.4
1052.4 - 1140.0
1140.0 - 1227.6
1227.6 - 1315.2
1315.2 - 1402.8
N
W
E
S
0
2.5
5
10
15
20
Kilometers

2008


N
W
E
S
0
2.5
5
10
15
20
Kilometers
Legend
County boundary
Sublocation
2008 Annual Rainfall (mm)
526.8 - 614.4
614.4 - 702.0
702.0 - 789.6
789.6 - 877.2
877.2 - 964.8
964.8 - 1052.4
1052.4 - 1140.0
1140.0 - 1227.6
1227.6 - 1315.2
1315.2 - 1402.8

2018



N
W
E
S
0
2.5
5
10
15
20
Kilometers
Legend
County boundary
Sublocation
2018 Annual Rainfall (mm)
526.8 - 614.4
614.4 - 702.0
702.0 - 789.6
789.6 - 877.2
877.2 - 964.8
964.8 - 1052.4
1052.4 - 1140.0
1140.0 - 1227.6
1227.6 - 1315.2
1315.2 - 1402.8

Appendix XIV: Interpolated Urban Form and Climatic Data for 1988

SN	Sublocations	Climate					Urban Form							
		AATx (℃)	AATn (℃)	HAT (℃)	LAT (℃)	R (mm)	BUA (Km^2)	BUA (%)	Forest (Km^2)	Forest (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
0	Mihango	24.66	13.34	31.21	8.06	930.20	0.70	4.59	0.03	0.20	1.08	7.07	14.64	95.41
1	Ruai	24.62	13.46	31.51	8.06	792.80	1.28	2.58	0.21	0.42	14.93	30.10	48.34	97.42
2	Eastleigh North	24.82	13.86	30.78	8.06	1,198.2	0.17	19.23	0.05	5.25	0.91	100.24	0.74	80.77
3	California	24.91	13.92	30.63	8.06	1,221.5	0.06	11.83	0.00	0.23	0.48	99.70	0.42	88.17
4	Ngandu	24.71	13.28	31.4	8.06	702.00	0.17	0.34	0.02	0.05	4.86	9.34	51.86	99.66
5	Mbotela	24.85	13.84	30.32	8.06	1,136.2	0.37	83.25	0.00	0.00	0.42	94.87	0.07	16.75
6	Makongeni	24.91	14.05	30.72	8.06	1,141.8	0.52	78.35	0.00	0.75	0.66	99.89	0.14	21.65
7	Kaloleni	24.87	14.08	30.68	8.06	1,198.3	0.37	59.28	0.00	0.00	0.61	98.73	0.25	40.72
8	Shauri Moyo	24.79	14.01	30.77	8.06	1,212.9	0.45	69.82	0.00	0.00	0.63	97.96	0.19	30.18
9	Muthurwa	24.84	14.11	30.18	8.06	1,223.4	0.14	26.37	0.01	2.56	0.50	96.83	0.38	73.63
10	Ofafa Maringo	24.89	13.85	30.62	8.06	1,098.9	0.31	45.95	0.00	0.00	0.52	77.17	0.37	54.05
11	Hamza	24.86	13.72	30.92	8.06	1,054.4	0.43	46.59	0.00	0.00	0.37	39.30	0.50	53.41
12	Lumumba	24.87	13.69	30.78	8.06	1,128.2	0.02	6.40	0.00	0.00	0.37	94.42	0.37	93.60
13	Majengo	24.83	13.92	30.52	8.06	1,145.8	0.11	35.65	0.00	0.00	0.30	96.91	0.20	64.35
14	Bondeni	24.94	13.89	30.68	8.06	1,152.9	0.05	31.50	0.00	0.00	0.17	102.91	0.12	68.50
15	Gikomba	24.88	13.95	30.26	8.06	1,199.9	0.01	9.94	0.00	0.00	0.07	100.02	0.06	90.06
16	Kamukunji	24.87	14.02	30.42	8.06	1,202.6	0.16	69.78	0.00	0.00	0.23	98.52	0.07	30.22
17	Kimathi	24.91	13.92	30.82	8.06	1,138.6	0.26	18.91	0.00	0.09	1.30	96.39	1.09	81.09
18	Eastleigh South	24.81	13.86	30.54	8.06	1,145.7	0.09	8.49	0.04	3.21	1.09	98.60	1.02	91.51
19	Air Base	24.85	13.85	30.68	8.06	1,202.6	1.07	21.19	0.19	3.80	4.10	81.01	3.99	78.81
20	Uhuru	24.89	13.72	30.79	8.06	1,125.8	0.75	49.09	0.01	0.44	1.05	68.58	0.78	50.91
21	Harambee	24.92	13.67	30.89	8.06	1,050.6	0.71	32.25	0.00	0.00	1.59	72.14	1.49	67.75
22	Bomas	24.98	14.12	30.72	8.06	1,068.7 0	0.55	0.44	6.30	5.03	30.96	24.69	124.81	99.56

SN	Sublocations	Climate					Urban Form							
		AATx (℃)	AATn (℃)	HAT (℃)	LAT (℃)	R (mm)	BUA (Km^2)	BUA (%)	Forest (Km^2)	Forest (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
23	Embakasi	24.49	13.39	30.99	8.06	750.60	2.13	4.66	0.07	0.16	5.42	11.88	43.53	95.34
24	Umoja	24.79	13.65	30.98	8.06	980.80	1.24	39.60	0.00	0.00	1.52	48.65	1.88	60.40
25	Mlango Kubwa	24.82	13.92	30.38	8.06	1,290.8	0.17	38.71	0.02	3.46	0.45	99.56	0.28	61.29
26	Mabatini	24.85	13.72	30.42	8.06	1,225.2	0.14	38.21	0.03	7.12	0.31	82.67	0.23	61.79
27	Mathare	24.88	13.81	30.34	8.06	1,305.6	0.48	58.76	0.00	0.00	0.71	86.63	0.34	41.24
28	Pangani	24.83	13.73	30.1	8.06	1,265.7	0.70	41.79	0.03	1.56	1.51	90.21	0.97	58.21
29	Ziwani/Kariok or	24.87	13.82	30.19	8.06	1,298.6	0.47	56.10	0.00	0.00	0.59	71.65	0.36	43.90
30	Ngara East	24.91	13.71	30.13	8.06	1,315.0	1.01	75.72	0.01	0.53	1.29	96.60	0.33	24.28
31	Garden	24.93	13.76	30.23	8.06	1,228.6	0.71	5.51	5.91	45.95	12.28	95.51	12.15	94.49
32	Roysambu	24.9	13.68	30.18	8.06	1,141.6	0.30	3.03	0.67	6.79	7.52	75.60	9.64	96.97
33	Kiwanja	24.88	13.82	30.14	8.06	1,082.6	2.11	23.79	0.21	2.39	5.47	61.79	6.74	76.21
34	Kahawa West	24.93	13.69	30.09	8.06	1,111.1	0.94	18.31	0.25	4.80	2.98	57.81	4.21	81.69
35	Kongo Soweto	24.85	13.72	30.12	8.06	1,062.7	0.15	11.85	0.26	21.27	1.16	94.23	1.08	88.15
36	Kamuthi	24.91	13.75	30.07	8.06	1,138.2	0.35	30.44	0.18	15.61	1.02	89.12	0.80	69.56
37	Githurai	24.91	13.81	29.82	8.06	1,080.8	0.35	17.70	0.06	3.07	1.61	81.31	1.63	82.30
38	Zimmerman	24.89	13.71	29.46	8.06	1,099.9	0.36	19.09	0.02	0.82	1.40	74.61	1.52	80.91
39	Savannah	24.75	13.51	30.92	8.06	990.40	1.15	23.94	0.08	1.64	2.23	46.33	3.66	76.06
40	Kayole	24.72	13.48	31.21	8.06	890.60	0.38	15.62	0.00	0.05	0.27	11.17	2.07	84.38
41	Komarock	24.81	13.66	30.92	8.06	964.80	0.53	16.99	-	-	0.17	5.54	2.61	83.01
42	Karen	24.67	13.11	28.95	8.06	1,308.6	0.66	2.83	6.74	28.68	17.79	75.74	22.83	97.17
43	Hardy	24.99	13.52	29.93	8.06	1,227.0	0.73	4.98	2.30	15.67	9.80	66.92	13.92	95.02
44	Langata	24.95	13.3	30.16	8.06	1,245.8	0.19	1.11	3.45	19.58	12.03	68.20	17.45	98.89
45	Mukuru Kwa Njenga	24.58	13.52	30.91	8.06	780.60	0.13	1.52	0.00	0.00	0.37	4.37	8.32	98.48

SN	Sublocations	Climate					Urban Form							
		AATx (℃)	AATn (℃)	HAT (℃)	LAT (℃)	R (mm)	BUA (Km^2)	BUA (%)	Forest (Km^2)	Forest (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
46	South C	24.68	13.71	31.01	8.06	850.60	0.09	0.57	0.00	0.01	1.07	6.99	15.23	99.43
47	Land Mawe	24.79	14.12	30.53	8.06	1,150.5	2.41	43.59	0.04	0.63	5.23	94.34	3.13	56.41
48	Viwandani	24.81	13.68	30.85	8.06	1,032.6	2.34	40.73	0.17	2.87	4.80	83.49	3.41	59.27
49	Imara Daima	24.72	13.66	31.25	8.06	950.40	0.61	15.17	0.00	0.00	2.18	53.91	3.43	84.83
50	Hazina	24.83	14.02	30.66	8.06	1,068.8	0.09	1.94	0.00	0.00	1.19	26.86	4.34	98.06
51	Nairobi South	24.86	14.21	30.42	8.06	1,099.9	0.55	34.90	0.00	0.00	1.06	67.58	1.02	65.10
52	Karura	24.92	13.72	28.99	8.06	1,300.8	0.98	4.97	10.84	55.20	19.10	97.31	18.65	95.03
53	Njathaini	24.89	13.81	30.42	8.06	1,220.6	0.33	6.06	1.79	33.32	4.42	82.18	5.05	93.94
54	Huruma	24.81	13.68	30.31	8.06	1,156.7	0.09	12.20	0.00	0.25	0.53	73.95	0.63	87.80
55	Kiamaiko	24.87	13.73	30.62	8.06	1,210.8	0.14	20.15	0.00	0.00	0.47	68.16	0.55	79.85
56	Utalii	24.88	13.8	30.74	8.06	1,194.8	0.89	51.85	0.07	3.84	1.36	79.51	0.82	48.15
57	Mathare North	24.82	13.6	30.87	8.06	1,167.6	0.39	83.03	0.00	0.29	0.40	85.91	0.08	16.97
58	Mathare 4a	24.86	13.75	30.66	8.06	1,200.8	0.11	45.66	0.01	4.70	0.20	79.64	0.14	54.34
59	Mowlem	24.88	13.67	30.92	8.06	1,052.4	1.08	30.68	0.07	1.87	2.20	62.48	2.44	69.32
60	Kariobangi South	24.83	13.74	30.85	8.06	1,120.6	0.45	31.59	0.02	1.08	1.14	79.41	0.98	68.41
61	Njiru	24.85	13.54	31.21	8.06	1,900.9	1.87	35.39	0.15	2.93	1.90	35.99	3.42	64.61
62	Saika	24.89	13.58	31.34	8.06	1,010.4	0.52	13.05	0.08	2.10	1.43	36.10	3.44	86.95
63	Mwiki	24.75	13.49	31.51	8.06	938.60	2.37	12.35	1.18	6.14	8.10	42.17	16.83	87.65
64	Dandora B	24.81	13.68	30.89	8.06	1,040.8	1.17	59.00	0.07	3.32	0.77	38.80	0.81	41.00
65	Dandora A	24.83	13.72	30.78	8.06	1,098.6	0.94	47.98	0.07	3.80	1.16	59.26	1.01	52.02
66	Korogocho	24.85	13.78	30.62	8.06	1,166.6	0.07	38.07	0.03	16.74	0.13	67.22	0.12	61.93
67	Nyayo	24.89	13.81	30.59	8.06	1,210.4	0.12	50.96	0.04	18.42	0.16	66.72	0.12	49.04
68	Gitathuru	24.91	13.83	30.42	8.06	1,192.8	0.32	63.71	0.00	0.60	0.25	49.66	0.18	36.29
69	Kariobangi North	24.82	13.85	30.48	8.06	1,139.6	0.53	48.81	0.04	3.28	0.60	54.72	0.56	51.19

SN	Sublocations	Climate					Urban Form							
		AATx (℃)	AATn (℃)	HAT (℃)	LAT (℃)	R (mm)	BUA (Km^2)	BUA (%)	Forest (Km^2)	Forest (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
70	Ruaraka	24.84	13.79	30.55	8.06	1,162.8	1.98	49.74	0.06	1.55	2.80	70.29	2.00	50.26
71	Kasarani	24.86	13.76	30.69	8.06	1,098.4	2.41	20.65	0.21	1.80	5.84	49.97	9.27	79.35
72	Muthaiga	24.78	13.68	29.71	8.06	1,292.4	1.55	8.10	10.40	54.49	18.88	98.94	17.53	91.90
73	Lenana	24.76	13.11	28.94	8.06	1,308.9	0.23	1.38	5.77	34.35	14.18	84.35	16.58	98.62
74	Mutuini	24.58	13.13	28.84	8.06	1,322.2	0.07	2.24	0.86	26.04	1.96	59.52	3.23	97.76
75	Kirigu	24.54	13.15	28.42	8.06	1,334.8	0.01	0.85	0.19	10.90	0.68	39.56	1.70	99.15
76	Kabiria	24.57	13.19	28.53	8.06	1,346.2	0.02	0.67	0.96	34.82	2.48	90.31	2.73	99.33
77	Kitisuru	24.61	13.46	28.95	8.06	1,315.9	0.36	4.11	4.20	47.77	7.70	87.61	8.43	95.89
78	Spring Valley	24.65	13.51	29.01	8.06	1,292.8	0.15	6.88	0.62	29.19	2.13	99.93	1.98	93.12
79	Upper Parklands	24.75	13.62	28.99	8.06	1,285.7	0.15	6.35	0.77	32.41	2.37	99.98	2.22	93.65
80	Highridge	24.82	13.68	29.45	8.06	1,253.8	0.51	13.31	0.93	24.20	3.83	100.01	3.32	86.69
81	Ngara West	24.89	13.82	29.62	8.06	1,234.8	0.27	20.73	0.08	6.43	1.29	99.92	1.02	79.27
82	City Centre	24.93	13.94	30.16	8.06	1,227.9	0.24	17.21	0.09	6.19	1.31	93.96	1.15	82.79
83	City Square	24.91	13.99	30.14	8.06	1,204.6	0.08	6.47	0.17	12.82	1.31	100.23	1.23	93.53
84	Nairobi West	24.94	14.12	30.24	8.06	1,134.8	0.45	6.31	0.11	1.61	2.77	39.24	6.62	93.69
85	Kenyatta Golf course	24.89	13.92	30.04	8.06	1,195.6	2.32	43.92	0.13	2.38	3.91	74.02	2.96	56.08
86	Mugumoini	24.95	13.86	29.83	8.06	1,160.4	0.23	7.81	0.42	14.14	2.04	68.29	2.75	92.19
87	Laini Saba	24.91	13.88	29.55	8.06	1,192.8	0.20	51.87	0.00	1.19	0.15	38.65	0.18	48.13
88	Silanga	24.89	13.91	29.45	8.06	1,201.4	0.20	76.05	0.00	0.00	0.21	79.68	0.06	23.95
89	Olympic	24.92	13.58	29.58	8.06	1,235.4	0.01	0.92	0.71	94.11	0.75	100.21	0.74	99.08
90	Makina	24.85	13.61	29.24	8.06	1,245.6	0.05	7.71	0.21	31.04	0.58	84.67	0.63	92.29
91	Kibera	24.87	13.66	28.98	8.06	1,250.8	0.11	60.68	0.00	0.00	0.09	51.61	0.07	39.32
92	Soweto	24.86	13.72	29.43	8.06	1,206.4	0.23	61.90	0.00	0.00	0.21	56.74	0.14	38.10
93	Lindi	24.82	13.84	29.66	8.06	1,220.4	0.10	18.87	0.00	0.91	0.44	85.59	0.41	81.13

SN	Sublocations	Climate					Urban Form							
		AATx (℃)	AATn (℃)	HAT (℃)	LAT (℃)	R (mm)	BUA (Km^2)	BUA (%)	Forest (Km^2)	Forest (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
94	Gatwikira	24.88	13.48	29.24	8.06	1,262.6	0.03	11.51	0.13	46.59	0.28	101.06	0.25	88.49
95	Uthiru	24.28	13.09	28.98	8.06	1,400.9	0.21	6.88	0.51	16.41	2.52	80.88	2.90	93.12
96	Ruthimitu	24.48	13.14	29.43	8.06	1,392.3	0.36	7.22	0.46	9.39	2.52	50.92	4.58	92.78
97	Waithaka	24.51	13.21	29.85	8.06	1,398.2	0.05	2.05	0.05	2.39	2.09	91.71	2.23	97.95
98	Loresho	24.26	13.27	28.81	8.06	1,382.5	0.63	6.75	2.33	24.76	8.86	94.28	8.77	93.25
99	Kyuna	24.58	13.46	28.51	8.06	1,322.6	0.48	14.15	0.45	13.15	3.32	97.47	2.93	85.85
100	Kilimani	24.82	13.55	28.96	8.06	1,230.4	0.69	7.66	0.51	5.67	8.39	93.73	8.26	92.34
101	Riruta	24.51	13.12	29.81	8.06	1,364.5	0.05	1.08	0.66	15.72	3.50	83.45	4.14	98.92
102	Ngando	24.66	13.18	28.76	8.06	1,300.4	0.04	1.28	1.99	63.23	2.93	93.43	3.10	98.72
103	Kawangware	24.58	13.26	28.88	8.06	1,320.6	0.16	6.69	0.04	1.71	2.03	83.72	2.27	93.31
104	Gatina	24.62	13.24	28.69	8.06	1,313.3	0.58	36.90	0.07	4.67	1.14	72.63	0.99	63.10
105	Maziwa	24.65	13.28	28.56	8.06	1,296.7	0.50	6.93	1.04	14.39	6.85	95.03	6.71	93.07
106	Muthangari	24.62	13.45	28.97	8.06	1,300.4	0.18	4.66	1.34	34.24	3.90	99.75	3.73	95.34
107	Gichagi	24.49	13.17	28.42	8.06	1,375.8	0.08	8.33	0.08	8.79	0.94	100.06	0.86	91.67
108	Kangemi	24.51	13.27	28.38	8.06	1,388.9	0.17	10.86	0.20	12.90	1.50	96.66	1.38	89.14
109	Mountain View	24.35	13.14	28.34	8.06	1,398.4	0.06	2.50	0.45	20.21	2.21	99.89	2.15	97.50
110	Kileleshwa	24.81	13.35	29.02	8.06	1,299.1	0.19	3.54	1.32	24.96	5.29	100.09	5.10	96.46
111	Woodley	24.92	13.3	29.33	8.06	1,300.9	0.39	8.76	2.87	64.72	3.76	84.96	4.04	91.24

Appendix XV: Interpolated Urban Form and Climatic Data for 1998

SN	Sublocation	Climate					Urban Form							
		AATx (ºC)	AATn (ºC)	HAT (ºC)	LAT (ºC)	R (mm)	BUA (Km2)	BUA %)	F (Km2)	F (%)	NDVI (Km2)	NDVI (%)	OSN (Km2)	OSN (%)
0	Mihango	24.79	13.85	30.24	9.04	1,402.70	0.39	2.55	0.03	0.22	0.19	1.22	14.95	97.45
1	Ruai	25.07	14.04	30.88	9.04	1,315.10	0.72	1.45	0.00	0.00	14.14	28.50	48.90	98.55
2	Eastleigh North	24.79	13.66	28.96	9.04	1,402.70	0.37	40.40	0.00	0.00	0.00	0.00	0.54	59.60
3	California	24.79	13.66	28.96	9.04	1,402.70	0.36	74.93	0.00	0.00	0.00	0.00	0.12	25.07
4	Ngandu	25.07	14.04	30.88	9.04	1,227.50	0.40	0.77	0.00	0.00	4.40	8.46	51.63	99.23
5	Mbotela	24.79	13.85	30.24	9.04	1,402.70	0.43	97.21	0.00	0.00	0.00	0.00	0.01	2.79
6	Makongeni	24.79	13.85	30.88	9.04	1,402.70	0.63	96.17	0.00	0.00	0.00	0.00	0.03	3.83
7	Kaloleni	24.79	13.85	30.88	9.04	1,402.70	0.56	90.65	0.00	0.00	0.00	0.00	0.06	9.35
8	Shauri Moyo	24.79	13.66	28.96	9.04	1,402.70	0.49	76.95	0.00	0.21	0.00	0.00	0.15	23.05
9	Muthurwa	24.79	13.66	30.88	9.04	1,402.70	0.32	60.87	0.01	2.44	0.03	6.15	0.20	39.13
10	Ofafa Maringo	24.79	13.85	30.24	9.04	1,402.70	0.35	51.95	0.00	0.00	0.00	0.00	0.33	48.05
11	Hamza	24.79	13.85	30.24	9.04	1,402.70	0.31	32.99	0.00	0.00	0.03	3.23	0.62	67.01
12	Lumumba	24.79	13.85	30.24	9.04	1,402.70	0.32	82.28	0.00	0.00	0.00	0.00	0.07	17.72
13	Majengo	24.79	13.66	30.24	9.04	1,402.70	0.22	72.37	0.02	7.02	0.00	0.00	0.09	27.63
14	Bondeni	24.79	13.66	30.24	9.04	1,402.70	0.14	83.61	0.00	2.01	0.00	0.00	0.03	16.39
15	Gikomba	24.79	13.66	30.24	9.04	1,402.70	0.07	95.97	0.00	0.00	0.00	0.00	0.00	4.03
16	Kamukunji	24.79	13.66	30.24	9.04	1,402.70	0.18	77.57	0.01	2.76	0.00	0.00	0.05	22.43
17	Kimathi	24.79	13.85	30.24	9.04	1,402.70	0.71	52.42	0.01	0.47	0.04	3.04	0.64	47.58
18	Eastleigh South	24.79	13.66	30.24	9.04	1,402.70	0.24	21.65	0.00	0.39	0.01	0.90	0.87	78.35
19	Air Base	24.79	13.66	28.96	9.04	1,402.70	2.08	41.05	0.04	0.70	0.37	7.33	2.98	58.95
20	Uhuru	24.79	13.85	28.96	9.04	1,402.70	0.55	35.94	0.00	0.00	0.11	7.39	0.98	64.06
21	Harambee	24.79	13.85	30.24	9.04	1,402.70	1.34	61.03	0.01	0.24	0.02	1.09	0.86	38.97
22	Bomas	25.07	13.85	31.52	8.06	1,402.70	1.26	1.00	4.11	3.28	10.92	8.71	124.10	99.00
23	Embakasi	24.79	14.04	30.24	8.06	1,139.90	4.81	10.54	0.00	0.01	2.02	4.42	40.85	89.46

SN	Sublocation	Climate					Urban Form							
		AATx (ºC)	AATn (ºC)	HAT (ºC)	LAT (ºC)	R (mm)	BUA (Km2)	BUA %)	F (Km2)	F (%)	NDVI (Km2)	NDVI (%)	OSN (Km2)	OSN (%)
24	Umoja	24.79	13.85	30.24	9.04	1,402.70	1.66	53.30	0.00	0.00	0.16	5.13	1.46	46.70
25	Mlango Kubwa	24.79	13.66	28.96	9.04	1,402.70	0.53	117.60	0.01	2.11	0.01	3.11	0.08	17.60
26	Mabatini	24.79	13.66	28.96	9.04	1,402.70	0.08	21.11	0.00	0.34	0.02	4.32	0.29	78.89
27	Mathare	24.79	13.66	28.96	9.04	1,402.70	0.50	61.52	0.07	8.25	0.00	0.00	0.32	38.48
28	Pangani	24.79	13.66	28.96	9.04	1,402.70	1.20	72.15	0.00	0.00	0.11	6.29	0.47	27.85
29	Ziwani/Kariokor	24.79	13.66	30.24	9.04	1,402.70	0.78	93.69	0.00	0.00	0.00	0.00	0.05	6.31
30	Ngara East	24.79	13.66	30.24	9.04	1,402.70	0.85	63.30	0.03	2.38	0.01	0.60	0.49	36.70
31	Garden	24.79	13.66	28.96	10.32	1,402.70	0.27	2.10	4.58	35.60	10.92	84.91	12.59	97.90
32	Roysambu	24.79	13.66	28.96	10.32	1,402.70	0.24	2.46	0.58	5.81	3.31	33.33	9.70	97.54
33	Kiwanja	24.79	13.85	28.96	10.32	1,402.70	1.20	13.52	0.04	0.45	1.10	12.44	7.65	86.48
34	Kahawa West	24.79	13.85	28.96	10.32	1,402.70	0.48	9.33	0.01	0.22	0.90	17.42	4.67	90.67
35	Kongo Soweto	24.79	13.85	28.96	10.32	1,402.70	0.05	3.97	0.01	0.96	0.99	80.73	1.18	96.03
36	Kamuthi	24.79	13.85	28.96	10.32	1,402.70	0.16	14.34	0.05	3.98	0.28	24.35	0.99	85.66
37	Githurai	24.79	13.85	28.96	10.32	1,402.70	0.48	24.08	0.01	0.51	0.37	18.79	1.50	75.92
38	Zimmerman	24.79	13.85	28.96	10.32	1,402.70	0.25	13.05	0.02	1.29	0.29	15.27	1.63	86.95
39	Savannah	24.79	13.85	30.24	9.04	1,402.70	1.50	31.22	0.00	0.00	0.73	15.26	3.31	68.78
40	Kayole	24.79	13.85	28.96	9.04	1,402.70	1.41	57.45	0.00	0.00	0.08	3.18	1.04	42.55
41	Komarock	24.79	13.85	28.96	9.04	1,402.70	1.22	38.87	0.00	0.00	0.33	10.51	1.92	61.13
42	Karen	24.93	13.85	29.62	8.06	1,402.70	0.57	2.42	3.76	16.01	13.34	56.79	22.92	97.58
43	Hardy	24.93	13.85	33.43	8.06	1,402.70	0.94	6.41	1.62	11.08	6.85	46.76	13.71	93.59
44	Langata	24.93	13.85	33.43	8.06	1,402.70	0.20	1.14	3.30	18.70	5.24	29.69	17.44	98.86
45	Mukuru Kwa Njenga	25.07	13.85	30.88	8.06	1,402.70	0.77	9.11	0.00	0.02	0.25	3.01	7.68	90.89
46	South C	25.07	13.85	30.88	8.06	1,315.10	0.84	5.45	0.00	0.00	0.05	0.31	14.48	94.55

SN	Sublocation	Climate					Urban Form							
		AATx (ºC)	AATn (ºC)	HAT (ºC)	LAT (ºC)	R (mm)	BUA (Km2)	BUA %)	F (Km2)	F (%)	NDVI (Km2)	NDVI (%)	OSN (Km2)	OSN (%)
47	Land Mawe	25.07	13.85	30.88	9.04	1,402.70	3.20	57.68	0.04	0.75	0.54	9.78	2.34	42.32
48	Viwandani	24.79	13.85	30.88	9.04	1,402.70	3.50	60.84	0.00	0.00	0.73	12.61	2.25	39.16
49	Imara Daima	25.07	13.85	30.88	9.04	1,402.70	1.71	42.43	0.00	0.00	0.05	1.34	2.33	57.57
50	Hazina	25.07	13.85	31.52	9.04	1,402.70	1.28	28.99	0.00	0.00	0.03	0.77	3.15	71.01
51	Nairobi South	25.07	13.85	31.52	9.04	1,402.70	1.39	88.22	0.00	0.00	0.03	2.17	0.18	11.78
52	Karura	24.79	13.46	28.33	9.04	1,402.70	0.24	1.22	4.58	23.33	17.29	88.05	19.39	98.78
53	Njathaini	24.79	13.66	28.96	10.32	1,402.70	0.14	2.68	1.02	18.96	3.34	62.01	5.24	97.32
54	Huruma	24.79	13.66	28.96	9.04	1,402.70	0.44	60.79	0.00	0.00	0.00	0.00	0.28	39.21
55	Kiamaiko	24.79	13.85	28.96	9.04	1,402.70	0.37	52.92	0.00	0.00	0.00	0.00	0.32	47.08
56	Utalii	24.79	13.66	28.96	10.32	1,402.70	0.65	37.85	0.02	1.05	0.17	9.82	1.06	62.15
57	Mathare North	24.79	13.66	28.96	10.32	1,402.70	0.31	66.08	0.00	0.00	0.05	9.79	0.16	33.92
58	Mathare 4a	24.79	13.66	28.96	9.04	1,402.70	0.14	56.88	0.00	0.00	0.00	0.00	0.11	43.12
59	Mowlem	24.79	13.85	28.96	9.04	1,402.70	1.04	29.57	0.01	0.34	0.50	14.23	2.48	70.43
60	Kariobangi South	24.79	13.85	28.96	9.04	1,402.70	0.85	59.35	0.01	0.72	0.14	9.79	0.58	40.65
61	Njiru	24.79	13.85	28.96	9.04	1,402.70	1.90	35.86	0.02	0.30	0.74	13.91	3.39	64.14
62	Saika	24.79	13.85	28.96	9.04	1,402.70	1.24	31.24	0.00	0.00	0.39	9.92	2.72	68.76
63	Mwiki	24.79	13.85	28.96	9.04	1,402.70	1.98	10.29	0.45	2.34	4.07	21.17	17.22	89.71
64	Dandora B	24.79	13.85	28.96	9.04	1,402.70	1.26	63.79	0.00	0.00	0.17	8.69	0.72	36.21
65	Dandora A	24.79	13.85	28.96	9.04	1,402.70	1.20	61.55	0.00	0.14	0.15	7.54	0.75	38.45
66	Korogocho	24.79	13.85	28.96	9.04	1,402.70	0.12	63.67	0.00	0.00	0.01	3.16	0.07	36.33
67	Nyayo	24.79	13.85	28.96	9.04	1,402.70	0.21	89.38	0.00	0.00	0.02	9.17	0.03	10.62
68	Gitathuru	24.79	13.85	28.96	9.04	1,402.70	0.36	71.73	0.00	0.00	0.00	0.00	0.14	28.27
69	Kariobangi North	24.79	13.85	28.96	9.04	1,402.70	0.76	70.08	0.00	0.00	0.00	0.00	0.33	29.92
70	Ruaraka	24.79	13.85	28.96	10.32	1,402.70	1.74	43.73	0.06	1.56	0.33	8.29	2.24	56.27

SN	Sublocation	Climate					Urban Form							
		AATx (ºC)	AATn (ºC)	HAT (ºC)	LAT (ºC)	R (mm)	BUA (Km2)	BUA %)	F (Km2)	F (%)	NDVI (Km2)	NDVI (%)	OSN (Km2)	OSN (%)
71	Kasarani	24.79	13.85	28.96	10.32	1,402.70	2.04	17.44	0.25	2.18	1.74	14.89	9.64	82.56
72	Muthaiga	24.79	13.46	28.96	9.04	1,402.70	1.11	5.80	8.12	42.57	13.65	71.53	17.97	94.20
73	Lenana	24.79	13.85	32.79	8.06	1,402.70	0.12	0.73	4.75	28.24	11.30	67.23	16.69	99.27
74	Mutuini	24.79	13.66	31.52	8.06	1,402.70	0.03	0.79	0.42	12.85	2.43	73.58	3.27	99.21
75	Kirigu	24.79	13.46	30.88	8.06	1,402.70	0.03	1.62	0.08	4.94	0.37	21.58	1.68	98.38
76	Kabiria	24.79	13.46	30.88	8.06	1,402.70	0.01	0.26	0.37	13.61	1.69	61.56	2.74	99.74
77	Kitisuru	24.79	13.46	28.33	8.06	1,402.70	0.07	0.77	1.90	21.59	6.31	71.75	8.72	99.23
78	Spring Valley	24.79	13.46	28.96	9.04	1,402.70	0.10	4.73	0.33	15.26	1.69	79.20	2.03	95.27
79	Upper Parklands	24.79	13.46	28.96	9.04	1,402.70	0.10	4.24	0.24	10.04	2.04	86.16	2.27	95.76
80	Highridge	24.79	13.66	28.96	9.04	1,402.70	0.81	21.11	0.64	16.70	1.90	49.69	3.02	78.89
81	Ngara West	24.79	13.66	30.24	9.04	1,402.70	0.73	56.31	0.25	19.04	0.43	33.49	0.56	43.69
82	City Centre	25.07	13.66	30.24	9.04	1,402.70	0.38	27.16	0.07	4.77	0.23	16.26	1.01	72.84
83	City Square	25.07	13.66	30.88	9.04	1,402.70	0.17	12.72	0.21	16.16	0.50	38.17	1.14	87.28
84	Nairobi West	25.07	13.85	29.62	9.04	1,402.70	1.01	14.28	0.00	0.00	0.68	9.55	6.06	85.72
85	Kenyatta Golf course	25.07	13.85	31.52	9.04	1,402.70	2.29	43.31	0.04	0.67	0.75	14.24	2.99	56.69
86	Mugumoini	24.93	13.85	32.79	8.06	1,402.70	0.77	25.99	0.41	13.80	0.79	26.61	2.21	74.01
87	Laini Saba	24.93	13.85	29.62	8.06	1,402.70	0.08	20.97	0.00	0.00	0.00	0.00	0.30	79.03
88	Silanga	24.93	13.85	29.62	8.06	1,402.70	0.17	66.68	0.00	0.00	0.00	0.00	0.09	33.32
89	Olympic	24.93	13.85	32.79	8.06	1,402.70	-	-	0.70	93.91	0.70	93.07	0.75	100.00
90	Makina	24.93	13.85	32.79	8.06	1,402.70	0.07	10.45	0.35	50.81	0.41	60.44	0.61	89.55
91	Kibera	24.93	13.85	29.62	8.06	1,402.70	0.13	70.71	0.00	0.00	0.00	0.00	0.05	29.29
92	Soweto	24.93	13.85	29.62	8.06	1,402.70	0.20	54.05	0.00	0.79	0.00	0.00	0.17	45.95
93	Lindi	24.93	13.85	32.79	8.06	1,402.70	0.11	21.49	0.00	0.00	0.05	9.41	0.40	78.51
94	Gatwikira	24.93	13.85	32.79	8.06	1,402.70	0.02	6.59	0.10	36.27	0.19	67.86	0.26	93.41

SN	Sublocation	Climate					Urban Form							
		AATx (ºC)	AATn (ºC)	HAT (ºC)	LAT (ºC)	R (mm)	BUA (Km2)	BUA %)	F (Km2)	F (%)	NDVI (Km2)	NDVI (%)	OSN (Km2)	OSN (%)
95	Uthiru	24.79	13.46	28.96	8.06	1,402.70	0.04	1.43	0.17	5.58	1.51	48.68	3.07	98.57
96	Ruthimitu	24.79	13.46	28.96	8.06	1,402.70	0.19	3.91	0.08	1.69	1.56	31.48	4.75	96.09
97	Waithaka	24.79	13.46	28.96	8.06	1,402.70	0.06	2.53	0.03	1.22	0.83	36.27	2.22	97.47
98	Loresho	24.51	13.27	28.96	8.06	1,402.70	0.56	5.91	1.05	11.18	3.08	32.71	8.84	94.09
99	Kyuna	24.79	13.46	28.96	8.06	1,402.70	0.50	14.77	0.32	9.40	1.34	39.15	2.91	85.23
100	Kilimani	25.07	13.66	31.52	9.04	1,402.70	1.10	12.27	0.73	8.21	3.16	35.28	7.85	87.73
101	Riruta	25.07	13.46	31.52	8.06	1,402.70	0.14	3.40	0.18	4.41	1.47	35.18	4.05	96.60
102	Ngando	24.93	13.66	29.62	8.06	1,402.70	0.04	1.13	1.52	48.34	2.43	77.42	3.10	98.87
103	Kawangware	25.07	13.46	30.88	8.06	1,402.70	0.30	12.18	0.02	0.72	0.45	18.48	2.13	87.82
104	Gatina	25.07	13.46	30.88	8.06	1,402.70	0.58	37.11	0.01	0.73	0.20	12.87	0.99	62.89
105	Maziwa	25.07	13.66	29.62	8.06	1,402.70	0.96	13.36	0.66	9.18	2.87	39.79	6.25	86.64
106	Muthangari	24.79	13.46	28.96	8.06	1,402.70	0.16	4.19	0.44	11.36	1.85	47.34	3.75	95.81
107	Gichagi	24.79	13.46	28.96	8.06	1,402.70	0.02	1.62	0.07	7.46	0.43	46.17	0.92	98.38
108	Kangemi	24.79	13.46	28.96	8.06	1,402.70	0.20	13.16	0.04	2.66	0.68	44.06	1.35	86.84
109	Mountain View	24.79	13.46	28.33	8.06	1,402.70	0.03	1.45	0.16	7.20	1.23	55.66	2.18	98.55
110	Kileleshwa	25.07	13.66	30.88	8.06	1,402.70	0.11	1.99	0.78	14.71	2.48	46.79	5.18	98.01
111	Woodley	24.93	13.85	32.79	8.06	1,402.70	0.31	7.05	1.72	38.74	2.97	67.00	4.12	92.95

Appendix XVI: Interpolated Urban Form and Climatic Data for 2008

SN	Sublocation	Climate					Urban Form							
		AATx (ºC)	AATn (ºC)	HAT (ºC)	LAT (ºC)	R (mm)	BUA (Km^2)	BUA (%)	F (Km^2)	F (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
0	Mihango	24.79	14.23	30.88	10.32	614.4	1.1	7.17	0.00	0.00	0.29	1.89	14.24	92.83
1	Ruai	24.79	14.23	30.88	10.32	658.2	1.9	3.83	0.04	0.08	4.19	8.44	47.72	96.17
2	Eastleigh North	25	14.23	30.88	11.01	789.6	0.59	64.84	0.00	0.00	0.03	3.30	0.32	35.16
3	California	25.07	14.23	30.88	11.01	789.6	0.38	79.17	0.00	0.00	0.00	0.00	0.1	20.83
4	Ngandu	25.79	14.23	30.88	9.04	702	0.3	0.58	0.03	0.06	1.46	2.81	51.73	99.42
5	Mbotela	25.07	14.42	30.88	11.01	789.6	0.4	90.91	0.00	0.00	0.00	0.00	0.04	9.09
6	Makongeni	25.07	14.42	26.92	11.01	789.6	0.63	95.45	0.00	0.00	0.00	0.00	0.03	4.55
7	Kaloleni	25.07	14.42	26.92	11.01	789.6	0.53	85.48	0.00	0.00	0.00	0.00	0.09	14.52
8	Shauri Moyo	25.07	14.42	26.92	11.01	789.6	0.54	84.38	0.00	0.00	0.00	0.00	0.1	15.63
9	Muthurwa	25.07	14.23	26.92	11.01	789.6	0.31	59.62	0.02	3.85	0.11	21.15	0.21	40.38
10	Ofafa Maringo	25.07	14.23	30.88	11.01	789.6	0.25	36.76	0.00	0.00	0.00	0.00	0.43	63.24
11	Hamza	25	14.23	30.88	11.01	702	0.25	26.88	0.00	0.00	0.02	2.15	0.68	73.12
12	Lumumba	25	14.23	30.88	11.01	702	0.17	43.59	0.00	0.00	0.01	2.56	0.22	56.41
13	Majengo	25.07	14.23	26.92	11.01	789.6	0.25	80.65	0.00	0.00	0.00	0.00	0.06	19.35
14	Bondeni	25.07	14.23	26.92	11.01	789.6	0.09	52.94	0.00	0.00	0.00	0.00	0.08	47.06
15	Gikomba	25.07	14.23	26.92	11.01	789.6	0.06	85.71	0.00	0.00	0.00	0.00	0.01	14.29
16	Kamukunji	25.07	14.23	26.92	11.01	789.6	0.18	78.26	0.00	0.00	0.00	0.00	0.05	21.74
17	Kimathi	25.07	14.42	30.88	11.01	702	1.32	97.78	0.00	0.00	0.00	0.00	0.03	2.22
18	Eastleigh South	25.07	14.23	30.88	11.01	702	0.6	54.05	0.00	0.00	0.12	10.81	0.51	45.95
19	Air Base	24.7	14.23	30.88	11.01	702	2.34	46.25	0.00	0.00	0.22	4.35	2.72	53.75
20	Uhuru	24.79	14.23	30.88	11.01	702	0.93	60.78	0.00	0.00	0.23	15.03	0.6	39.22
21	Harambee	24.79	14.23	30.88	11.01	702	1.24	56.36	0.00	0.00	0.08	3.64	0.96	43.64

SN	Sublocation	Climate					Urban Form							
		AATx (ºC)	AAT n (ºC)	HAT (ºC)	LAT (ºC)	R (mm)	BUA (Km^2)	BUA (%)	F (Km^2)	F (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
22	Bomas	24.86	14.42	29.62	11.01	833.3	0.61	0.49	6.79	5.42	6.08	4.85	124.75	99.51
23	Embakasi	24.79	14.23	30.88	11.01	702	9.01	19.73	0.00	0.00	1.48	3.24	36.65	80.27
24	Umoja	24.79	14.23	30.88	11.01	702	2.4	76.92	0.00	0.00	0.14	4.49	0.72	23.08
25	Mlango Kubwa	24.79	14.23	30.88	11.01	702	0.41	91.11	0.00	0.00	0.00	0.00	0.04	8.89
26	Mabatini	24.79	14.23	30.88	11.01	702	0.27	72.97	0.00	0.00	0.00	0.00	0.1	27.03
27	Mathare	24.79	14.23	30.88	11.01	789.6	0.75	91.46	0.00	0.00	0.06	7.32	0.07	8.54
28	Pangani	25	14.23	29.62	11.01	789.6	1.49	89.22	0.00	0.00	0.07	4.19	0.18	10.78
29	Ziwani/Kario kor	25.07	14.23	29.62	11.01	789.6	0.83	100.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Ngara East	25.07	14.23	29.62	11.01	789.6	1.16	86.57	0.01	0.75	0.07	5.22	0.18	13.43
31	Garden	24.79	14.23	30.88	11.01	702	0.64	4.98	2.89	22.47	8.19	63.69	12.22	95.02
32	Roysambu	24.79	14.23	32.79	11.01	702	0.79	7.95	0.28	2.82	3.79	38.13	9.15	92.05
33	Kiwanja	24.79	14.23	32.79	11.01	614.4	1.89	21.36	0.21	2.37	1.32	14.92	6.96	78.64
34	Kahawa West	24.79	14.23	32.79	11.01	614.4	0.65	12.62	0.14	2.72	0.89	17.28	4.5	87.38
35	Kongo Soweto	24.79	14.23	32.79	11.01	614.4	0.07	5.69	0.05	4.07	0.28	22.76	1.16	94.31
36	Kamuthi	24.79	14.23	32.79	11.01	614.4	0.37	32.17	0.08	6.96	0.28	24.35	0.78	67.83
37	Githurai	24.79	14.23	32.79	11.01	614.4	0.52	26.26	0.04	2.02	0.68	34.34	1.46	73.74
38	Zimmerman	24.79	14.23	32.79	11.01	614.4	0.71	37.77	0.04	2.13	0.43	22.87	1.17	62.23
39	Savannah	24.79	14.23	30.88	10.32	702	2.7	56.13	0.00	0.00	0.38	7.90	2.11	43.87
40	Kayole	24.79	14.23	30.88	10.32	614.4	2.07	84.49	0.00	0.00	0.15	6.12	0.38	15.51
41	Komarock	24.79	14.23	30.88	10.7	658.2	1.97	62.74	0.00	0.00	0.09	2.87	1.17	37.26
42	Karen	25.07	13.46	27.69	7.08	877.2	0.24	1.02	5.87	24.99	15.18	64.62	23.25	98.98
43	Hardy	24.93	14.23	28.33	8.06	789.6	0.64	4.37	2.01	13.72	8.01	54.68	14.01	95.63

SN	Sublocation	Climate					Urban Form							
		AATx (ºC)	AATn (ºC)	HAT (ºC)	LAT (ºC)	R (mm)	BUA (Km^2)	BUA (%)	F (Km^2)	F (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
44	Langata	24.7	13.85	28.33	8.06	789.6	0.08	0.45	3.76	21.32	11.64	65.99	17.56	99.55
45	Mukuru Kwa Njenga	24.79	14.23	29.62	10.32	702	3.7	43.79	0.00	0.00	0.33	3.91	4.75	56.21
46	South C	25.07	14.42	29.62	10.67	789.6	0.02	0.13	0.00	0.00	0.00	0.00	15.3	99.87
47	Land Mawe	25.07	14.42	29.62	11.01	833.4	4.27	77.08	0.04	0.72	0.77	13.90	1.27	22.92
48	Viwandani	25.07	14.33	30.88	11.01	789.6	4.42	76.87	0.00	0.00	0.54	9.39	1.33	23.13
49	Imara Daima	25.07	14.42	30.88	11.67	789.6	0.33	8.17	0.00	0.00	0.12	2.97	3.71	91.83
50	Hazina	25.07	14.42	29.62	11.01	789.6	1.11	25.06	0.00	0.00	0.24	5.42	3.32	74.94
51	Nairobi South	25.07	14.42	29.62	10.32	833.4	0.8	50.96	0.00	0.00	0.15	9.55	0.77	49.04
52	Karura	24.79	13.85	29.62	11.01	833.4	0.42	2.14	4.49	22.87	12.6	64.19	19.21	97.86
53	Njathaini	24.79	14.23	32.79	11.01	702	0.32	5.95	0.9	16.73	2.29	42.57	5.06	94.05
54	Huruma	24.79	14.23	30.88	11.01	702	0.43	59.72	0.00	0.00	0.01	1.39	0.29	40.28
55	Kiamaiko	24.79	14.23	30.88	11.01	702	0.36	52.17	0.00	0.00	0.03	4.35	0.33	47.83
56	Utalii	24.79	14.23	30.88	11.01	702	0.65	38.01	0.00	0.00	0.26	15.20	1.06	61.99
57	Mathare North	24.79	14.23	30.88	11.01	702	0.31	65.96	0.00	0.00	0.06	12.77	0.16	34.04
58	Mathare 4a	24.79	14.04	30.88	11.01	702	0.23	92.00	0.00	0.00	0.08	32.00	0.02	8.00
59	Mowlem	24.79	14.23	30.88	11.01	702	1.94	55.11	0.00	0.00	0.19	5.40	1.58	44.89
60	Kariobangi South	24.79	14.23	30.88	11.01	702	1.05	73.43	0.00	0.00	0.11	7.69	0.38	26.57
61	Njiru	24.79	14.23	32.79	10.32	614.4	2.95	55.77	0.09	1.70	0.62	11.72	2.34	44.23
62	Saika	24.79	14.23	32.79	11.01	614.4	2.5	63.13	0.00	0.00	0.24	6.06	1.46	36.87
63	Mwiki	24.79	14.23	32.79	10.32	614.4	2.1	10.94	0.16	0.83	3.86	20.10	17.1	89.06
64	Dandora B	24.79	14.23	32.79	11.01	614.4	1.49	75.25	0.00	0.00	0.21	10.61	0.49	24.75
65	Dandora A	24.79	14.23	32.79	11.01	658.2	1.35	69.23	0.00	0.00	0.29	14.87	0.6	30.77

SN	Sublocation	Climate					Urban Form							
		AATx (ºC)	AAT n (ºC)	HAT (ºC)	LAT (ºC)	R (mm)	BUA (Km^2)	BUA (%)	F (Km^2)	F (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
66	Korogocho	24.79	14.23	32.79	11.01	702	0.15	78.95	0.00	0.00	0.00	0.00	0.04	21.05
67	Nyayo	24.79	14.23	32.79	11.01	702	0.16	66.67	0.00	0.00	0.00	0.00	0.08	33.33
68	Gitathuru	24.79	14.23	32.79	11.01	702	0.41	82.00	0.00	0.00	0.09	18.00	0.09	18.00
69	Kariobangi North	24.79	14.23	32.79	11.01	702	0.74	67.89	0.00	0.00	0.00	0.00	0.35	32.11
70	Ruaraka	24.79	14.23	32.79	11.01	702	2.18	54.77	0.04	1.01	0.57	14.32	1.80	45.23
71	Kasarani	24.79	14.23	32.79	11.01	614.4	4.26	36.47	0.1	0.86	2.25	19.26	7.42	63.53
72	Muthaiga	24.79	14.04	29.62	10.67	833.4	2.38	12.47	0.19	1.00	14.06	73.69	16.7	87.53
73	Lenana	24.65	13.36	27.69	7.08	877.2	0.18	1.07	5.82	34.62	11.58	68.89	16.63	98.93
74	Mutuini	24.79	13.66	27.69	7.08	964.8	0.07	2.12	0.71	21.52	1.57	47.58	3.23	97.88
75	Kirigu	24.79	13.5	27.69	7.08	964.8	0.03	1.75	0.2	11.70	0.55	32.16	1.68	98.25
76	Kabiria	24.72	13.5	27.69	7.08	964.8	0.24	8.73	0.55	20.00	1.81	65.82	2.51	91.27
77	Kitisuru	24.45	13.85	28.96	9.04	964.8	0.11	1.25	2.76	31.40	0.53	6.03	8.68	98.75
78	Spring Valley	24.79	13.85	28.96	10.32	877.2	0.52	24.41	0.58	27.23	1.38	64.79	1.61	75.59
79	Upper Parklands	24.79	13.85	28.96	10.32	877.2	0.89	37.55	0.3	12.66	1.56	65.82	1.48	62.45
80	Highridge	24.79	14.23	29.62	10.32	833.4	2.21	57.70	0.73	19.06	1.16	30.29	1.62	42.30
81	Ngara West	24.65	14.23	29.62	11.01	789.6	0.51	39.53	0.19	14.73	0.54	41.86	0.78	60.47
82	City Centre	25.07	14.23	29.62	11.01	789.6	0.62	44.60	0.04	2.88	0.39	28.06	0.77	55.40
83	City Square	25.07	14.23	29.62	11.01	877.2	0.53	40.46	0.13	9.92	0.51	38.93	0.78	59.54
84	Nairobi West	24.93	14.23	28.96	11.01	877.2	1.13	15.98	0.34	4.81	1.44	20.37	5.94	84.02
85	Kenyatta Golf course	25.07	14.23	28.96	10.67	877.2	2.61	49.43	0.31	5.87	1.02	19.32	2.67	50.57
86	Mugumoini	24.93	14.28	28.96	10.32	877.2	0.52	17.45	0.26	8.72	0.79	26.51	2.46	82.55
87	Laini Saba	24.93	14.33	28.96	10.32	877.2	0.15	39.47	0.00	0.00	0.04	10.53	0.23	60.53

SN	Sublocation	Climate					Urban Form							
		AATx (ºC)	AAT n (ºC)	HAT (ºC)	LAT (ºC)	R (mm)	BUA (Km^2)	BUA (%)	F (Km^2)	F (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
88	Silanga	23.93	14.33	28.96	10.32	877.2	0.19	73.08	0.00	0.00	0.00	0.00	0.07	26.92
89	Olympic	25.07	13.95	28.33	9.04	789.6	0	-	0.66	88.00	0.79	105.33	0.75	100.00
90	Makina	25.07	14.28	28.33	9.04	877.2	0.19	27.94	0.26	38.24	0.43	63.24	0.49	72.06
91	Kibera	25.07	14.28	28.96	10.32	877.2	0.13	72.22	0.00	0.00	0.00	0.00	0.05	27.78
92	Soweto	24.93	14.28	28.96	10.32	877.2	0.14	37.84	0.00	0.00	0.08	21.62	0.23	62.16
93	Lindi	24.93	14.28	28.96	10.32	877.2	0.17	33.33	0.00	0.00	0.07	13.73	0.34	66.67
94	Gatwikira	24.93	14.28	28.96	9.04	877.2	0.09	32.14	0.06	21.43	0.11	39.29	0.19	67.86
95	Uthiru	24.51	13.27	27.69	7.08	1052.4	0.05	1.61	0.44	14.15	1.98	63.67	3.06	98.39
96	Ruthimitu	24.51	13.27	27.69	7.08	1052.4	0.19	3.85	0.21	4.25	1.8	36.44	4.75	96.15
97	Waithaka	24.51	13.46	27.69	7.08	1052.4	0.11	4.82	0.05	2.19	1.26	55.26	2.17	95.18
98	Loresho	24.65	13.46	28.01	7.08	1402.8	0.83	8.83	0.1	1.06	4.75	50.53	8.57	91.17
99	Kyuna	24.51	13.85	28.33	9.04	964.8	0.79	23.17	0.41	12.02	1.66	48.68	2.62	76.83
100	Kilimani	25.07	13.95	28.96	10.32	877.2	3.43	38.32	0.51	5.70	3.12	34.86	5.52	61.68
101	Riruta	24.65	13.46	27.69	7.08	964.8	0.16	3.82	0.32	7.64	2.37	56.56	4.03	96.18
102	Ngando	24.72	13.66	27.69	7.08	877.2	0.21	6.69	1.68	53.50	2.37	75.48	2.93	93.31
103	Kawangware	24.72	13.66	27.69	7.08	964.8	0.59	24.28	0.02	0.82	0.75	30.86	1.84	75.72
104	Gatina	24.65	13.66	28.33	7.08	964.8	1.03	65.61	0.00	0.00	0.19	12.10	0.54	34.39
105	Maziwa	24.65	13.85	28.33	7.08	877.2	0.72	9.99	0.38	5.27	2.5	34.67	6.49	90.01
106	Muthangari	24.79	13.85	28.65	9.04	921	0.56	14.32	0.7	17.90	2.13	54.48	3.35	85.68
107	Gichagi	24.51	13.27	27.69	7.08	1052.4	0.04	4.26	0.89	94.68	0.63	67.02	0.9	95.74
108	Kangemi	24.51	13.66	28.33	7.08	1052.4	0.27	17.42	0.08	5.16	0.92	59.35	1.28	82.58
109	Mountain View	24.51	13.27	27.69	7.08	1052.4	0.08	3.62	0.28	12.67	1.56	70.59	2.13	96.38
110	Kileleshwa	24.79	14.04	28.96	9.04	877.2	0.78	14.74	0.57	10.78	2.87	54.25	4.51	85.26
111	Woodley	25.07	13.46	28.33	7.08	789.6	0.43	9.71	1.93	43.57	2.79	62.98	4.00	90.29

Appendix XVII: Interpolated Urban Form and Climatic Data for 2018

SN	Sublocations	Climate					Urban Form							
		AATx (℃)	AATn (℃)	HAT (℃)	LAT (℃)	R (mm)	BUA (Km^2)	BUA (%)	Forest (Km^2)	Forest (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
0	Mihango	24.2	14.28	32.17	11.99	918.00	7.01	45.70	0.00	0.00	0.33	2.15	8.33	54.30
1	Ruai	24.2	14.28	32.17	11.01	898.00	17.55	35.37	0.10	0.20	4.28	8.63	32.07	64.63
2	Eastleigh North	24.58	14.52	31.12	13.31	998.00	0.61	67.03	0.00	0.00	0.04	4.40	0.30	32.97
3	California	24.65	14.73	31.12	12.49	998.00	0.52	108.33	0.00	0.00	0.05	10.42	0.04	8.33
4	Ngandu	24.17	14.19	31.64	9.68	881.00	5.25	10.09	0.02	0.04	2.07	3.98	46.78	89.91
5	Mbotela	24.65	14.64	31.12	12.49	998.00	0.43	97.73	0.00	0.00	0.00	0.00	0.01	2.27
6	Makongeni	24.79	14.64	30.56	11.99	998.00	0.66	100.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Kaloleni	24.79	14.64	30.56	11.5	998.00	0.61	98.39	0.00	0.00	0.00	0.00	0.01	1.61
8	Shauri Moyo	24.79	14.73	30.84	12.49	998.00	0.62	96.88	0.00	0.00	0.00	0.00	0.02	3.13
9	Muthurwa	24.79	14.64	30.28	11.5	998.00	0.34	65.38	0.00	0.38	0.12	23.08	0.18	34.62
10	Ofafa Maringo	24.58	14.64	31.12	12.49	998.00	0.57	83.82	0.00	0.00	0.00	0.00	0.11	16.18
11	Hamza	24.51	14.52	31.4	12.49	977.00	0.66	70.97	0.00	0.00	0.03	3.23	0.27	29.03
12	Lumumba	24.51	14.52	31.64	12.98	998.00	0.39	100.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Majengo	24.79	14.73	31.12	12.49	998.00	0.28	90.32	0.00	0.00	0.00	0.00	0.03	9.68
14	Bondeni	24.79	14.73	30.84	12.49	998.00	0.11	64.71	0.00	0.00	0.00	0.00	0.06	35.29
15	Gikomba	24.79	14.73	30.56	12.49	998.00	0.06	85.71	0.00	0.00	0.00	0.00	0.01	14.29
16	Kamukunji	24.79	14.73	30.56	12.49	998.00	0.19	82.61	0.00	0.00	0.00	0.00	0.04	17.39
17	Kimathi	24.58	14.73	31.4	12.98	998.00	1.24	91.85	0.00	0.00	0.00	0.00	0.11	8.15
18	Eastleigh South	24.58	14.73	31.4	13.31	998.00	0.91	81.98	0.00	0.00	0.71	63.96	0.20	18.02
19	Air Base	24.51	14.52	31.64	13.64	998.00	2.92	57.71	0.01	0.28	0.28	5.53	2.14	42.29
20	Uhuru	24.51	14.52	31.92	13.64	998.00	1.09	71.24	0.00	0.00	0.33	21.57	0.44	28.76
21	Harambee	24.51	14.52	31.64	12.98	977.00	1.91	86.82	0.00	0.00	0.09	4.09	0.29	13.18
22	Bomas	24.79	14.91	29.16	8.55	998.00	3.94	3.14	2.06	1.64	23.73	18.93	121.42	96.86
23	Embakasi	24.17	14.19	31.64	10.32	881.00	15.66	34.30	0.00	0.00	1.5	3.29	30.00	65.70

SN	Sublocations	Climate					Urban Form							
		AATx (°C)	AATn (°C)	HAT (°C)	LAT (°C)	R (mm)	BUA (Km^2)	BUA (%)	Forest (Km^2)	Forest (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
24	Umoja	24.38	14.52	31.92	12.98	957.00	2.95	94.55	0.00	0.00	0.16	5.13	0.17	5.45
25	Mlango Kubwa	24.58	14.52	31.64	13.31	998.00	0.38	84.44	0.00	0.00	0.00	0.00	0.07	15.56
26	Mabatini	24.58	14.52	31.92	14.29	998.00	0.34	91.89	0.00	0.00	0.00	0.00	0.03	8.11
27	Mathare	24.58	14.52	31.64	13.64	998.00	0.74	90.24	0.00	0.00	0.00	0.00	0.08	9.76
28	Pangani	24.58	14.52	31.12	12.98	998.00	1.5	89.82	0.00	0.00	0.06	3.59	0.17	10.18
29	Ziwani/Kariok or	24.79	14.64	30.84	12.49	998.00	0.81	97.59	0.00	0.00	0.00	0.00	0.02	2.41
30	Ngara East	24.65	14.52	30.84	11.99	998.00	1.16	86.57	0.00	0.00	0.17	12.69	0.18	13.43
31	Garden	24.51	14.52	31.92	14.29	998.00	1.33	10.34	2.56	19.93	9.14	71.07	11.53	89.66
32	Roysambu	24.45	14.52	32.67	15.44	998.00	2.26	22.74	0.19	1.91	5.72	57.55	7.68	77.26
33	Kiwanja	24.45	14.52	32.67	15.44	998.00	3.1	35.03	0.22	2.44	1.74	19.66	5.75	64.97
34	Kahawa West	24.45	14.52	32.67	15.44	998.00	1.01	19.61	0.05	0.87	1.32	25.63	4.14	80.39
35	Kongo Soweto	24.45	14.52	32.67	15.44	998.00	0.64	52.03	0.09	7.15	0.67	54.47	0.59	47.97
36	Kamuthi	24.45	14.52	32.67	15.44	998.00	0.51	44.35	0.00	0.00	0.48	41.74	0.64	55.65
37	Githurai	24.45	14.52	32.67	15.44	998.00	1.39	70.20	0.00	0.00	0.88	44.44	0.59	29.80
38	Zimmerman	24.45	14.52	32.67	15.44	998.00	1.19	63.30	0.10	5.11	0.61	32.45	0.69	36.70
39	Savannah	24.24	14.52	31.92	11.99	938.00	4.33	90.02	0.04	0.87	0.74	15.38	0.48	9.98
40	Kayole	24.24	14.52	32.17	12.98	938.00	2.39	97.55	0.00	0.00	0.00	0.00	0.06	2.45
41	Komarock	24.24	14.52	32.17	13.31	957.00	3.08	98.09	0.00	0.00	0.28	8.92	0.06	1.91
42	Karen	24.24	13.6	28.09	6.59	1,143.0	2.14	9.11	7.90	33.64	16.95	72.16	21.35	90.89
43	Hardy	24.65	14.02	27.86	6.59	1,185.0	2.36	16.11	2.20	15.02	8.81	60.14	12.29	83.89
44	Langata	24.51	13.93	27.86	6.59	1,185.0	1.88	10.66	2.09	11.87	12.81	72.62	15.76	89.34
45	Mukuru Kwa Njenga	24.24	14.52	30.84	9.04	898.00	6.71	79.41	0.00	0.00	0.27	3.20	1.74	20.59
46	South C	24.65	14.64	30.28	9.04	938.00	4.16	27.15	0.00	0.00	0.22	1.44	11.16	72.85

SN	Sublocations	Climate					Urban Form							
		AATx (℃)	AATn (℃)	HAT (℃)	LAT (℃)	R (mm)	BUA (Km^2)	BUA (%)	Forest (Km^2)	Forest (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
47	Land Mawe	24.79	14.64	30.28	11.01	998.00	4.68	84.48	0.01	0.23	0.94	16.97	0.86	15.52
48	Viwandani	24.58	14.64	30.84	11.01	977.00	5.67	98.61	0.00	0.00	0.57	9.91	0.08	1.39
49	Imara Daima	24.51	14.64	30.56	10.32	938.00	3.39	83.91	0.00	0.00	0.21	5.20	0.65	16.09
50	Hazina	24.79	14.82	30.28	10.32	977.00	2.43	54.85	0.00	0.00	0.44	9.93	2.00	45.15
51	Nairobi South	24.79	14.91	30	10.32	998.00	1.33	84.71	0.00	0.00	0.19	12.10	0.24	15.29
52	Karura	24.24	14.02	31.12	11.99	957.00	2.21	11.26	4.02	20.49	13.93	70.96	17.42	88.74
53	Njathaini	24.45	14.52	32.67	15.44	998.00	1.027	19.09	0.87	16.23	3.06	56.88	4.35	80.91
54	Huruma	24.45	14.52	32.17	14.29	998.00	0.088	12.22	0.00	0.00	0.01	1.39	0.63	87.78
55	Kiamaiko	24.45	14.52	32.17	14.29	998.00	0.328	47.54	0.00	0.00	0.05	7.25	0.36	52.46
56	Utalii	24.51	14.52	31.92	14.29	998.00	1.44	84.21	0.00	0.00	0.47	27.49	0.27	15.79
57	Mathare North	24.45	14.52	32.17	14.29	998.00	0.454	96.60	0.00	0.00	0.06	12.77	0.02	3.40
58	Mathare 4a	24.58	14.52	31.92	14.29	998.00	0.192	76.80	0.00	0.00	0.00	0.00	0.06	23.20
59	Mowlem	24.24	14.52	32.17	13.64	977.00	3.339	94.86	0.00	0.00	0.31	8.81	0.18	5.14
60	Kariobangi South	24.38	14.52	32.17	14.29	998.00	1.301	90.98	0.00	0.00	0.14	9.79	0.13	9.02
61	Njiru	24.24	14.52	32.67	13.31	957.00	4.21	79.58	0.03	0.62	0.79	14.93	1.08	20.42
62	Saika	24.24	14.52	32.67	13.64	957.00	3.68	92.93	0.00	0.00	0.29	7.32	0.28	7.07
63	Mwiki	24.24	14.52	32.45	13.31	957.00	9.228	48.06	0.04	0.22	4.33	22.55	9.97	51.94
64	Dandora B	24.24	14.52	32.67	14.29	998.00	1.712	86.46	0.00	0.00	0.16	8.08	0.27	13.54
65	Dandora A	24.38	14.52	32.45	14.29	998.00	1.829	93.79	0.00	0.00	0.25	12.82	0.12	6.21
66	Korogocho	24.45	14.52	32.17	14.29	998.00	0.187	98.42	0.00	0.00	0.00	0.00	0.00	1.58
67	Nyayo	24.45	14.52	32.67	14.29	998.00	0.235	97.92	0.00	0.00	0.00	0.00	0.01	2.08
68	Gitathuru	24.45	14.52	32.67	14.29	998.00	0.488	97.60	0.00	0.00	0.12	24.00	0.01	2.40
69	Kariobangi North	24.45	14.52	32.17	14.29	998.00	0.819	75.14	0.00	0.00	0.00	0.00	0.27	24.86
70	Ruaraka	24.45	14.52	32.67	15.44	998.00	3.92	98.49	0.01	0.20	0.53	13.32	0.06	1.51

SN	Sublocations	Climate					Urban Form							
		AATx (℃)	AATn (℃)	HAT (℃)	LAT (℃)	R (mm)	BUA (Km^2)	BUA (%)	Forest (Km^2)	Forest (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
71	Kasarani	24.45	14.52	32.67	15.44	998.00	7.38	63.18	0.04	0.36	2.69	23.03	4.30	36.82
72	Muthaiga	24.45	14.19	31.12	12.98	977.00	3.44	18.03	8.72	45.71	15.66	82.08	15.64	81.97
73	Lenana	24.2	13.6	28.09	6.59	1,143.0	1.62	9.64	5.30	31.51	13.23	78.70	15.19	90.36
74	Mutuini	24.1	13.6	28.64	6.59	1,046.0	0.31	9.39	0.88	26.55	1.79	54.24	2.99	90.61
75	Kirigu	23.96	13.6	29.16	6.59	998.00	0.3	17.54	0.21	12.05	0.73	42.69	1.41	82.46
76	Kabiria	23.96	13.6	29.16	6.59	998.00	0.36	13.09	0.46	16.62	2.17	78.91	2.39	86.91
77	Kitisuru	24.2	13.88	30.28	10.32	898.00	1	11.38	2.79	31.76	6.62	75.31	7.79	88.62
78	Spring Valley	24.38	14.02	30.28	11.01	957.00	0.79	37.09	0.20	9.39	1.61	75.59	1.34	62.91
79	Upper Parklands	24.38	14.02	30.56	11.01	998.00	1.3	54.85	0.10	4.14	1.167	49.24	1.07	45.15
80	Highridge	24.51	14.28	30.56	11.99	998.00	3.07	80.16	0.38	9.84	1.96	51.17	0.76	19.84
81	Ngara West	24.58	14.52	30.56	11.99	998.00	0.961	74.50	0.06	4.65	0.68	52.71	0.33	25.50
82	City Centre	24.65	14.52	30.28	11.5	998.00	0.97	69.78	0.00	0.22	0.51	36.69	0.42	30.22
83	City Square	24.79	14.64	30	11.01	998.00	0.716	54.66	0.00	0.08	0.67	51.15	0.59	45.34
84	Nairobi West	24.93	14.82	29.16	9.04	1,046.0	2.95	41.73	0.12	1.74	1.97	27.86	4.12	58.27
85	Kenyatta Golf course	24.79	14.64	29.44	9.04	1,046.0	4.24	80.30	0.12	2.25	1.47	27.84	1.04	19.70
86	Mugumoini	24.93	14.64	28.36	7.8	1,096.0	1.314	44.09	0.09	2.85	0.76	25.50	1.67	55.91
87	Laini Saba	24.79	14.64	28.64	8.55	1,071.0	0.295	77.63	0.00	0.00	0.07	18.42	0.09	22.37
88	Silanga	24.79	14.52	28.36	8.55	1,096.0	0.246	94.62	0.00	0.00	0.00	0.00	0.01	5.38
89	Olympic	24.58	14.02	28.36	7.8	1,143.0	0.183	24.40	0.34	45.87	0.74	98.67	0.57	75.60
90	Makina	24.65	14.02	28.36	8.55	1,120.0	0.553	81.32	0.02	2.79	0.39	57.35	0.13	18.68
91	Kibera	24.79	14.11	28.36	8.55	1,096.0	0.15	83.33	0.00	0.00	0.00	0.00	0.03	16.67
92	Soweto	24.79	14.52	28.36	8.55	1,096.0	0.297	80.27	0.00	0.00	0.07	18.92	0.07	19.73
93	Lindi	24.79	14.28	28.36	8.55	1,096.0	0.381	74.71	0.00	0.00	0.07	13.73	0.13	25.29
94	Gatwikira	24.79	14.11	28.36	7.8	1,143.0	0.165	58.93	0.00	0.00	0.16	57.14	0.12	41.07

SN	Sublocations	Climate					Urban Form							
		AATx (℃)	AATn (℃)	HAT (℃)	LAT (℃)	R (mm)	BUA (Km^2)	BUA (%)	Forest (Km^2)	Forest (%)	NDVI (Km^2)	NDVI (%)	OSN (Km^2)	OSN (%)
95	Uthiru	23.54	13.6	29.44	8.55	957.00	0.448	14.41	0.69	22.19	2.12	68.17	2.66	85.59
96	Ruthimitu	23.82	13.6	29.16	7.8	957.00	1.215	24.60	0.33	6.70	2.2	44.53	3.73	75.40
97	Waithaka	23.82	13.6	29.16	7.8	957.00	0.497	21.80	0.03	1.45	1.6	70.18	1.78	78.20
98	Loresho	23.82	13.6	30	9.04	843.00	2.484	26.43	1.04	11.06	6.05	64.36	6.92	73.57
99	Kyuna	24.2	13.88	30	10.32	938.00	1.187	34.81	0.50	14.57	2.23	65.40	2.22	65.19
100	Kilimani	24.58	14.19	29.72	10.32	1,046.0	5.29	59.11	0.32	3.53	4.75	53.07	3.66	40.89
101	Riruta	24.1	13.6	29.16	7.08	998.00	2.215	52.86	0.15	3.58	2.99	71.36	1.98	47.14
102	Ngando	24.2	13.6	28.36	6.59	1,096.0	0.907	28.89	1.67	53.09	2.48	78.98	2.23	71.11
103	Kawangware	24.1	13.6	29.16	8.55	998.00	2.079	85.56	0.03	1.40	1.14	46.91	0.35	14.44
104	Gatina	24.17	13.6	29.44	8.55	998.00	1.418	90.32	0.00	0.00	0.36	22.93	0.15	9.68
105	Maziwa	24.24	13.74	29.44	9.04	1,046.0	2.817	39.07	0.25	3.44	3.88	53.81	4.39	60.93
106	Muthangari	24.24	13.93	30	10.32	977.00	0.92	23.53	0.42	10.79	2.7	69.05	2.99	76.47
107	Gichagi	23.96	13.6	29.72	8.55	918.00	0.504	53.62	0.05	5.11	0.74	78.72	0.44	46.38
108	Kangemi	24.1	13.6	29.72	9.04	918.00	1.17	75.48	0.03	1.68	1.14	73.55	0.38	24.52
109	Mountain View	23.54	13.6	29.72	8.55	881.00	0.732	33.12	0.43	19.46	1.84	83.26	1.48	66.88
110	Kileleshwa	24.38	14.02	29.72	10.32	1,046.0	1.23	23.25	0.60	11.42	3.83	72.40	4.06	76.75
111	Woodley	24.45	13.88	28.36	7.8	1,143.0	0.02	0.45	2.04	46.12	2.96	66.82	4.41	99.55

Appendix XVIII: Climatic Parameters Percentage Change

Sublocations	Average annual Maximum Temp				Average annual Minimum Temp				Highest annual Temperature				Lowest annual Temperature				Rainfall			
	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018
Mihango	0.5	0.0	-2.4	-1.9	3.8	2.7	0.4	7.0	-3.1	2.1	4.2	3.1	12.2	14.2	16.2	48.8	50.8	-56.2	49.4	-1.3
Ruai	1.8	-1.1	-2.4	-1.7	4.3	1.4	0.4	6.1	-2.0	0.0	4.2	2.1	12.2	14.2	6.7	36.6	65.9	-50.0	36.4	13.3
Eastleigh North	-0.1	0.8	-1.7	-1.0	-1.4	4.2	2.0	4.8	-5.9	6.6	0.8	1.1	12.2	21.8	20.9	65.1	17.1	-43.7	26.4	-16.7
California	-0.5	1.1	-1.7	-1.0	-1.9	4.2	3.5	5.8	-5.5	6.6	0.8	1.6	12.2	21.8	13.4	55.0	14.8	-43.7	26.4	-18.3
Ngandu	1.5	2.9	-6.3	-2.2	5.7	1.4	-0.3	6.9	-1.7	0.0	2.5	0.8	12.2	0.0	7.1	20.1	74.9	-42.8	25.5	25.5
Mbotela	-0.2	1.1	-1.7	-0.8	0.1	4.1	1.5	5.8	-0.3	2.1	0.8	2.6	12.2	21.8	13.4	55.0	23.5	-43.7	26.4	-12.2
Makongeni	-0.5	1.1	-1.1	-0.5	-1.4	4.1	1.5	4.2	0.5	-12.8	13.5	-0.5	12.2	21.8	8.9	48.8	22.8	-43.7	26.4	-12.6
Kaloleni	-0.3	1.1	-1.1	-0.3	-1.6	4.1	1.5	4.0	0.7	-12.8	13.5	-0.4	12.2	21.8	4.5	42.7	17.1	-43.7	26.4	-16.7
Shauri Moyo	0.0	1.1	-1.1	0.0	-2.5	5.6	2.1	5.1	-5.9	-7.0	14.6	0.2	12.2	21.8	13.4	55.0	15.6	-43.7	26.4	-17.7
Muthurwa	-0.2	1.1	-1.1	-0.2	-3.2	4.2	2.9	3.8	2.3	-12.8	12.5	0.3	12.2	21.8	4.5	42.7	14.7	-43.7	26.4	-18.4
Ofafa Maringo	-0.4	1.1	-2.0	-1.2	0.0	2.7	2.9	5.7	-1.2	2.1	0.8	1.6	12.2	21.8	13.4	55.0	27.6	-43.7	26.4	-9.2
Hamza	-0.3	0.8	-2.0	-1.4	0.9	2.7	2.0	5.8	-2.2	2.1	1.7	1.6	12.2	21.8	13.4	55.0	33.0	-50.0	39.2	-7.3
Lumumba	-0.3	0.8	-2.0	-1.4	1.2	2.7	2.0	6.1	-1.8	2.1	2.5	2.8	12.2	21.8	17.9	61.0	24.3	-50.0	42.2	-11.5
Majengo	-0.2	1.1	-1.1	-0.2	-1.9	4.2	3.5	5.8	-0.9	-11.0	15.6	2.0	12.2	21.8	13.4	55.0	22.4	-43.7	26.4	-12.9
Bondeni	-0.6	1.1	-1.1	-0.6	-1.7	4.2	3.5	6.0	-1.4	-11.0	14.6	0.5	12.2	21.8	13.4	55.0	21.7	-43.7	26.4	-13.4

Sublocations	Average annual Maximum Temp				Average annual Minimum Temp				Highest annual Temperature				Lowest annual Temperature				Rainfall			
	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018
Gikomba	-0.4	1.1	-1.1	-0.4	-2.1	4.2	3.5	5.6	-0.1	-11.0	13.5	1.0	12.2	21.8	13.4	55.0	16.9	-43.7	26.4	-16.8
Kamukunji	-0.3	1.1	-1.1	-0.3	-2.6	4.2	3.5	5.1	-0.6	-11.0	13.5	0.5	12.2	21.8	13.4	55.0	16.6	-43.7	26.4	-17.0
Kimathi	-0.5	1.1	-2.0	-1.3	-0.5	4.1	2.1	5.8	-1.9	2.1	1.7	1.9	12.2	21.8	17.9	61.0	23.2	-50.0	42.2	-12.3
Eastleigh South	-0.1	1.1	-2.0	-0.9	-1.4	4.2	3.5	6.3	-1.0	2.1	1.7	2.8	12.2	21.8	20.9	65.1	22.4	-50.0	42.2	-12.9
Air Base	-0.2	-0.4	-0.8	-1.4	-1.4	4.2	2.0	4.8	-5.6	6.6	2.5	3.1	12.2	21.8	23.9	69.2	16.6	-50.0	42.2	-17.0
Uhuru	-0.4	0.0	-1.1	-1.5	0.9	2.7	2.0	5.8	-5.9	6.6	3.4	3.7	12.2	21.8	23.9	69.2	24.6	-50.0	42.2	-11.4
Harambee	-0.5	0.0	-1.1	-1.6	1.3	2.7	2.0	6.2	-2.1	2.1	2.5	2.4	12.2	21.8	17.9	61.0	33.5	-50.0	39.2	-7.0
Bomas	0.4	-0.8	-0.3	-0.8	-1.9	4.1	3.4	5.6	2.6	-6.0	-1.6	-5.1	0.0	36.6	-22.3	6.1	31.3	-40.6	19.8	-6.6
Embakasi	1.2	0.0	-2.5	-1.3	4.9	1.4	-0.3	6.0	-2.4	2.1	2.5	2.1	0.0	36.6	-6.3	28.0	51.9	-38.4	25.5	17.4
Umoja	0.0	0.0	-1.7	-1.7	1.5	2.7	2.0	6.4	-2.4	2.1	3.4	3.0	12.2	21.8	17.9	61.0	43.0	-50.0	36.3	-2.4
Mlango Kubwa	-0.1	0.0	-0.8	-1.0	-1.9	4.2	2.0	4.3	-4.7	6.6	2.5	4.1	12.2	21.8	20.9	65.1	8.7	-50.0	42.2	-22.7
Mabatini	-0.2	0.0	-0.8	-1.1	-0.4	4.2	2.0	5.8	-4.8	6.6	3.4	4.9	12.2	21.8	29.8	77.3	14.5	-50.0	42.2	-18.5
Mathare	-0.4	0.0	-0.8	-1.2	-1.1	4.2	2.0	5.1	-4.5	6.6	2.5	4.3	12.2	21.8	23.9	69.2	7.4	-43.7	26.4	-23.6
Pangani	-0.2	0.8	-1.7	-1.0	-0.5	4.2	2.0	5.8	-3.8	2.3	5.1	3.4	12.2	21.8	17.9	61.0	10.8	-43.7	26.4	-21.2
Ziwani/Kariokor	-0.3	1.1	-1.1	-0.3	-1.2	4.2	2.9	5.9	0.2	-2.1	4.1	2.2	12.2	21.8	13.4	55.0	8.0	-43.7	26.4	-23.1

Sublocations	Average annual Maximum Temp				Average annual Minimum Temp				Highest annual Temperature				Lowest annual Temperature				Rainfall			
	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018
Ngara East	-0.5	1.1	-1.7	-1.0	-0.4	4.2	2.0	5.9	0.4	-2.1	4.1	2.4	12.2	21.8	8.9	48.8	6.7	-43.7	26.4	-24.1
Garden	-0.6	0.0	-1.1	-1.7	-0.7	4.2	2.0	5.5	-4.2	6.6	3.4	5.6	28.0	6.7	29.8	77.3	14.2	-50.0	42.2	-18.8
Roysambu	-0.4	0.0	-1.4	-1.8	-0.1	4.2	2.0	6.1	-4.0	13.2	-0.4	8.3	28.0	6.7	40.2	91.6	22.9	-50.0	42.2	-12.6
Kiwanja	-0.4	0.0	-1.4	-1.7	0.2	2.7	2.0	5.1	-3.9	13.2	-0.4	8.4	28.0	6.7	40.2	91.6	29.6	-56.2	62.4	-7.8
Kahawa West	-0.6	0.0	-1.4	-1.9	1.2	2.7	2.0	6.1	-3.8	13.2	-0.4	8.6	28.0	6.7	40.2	91.6	26.2	-56.2	62.4	-10.2
Kongo Soweto	-0.2	0.0	-1.4	-1.6	0.9	2.7	2.0	5.8	-3.9	13.2	-0.4	8.5	28.0	6.7	40.2	91.6	32.0	-56.2	62.4	-6.1
Kamuthi	-0.5	0.0	-1.4	-1.8	0.7	2.7	2.0	5.6	-3.7	13.2	-0.4	8.6	28.0	6.7	40.2	91.6	23.2	-56.2	62.4	-12.3
Githurai	-0.5	0.0	-1.4	-1.8	0.3	2.7	2.0	5.1	-2.9	13.2	-0.4	9.6	28.0	6.7	40.2	91.6	29.8	-56.2	62.4	-7.7
Zimmerman	-0.4	0.0	-1.4	-1.8	1.0	2.7	2.0	5.9	-1.7	13.2	-0.4	10.9	28.0	6.7	40.2	91.6	27.5	-56.2	62.4	-9.3
Savannah	0.2	0.0	-2.2	-2.1	2.5	2.7	2.0	7.5	-2.2	2.1	3.4	3.2	12.2	14.2	16.2	48.8	41.6	-50.0	33.6	-5.3
Kayole	0.3	0.0	-2.2	-1.9	2.7	2.7	2.0	7.7	-7.2	6.6	4.2	3.1	12.2	14.2	25.8	61.0	57.5	-56.2	52.7	5.3
Komarock	-0.1	0.0	-2.2	-2.3	1.4	2.7	2.0	6.3	-6.3	6.6	4.2	4.0	12.2	18.4	24.4	65.1	45.4	-53.1	45.4	-0.8
Karen	1.1	0.6	-3.3	-1.7	5.6	-2.8	1.0	3.7	2.3	-6.5	1.4	-3.0	0.0	-12.2	-6.9	-18.2	7.2	-37.5	30.3	-12.7
Hardy	-0.2	0.0	-1.1	-1.4	2.4	2.7	-1.5	3.7	11.7	-15.3	-1.7	-6.9	0.0	0.0	-18.2	-18.2	14.3	-43.7	50.1	-3.4
Langata	-0.1	-0.9	-0.8	-1.8	4.1	0.0	0.6	4.7	10.8	-15.3	-1.7	-7.6	0.0	0.0	-18.2	-18.2	12.6	-43.7	50.1	-4.9
Mukuru Kwa Njenga	2.0	-1.1	-2.2	-1.4	2.4	2.7	2.0	7.4	-0.1	-4.1	4.1	-0.2	0.0	28.0	-12.4	12.2	79.7	-50.0	27.9	15.0

Sublocations	Average annual Maximum Temp				Average annual Minimum Temp				Highest annual Temperature				Lowest annual Temperature				Rainfall			
	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018
South C	1.6	0.0	-1.7	-0.1	1.0	4.1	1.5	6.8	-0.4	-4.1	2.2	-2.4	0.0	32.4	-15.3	12.2	54.6	-40.0	18.8	10.3
Land Mawe	1.1	0.0	-1.1	0.0	-1.9	4.1	1.5	3.7	1.1	-4.1	2.2	-0.8	12.2	21.8	0.0	36.6	21.9	-40.6	19.8	-13.3
Viwandani	-0.1	1.1	-2.0	-0.9	1.2	3.5	2.2	7.0	0.1	0.0	-0.1	0.0	12.2	21.8	0.0	36.6	35.8	-43.7	23.7	-5.4
Imara Daima	1.4	0.0	-2.2	-0.8	1.4	4.1	1.5	7.2	-1.2	0.0	-1.0	-2.2	12.2	29.1	-11.6	28.0	47.6	-43.7	18.8	-1.3
Hazina	1.0	0.0	-1.1	-0.2	-1.2	4.1	2.8	5.7	2.8	-6.0	2.2	-1.2	12.2	21.8	-6.3	28.0	31.2	-43.7	23.7	-8.6
Nairobi South	0.8	0.0	-1.1	-0.3	-2.5	4.1	3.4	4.9	3.6	-6.0	1.3	-1.4	12.2	14.2	0.0	28.0	27.5	-40.6	19.8	-9.3
Karura	-0.5	0.0	-2.2	-2.7	-1.9	2.9	1.2	2.2	-2.3	4.6	5.1	7.3	12.2	21.8	8.9	48.8	7.8	-40.6	14.8	-26.4
Njathaini	-0.4	0.0	-1.4	-1.8	-1.1	4.2	2.0	5.1	-4.8	13.2	-0.4	7.4	28.0	6.7	40.2	91.6	14.9	-50.0	42.2	-18.2
Huruma	-0.1	0.0	-1.4	-1.5	-0.1	4.2	2.0	6.1	-4.5	6.6	4.2	6.1	12.2	21.8	29.8	77.3	21.3	-50.0	42.2	-13.7
Kiamaiko	-0.3	0.0	-1.4	-1.7	0.9	2.7	2.0	5.8	-5.4	6.6	4.2	5.1	12.2	21.8	29.8	77.3	15.8	-50.0	42.2	-17.6
Utalii	-0.4	0.0	-1.1	-1.5	-1.0	4.2	2.0	5.2	-5.8	6.6	3.4	3.8	28.0	6.7	29.8	77.3	17.4	-50.0	42.2	-16.5
Mathare North	-0.1	0.0	-1.4	-1.5	0.4	4.2	2.0	6.8	-6.2	6.6	4.2	4.2	28.0	6.7	29.8	77.3	20.1	-50.0	42.2	-14.5
Mathare 4a	-0.3	0.0	-0.8	-1.1	-0.7	2.8	3.4	5.6	-5.5	6.6	3.4	4.1	12.2	21.8	29.8	77.3	16.8	-50.0	42.2	-16.9
Mowlem	-0.4	0.0	-2.2	-2.6	1.3	2.7	2.0	6.2	-6.3	6.6	4.2	4.0	12.2	21.8	23.9	69.2	33.3	-50.0	39.2	-7.2
Kariobangi South	-0.2	0.0	-1.7	-1.8	0.8	2.7	2.0	5.7	-6.1	6.6	4.2	4.3	12.2	21.8	29.8	77.3	25.2	-50.0	42.2	-10.9

Sublocations	Average annual Maximum Temp				Average annual Minimum Temp				Highest annual Temperature				Lowest annual Temperature				Rainfall			
	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018
Njiru	-0.2	0.0	-2.2	-2.5	2.3	2.7	2.0	7.2	-7.2	13.2	-0.4	4.7	12.2	14.2	29.0	65.1	-26.2	-56.2	55.8	-49.7
Saika	-0.4	0.0	-2.2	-2.6	2.0	2.7	2.0	6.9	-7.6	13.2	-0.4	4.2	12.2	21.8	23.9	69.2	38.8	-56.2	55.8	-5.3
Mwiki	0.2	0.0	-2.2	-2.1	2.7	2.7	2.0	7.6	-8.1	13.2	-1.0	3.0	12.2	14.2	29.0	65.1	49.4	-56.2	55.8	2.0
Dandora B	-0.1	0.0	-2.2	-2.3	1.2	2.7	2.0	6.1	-6.2	13.2	-0.4	5.8	12.2	21.8	29.8	77.3	34.8	-56.2	62.4	-4.1
Dandora A	-0.2	0.0	-1.7	-1.8	0.9	2.7	2.0	5.8	-5.9	13.2	-1.0	5.4	12.2	21.8	29.8	77.3	27.7	-53.1	51.6	-9.2
Korogocho	-0.2	0.0	-1.4	-1.6	0.5	2.7	2.0	5.4	-5.4	13.2	-1.9	5.1	12.2	21.8	29.8	77.3	20.2	-50.0	42.2	-14.5
Nyayo	-0.4	0.0	-1.4	-1.8	0.3	2.7	2.0	5.1	-5.3	13.2	-0.4	6.8	12.2	21.8	29.8	77.3	15.9	-50.0	42.2	-17.5
Gitathuru	-0.5	0.0	-1.4	-1.8	0.1	2.7	2.0	5.0	-4.8	13.2	-0.4	7.4	12.2	21.8	29.8	77.3	17.6	-50.0	42.2	-16.3
Kariobangi North	-0.1	0.0	-1.4	-1.5	0.0	2.7	2.0	4.8	-5.0	13.2	-1.9	5.5	12.2	21.8	29.8	77.3	23.1	-50.0	42.2	-12.4
Ruaraka	-0.2	0.0	-1.4	-1.6	0.4	2.7	2.0	5.3	-5.2	13.2	-0.4	6.9	28.0	6.7	40.2	91.6	20.6	-50.0	42.2	-14.2
Kasarani	-0.3	0.0	-1.4	-1.6	0.7	2.7	2.0	5.5	-5.6	13.2	-0.4	6.5	28.0	6.7	40.2	91.6	27.7	-56.2	62.4	-9.1
Muthaiga	0.0	0.0	-1.4	-1.3	-1.6	4.3	1.1	3.7	-2.5	2.3	5.1	4.7	12.2	18.0	21.6	61.0	8.5	-40.6	17.2	-24.4
Lenana	0.1	-0.6	-1.8	-2.3	5.6	-3.5	1.8	3.7	13.3	-15.6	1.4	-2.9	0.0	-12.2	-6.9	-18.2	7.2	-37.5	30.3	-12.7
Mutuini	0.9	0.0	-2.8	-2.0	4.0	0.0	-0.4	3.6	9.3	-12.2	3.4	-0.7	0.0	-12.2	-6.9	-18.2	6.1	-31.2	8.4	-20.9
Kirigu	1.0	0.0	-3.3	-2.4	2.4	0.3	0.7	3.4	8.7	-10.3	5.3	2.6	0.0	-12.2	-6.9	-18.2	5.1	-31.2	3.4	-25.2
Kabiria	0.9	-0.3	-3.1	-2.5	2.0	0.3	0.7	3.1	8.2	-10.3	5.3	2.2	0.0	-12.2	-6.9	-18.2	4.2	-31.2	3.4	-25.9

Sublocations	Average annual Maximum Temp				Average annual Minimum Temp				Highest annual Temperature				Lowest annual Temperature				Rainfall			
	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018
Kitisuru	0.7	-1.4	-1.0	-1.7	0.0	2.9	0.2	3.1	-2.1	2.2	4.6	4.6	0.0	12.2	14.2	28.0	6.6	-31.2	-6.9	-31.8
Spring Valley	0.6	0.0	-1.7	-1.1	-0.4	2.9	1.2	3.8	-0.2	0.0	4.6	4.4	12.2	14.2	6.7	36.6	8.5	-37.5	9.1	-26.0
Upper Parklands	0.2	0.0	-1.7	-1.5	-1.2	2.9	1.2	2.9	-0.1	0.0	5.5	5.4	12.2	14.2	6.7	36.6	9.1	-37.5	13.8	-22.4
Highridge	-0.1	0.0	-1.1	-1.2	-0.1	4.2	0.4	4.4	-1.7	2.3	3.2	3.8	12.2	14.2	16.2	48.8	11.9	-40.6	19.8	-20.4
Ngara West	-0.4	-0.6	-0.3	-1.2	-1.2	4.2	2.0	5.1	2.1	-2.1	3.2	3.2	12.2	21.8	8.9	48.8	13.6	-43.7	26.4	-19.2
City Centre	0.6	0.0	-1.7	-1.1	-2.0	4.2	2.0	4.2	0.3	-2.1	2.2	0.4	12.2	21.8	4.5	42.7	14.2	-43.7	26.4	-18.7
City Square	0.6	0.0	-1.1	-0.5	-2.4	4.2	2.9	4.6	2.5	-4.1	1.3	-0.5	12.2	21.8	0.0	36.6	16.4	-37.5	13.8	-17.2
Nairobi West	0.5	-0.6	0.0	0.0	-1.9	2.7	4.1	5.0	-2.1	-2.2	0.7	-3.6	12.2	21.8	-17.9	12.2	23.6	-37.5	19.2	-7.8
Kenyatta/ Golf course	0.7	0.0	-1.1	-0.4	-0.5	2.7	2.9	5.2	4.9	-8.1	1.7	-2.0	12.2	18.0	-15.3	12.2	17.3	-37.5	19.2	-12.5
Mugumoini	-0.1	0.0	0.0	-0.1	-0.1	3.1	2.5	5.6	9.9	-11.7	-2.1	-4.9	0.0	28.0	-24.4	-3.2	20.9	-37.5	24.9	-5.5
Laini Saba	0.1	0.0	-0.6	-0.5	-0.2	3.5	2.2	5.5	0.2	-2.2	-1.1	-3.1	0.0	28.0	-17.2	6.1	17.6	-37.5	22.1	-10.2
Silanga	0.2	-4.0	3.6	-0.4	-0.4	3.5	1.3	4.4	0.6	-2.2	-2.1	-3.7	0.0	28.0	-17.2	6.1	16.8	-37.5	24.9	-8.8
Olympic	0.0	0.6	-2.0	-1.4	2.0	0.7	0.5	3.2	10.9	-13.6	0.1	-4.1	0.0	12.2	-13.7	-3.2	13.5	-43.7	44.8	-7.5
Makina	0.3	0.6	-1.7	-0.8	1.8	3.1	-1.8	3.0	12.1	-13.6	0.1	-3.0	0.0	12.2	-5.4	6.1	12.6	-37.5	27.7	-10.1

Sublocations	Average annual Maximum Temp				Average annual Minimum Temp				Highest annual Temperature				Lowest annual Temperature				Rainfall			
	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018
Kibera	0.2	0.6	-1.1	-0.3	1.4	3.1	-1.2	3.3	2.2	-2.2	-2.1	-2.1	0.0	28.0	-17.2	6.1	12.1	-37.5	24.9	-12.4
Soweto	0.3	0.0	-0.6	-0.3	0.9	3.1	1.7	5.8	0.6	-2.2	-2.1	-3.6	0.0	28.0	-17.2	6.1	16.3	-37.5	24.9	-9.2
Lindi	0.4	0.0	-0.6	-0.1	0.1	3.1	0.0	3.2	10.6	-11.7	-2.1	-4.4	0.0	28.0	-17.2	6.1	14.9	-37.5	24.9	-10.2
Gatwikira	0.2	0.0	-0.6	-0.4	2.7	3.1	-1.2	4.7	12.1	-11.7	-2.1	-3.0	0.0	12.2	-13.7	-3.2	11.1	-37.5	30.3	-9.5
Uthiru	2.1	-1.1	-4.0	-3.0	2.8	-1.4	2.5	3.9	-0.1	-4.4	6.3	1.6	0.0	-12.2	20.8	6.1	0.1	-25.0	-9.1	-31.7
Ruthimitu	1.3	-1.1	-2.8	-2.7	2.4	-1.4	2.5	3.5	-1.6	-4.4	5.3	-0.9	0.0	-12.2	10.2	-3.2	0.7	-25.0	-9.1	-31.3
Waithaka	1.1	-1.1	-2.8	-2.8	1.9	0.0	1.0	3.0	-3.0	-4.4	5.3	-2.3	0.0	-12.2	10.2	-3.2	0.3	-25.0	-9.1	-31.6
Loresho	1.0	0.6	-3.4	-1.8	0.0	1.4	1.0	2.5	0.5	-3.3	7.1	4.1	0.0	-12.2	27.7	12.2	1.5	0.0	-39.9	-39.0
Kyuna	0.9	-1.1	-1.3	-1.5	0.0	2.9	0.2	3.1	1.6	-2.2	5.9	5.2	0.0	12.2	14.2	28.0	6.1	-31.2	-2.8	-29.1
Kilimani	1.0	0.0	-2.0	-1.0	0.8	2.1	1.7	4.7	8.8	-8.1	2.6	2.6	12.2	14.2	0.0	28.0	14.0	-37.5	19.2	-15.0
Riruta	2.3	-1.7	-2.2	-1.7	2.6	0.0	1.0	3.7	5.7	-12.2	5.3	-2.2	0.0	-12.2	0.0	-12.2	2.8	-31.2	3.4	-26.9
Ngando	1.1	-0.8	-2.1	-1.9	3.6	0.0	-0.4	3.2	3.0	-6.5	2.4	-1.4	0.0	-12.2	-6.9	-18.2	7.9	-37.5	24.9	-15.7
Kawangware	2.0	-1.4	-2.5	-2.0	1.5	1.5	-0.4	2.6	6.9	-10.3	5.3	1.0	0.0	-12.2	20.8	6.1	6.2	-31.2	3.4	-24.4
Gatina	1.8	-1.7	-1.9	-1.8	1.7	1.5	-0.4	2.7	7.6	-8.3	3.9	2.6	0.0	-12.2	20.8	6.1	6.8	-31.2	3.4	-24.0

Sublocations	Average annual Maximum Temp				Average annual Minimum Temp				Highest annual Temperature				Lowest annual Temperature				Rainfall			
	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018
Maziwa	1.7	-1.7	-1.7	-1.7	2.9	1.4	-0.8	3.5	3.7	-4.4	3.9	3.1	0.0	-12.2	27.7	12.2	8.2	-37.5	19.2	-19.3
Muthangari	0.7	0.0	-2.2	-1.5	0.1	2.9	0.6	3.6	0.0	-1.1	4.7	3.6	0.0	12.2	14.2	28.0	7.9	-34.3	6.1	-24.9
Gichagi	1.2	-1.1	-2.2	-2.2	2.2	-1.4	2.5	3.3	1.9	-4.4	7.3	4.6	0.0	-12.2	20.8	6.1	2.0	-25.0	-12.8	-33.3
Kangemi	1.1	-1.1	-1.7	-1.7	1.4	1.5	-0.4	2.5	2.0	-2.2	4.9	4.7	0.0	-12.2	27.7	12.2	1.0	-25.0	-12.8	-33.9
Mountain View	1.8	-1.1	-4.0	-3.3	2.4	-1.4	2.5	3.5	0.0	-2.3	7.3	4.9	0.0	-12.2	20.8	6.1	0.3	-25.0	-16.3	-37.0
Kileleshwa	1.0	-1.1	-1.7	-1.7	2.3	2.8	-0.1	5.0	6.4	-6.2	2.6	2.4	0.0	12.2	14.2	28.0	8.0	-37.5	19.2	-19.5
Woodley	0.0	0.6	-2.5	-1.9	4.1	-2.8	3.1	4.4	11.8	-13.6	0.1	-3.3	0.0	-12.2	10.2	-3.2	7.8	-43.7	44.8	-12.1

Appendix XIX: Urban Form Parameters Percentage Change

Sublocations	Built-up area				Forest				Normalized Difference Vegetation index				Open Space Network			
	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018
Mihango	-2.0	4.6	38.5	41.1	0.0	-0.2	0.0	-0.2	-5.9	0.7	0.3	-4.9	2.0	-4.6	-90.7	-41.1
Ruai	-1.1	2.4	31.5	32.8	-0.4	0.1	0.1	-0.2	-1.6	-20.1	0.2	-21.5	1.1	-2.4	-87.5	-32.8
Eastleigh North	21.2	24.4	2.2	47.8	-5.2	0.0	0.0	-5.2	-100.2	3.3	1.1	-95.8	-21.2	-24.4	-30.8	-47.8
California	63.1	4.2	29.2	96.5	-0.2	0.0	0.0	-0.2	-99.7	0.0	10.4	-89.3	-63.1	-4.2	-10.4	-96.5
Ngandu	0.4	-0.2	9.5	9.8	0.0	0.1	0.0	0.0	-0.9	-5.7	1.2	-5.4	-0.4	0.2	-95.4	-9.8
Mbotela	14.0	-6.3	6.8	14.5	0.0	0.0	0.0	0.0	-94.9	0.0	0.0	-94.9	-14.0	6.3	-9.1	-14.5
Makongeni	17.8	-0.7	4.5	21.6	-0.8	0.0	0.0	-0.8	-99.9	0.0	0.0	-99.9	-17.8	0.7	-4.5	-21.6
Kaloleni	31.4	-5.2	12.9	39.1	0.0	0.0	0.0	0.0	-98.7	0.0	0.0	-98.7	-31.4	5.2	-14.5	-39.1
Shauri moyo	7.1	7.4	12.5	27.1	0.2	-0.2	0.0	0.0	-98.0	0.0	0.0	-98.0	-7.1	-7.4	-15.6	-27.1
Muthurwa	34.5	-1.3	5.8	39.0	-0.1	1.4	-3.5	-2.2	-90.7	15.0	1.9	-73.8	-34.5	1.3	-17.3	-39.0
Ofafa Maringo	6.0	-15.2	47.1	37.9	0.0	0.0	0.0	0.0	-77.2	0.0	0.0	-77.2	-6.0	15.2	-63.2	-37.9
Hamza	-13.6	-6.1	44.1	24.4	0.0	0.0	0.0	0.0	-36.1	-1.1	1.1	-36.1	13.6	6.1	-69.9	-24.4
Lumumba	75.9	-38.7	56.4	93.6	0.0	0.0	0.0	0.0	-94.4	2.6	-2.6	-94.4	-75.9	38.7	-56.4	-93.6
Majengo	36.7	8.3	9.7	54.7	7.0	-7.0	0.0	0.0	-96.9	0.0	0.0	-96.9	-36.7	-8.3	-19.4	-54.7
Bondeni	52.1	-30.7	11.8	33.2	2.0	-2.0	0.0	0.0	-102.9	0.0	0.0	-102.9	-52.1	30.7	-47.1	-33.2
Gikomba	86.0	-10.3	0.0	75.8	0.0	0.0	0.0	0.0	-100.0	0.0	0.0	-100.0	-86.0	10.3	-14.3	-75.8
Kamukunji	7.8	0.7	4.3	12.8	2.8	-2.8	0.0	0.0	-98.5	0.0	0.0	-98.5	-7.8	-0.7	-21.7	-12.8
Kimathi	33.5	45.4	-5.9	72.9	0.4	-0.5	0.0	-0.1	-93.3	-3.0	0.0	-96.4	-33.5	-45.4	-2.2	-72.9
Eastleigh South	13.2	32.4	27.9	73.5	-2.8	-0.4	0.0	-3.2	-97.7	9.9	53.2	-34.6	-13.2	-32.4	18.0	-73.5
Air Base	19.9	5.2	11.5	36.5	-3.1	-0.7	0.3	-3.5	-73.7	-3.0	1.2	-75.5	-19.9	-5.2	-48.2	-36.5
Uhuru	-13.1	24.8	10.5	22.2	-0.4	0.0	0.0	-0.4	-61.2	7.6	6.5	-47.0	13.1	-24.8	-17.6	-22.2
Harambee	28.8	-4.7	30.5	54.6	0.2	-0.2	0.0	0.0	-71.0	2.5	0.5	-68.0	-28.8	4.7	-39.5	-54.6
Bomas	0.6	-0.5	2.7	2.7	-1.7	2.1	-3.8	-3.4	-16.0	-3.9	14.1	-5.8	-0.6	0.5	-80.6	-2.7

Sublocations	Built-up area				Forest				Normalized Difference Vegetation index				Open Space Network			
	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018
Embakasi	5.9	9.2	14.6	29.6	-0.2	0.0	0.0	-0.2	-7.5	-1.2	0.0	-8.6	-5.9	-9.2	-77.0	-29.6
Umoja	13.7	23.6	17.6	55.0	0.0	0.0	0.0	0.0	-43.5	-0.6	0.6	-43.5	-13.7	-23.6	-17.9	-55.0
Mlango Kubwa	78.9	-26.5	-6.7	45.7	-1.4	-2.1	0.0	-3.5	-96.4	-3.1	0.0	-99.6	-78.9	26.5	-8.9	-45.7
Mabatini	-17.1	51.9	18.9	53.7	-6.8	-0.3	0.0	-7.1	-78.3	-4.3	0.0	-82.7	17.1	-51.9	-27.0	-53.7
Mathare	2.8	29.9	-1.2	31.5	8.3	-8.3	0.0	0.0	-86.6	7.3	-7.3	-86.6	-2.8	-29.9	-8.5	-31.5
Pangani	30.4	17.1	0.6	48.0	-1.6	0.0	0.0	-1.6	-83.9	-2.1	-0.6	-86.6	-30.4	-17.1	-7.2	-48.0
Ziwani/Kariokor	37.6	6.3	-2.4	41.5	0.0	0.0	0.0	0.0	-71.6	0.0	0.0	-71.6	-37.6	-6.3	0.0	-41.5
Ngara East	-12.4	23.3	0.0	10.9	1.9	-1.6	-0.7	-0.5	-96.0	4.6	7.5	-83.9	12.4	-23.3	-0.7	-10.9
Garden	-3.4	2.9	5.4	4.8	-10.3	-13.1	-2.5	-26.0	-10.6	-21.2	7.4	-24.4	3.4	-2.9	-24.0	-4.8
Roysambu	-0.6	5.5	14.8	19.7	-1.0	-3.0	-0.9	-4.9	-42.3	4.8	19.4	-18.1	0.6	-5.5	-34.5	-19.7
Kiwanja	-10.3	7.8	13.7	11.2	-1.9	1.9	0.1	0.1	-49.4	2.5	4.7	-42.1	10.3	-7.8	-59.0	-11.2
Kahawa West	-9.0	3.3	7.0	1.3	-4.6	2.5	-1.8	-3.9	-40.4	-0.1	8.3	-32.2	9.0	-3.3	-61.7	-1.3
Kongo Soweto	-7.9	1.7	46.3	40.2	-20.3	3.1	3.1	-14.1	-13.5	-58.0	31.7	-39.8	7.9	-1.7	-39.8	-40.2
Kamuthi	-16.1	17.8	12.2	13.9	-11.6	3.0	-7.0	-15.6	-64.8	0.0	17.4	-47.4	16.1	-17.8	-26.1	-13.9
Githurai	6.4	2.2	43.9	52.5	-2.6	1.5	-2.0	-3.1	-62.5	15.6	10.1	-36.9	-6.4	-2.2	-29.3	-52.5
Zimmerman	-6.0	24.7	25.5	44.2	0.5	0.8	3.0	4.3	-59.3	7.6	9.6	-42.2	6.0	-24.7	-29.8	-44.2
Savannah	7.3	24.9	33.9	66.1	-1.6	0.0	0.9	-0.8	-31.1	-7.4	7.5	-30.9	-7.3	-24.9	-28.5	-66.1
Kayole	41.8	27.0	13.1	81.9	0.0	0.0	0.0	0.0	-8.0	2.9	-6.1	-11.2	-41.8	-27.0	-15.5	-81.9
Komarock	21.9	23.9	35.4	81.1	0.0	0.0	0.0	0.0	5.0	-7.6	6.1	3.4	-21.9	-23.9	-28.3	-81.1
Karen	-0.4	-1.4	8.1	6.3	-12.7	9.0	8.6	5.0	-18.9	7.8	7.5	-3.6	0.4	1.4	-26.8	-6.3
Hardy	1.4	-2.0	11.7	11.1	-4.6	2.6	1.3	-0.6	-20.2	7.9	5.5	-6.8	-1.4	2.0	-35.5	-11.1
Langata	0.0	-0.7	10.2	9.6	-0.9	2.6	-9.4	-7.7	-38.5	36.3	6.6	4.4	0.0	0.7	-26.9	-9.6
Mukuru Kwa Njenga	7.6	34.7	35.6	77.9	0.0	0.0	0.0	0.0	-1.4	0.9	-0.7	-1.2	-7.6	-34.7	-53.0	-77.9
South C	4.9	-5.3	27.0	26.6	0.0	0.0	0.0	0.0	-6.7	-0.3	1.4	-5.5	-4.9	5.3	-98.4	-26.6
Land Mawe	14.1	19.4	7.4	40.9	0.1	0.0	-0.5	-0.4	-84.6	4.1	3.1	-77.4	-14.1	-19.4	-6.0	-40.9

Sublocations	Built-up area				Forest				Normalized Difference Vegetation index				Open Space Network			
	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018
Viwandani	20.1	16.0	21.7	57.9	-2.9	0.0	0.0	-2.9	-70.9	-3.2	0.5	-73.6	-20.1	-16.0	-13.2	-57.9
Imara Daima	27.3	-34.3	75.7	68.7	0.0	0.0	0.0	0.0	-52.6	1.6	2.2	-48.7	-27.3	34.3	-86.6	-68.7
Hazina	27.1	-3.9	29.8	52.9	0.0	0.0	0.0	0.0	-26.1	4.7	4.5	-16.9	-27.1	3.9	-65.0	-52.9
Nairobi South	53.3	-37.3	33.8	49.8	0.0	0.0	0.0	0.0	-65.4	7.4	2.5	-55.5	-53.3	37.3	-36.9	-49.8
Karura	-3.8	0.9	9.1	6.3	-31.9	-0.5	-2.4	-34.7	-9.3	-23.9	6.8	-26.3	3.8	-0.9	-26.9	-6.3
Njathaini	-3.4	3.3	13.1	13.0	-14.4	-2.2	-0.5	-17.1	-20.2	-19.4	14.3	-25.3	3.4	-3.3	-37.2	-13.0
Huruma	48.6	-1.1	-47.5	0.0	-0.3	0.0	0.0	-0.3	-74.0	1.4	0.0	-72.6	-48.6	1.1	-38.9	0.0
Kiamaiko	32.8	-0.7	-4.6	27.4	0.0	0.0	0.0	0.0	-68.2	4.3	2.9	-60.9	-32.8	0.7	-40.6	-27.4
Utalii	-14.0	0.2	46.2	32.4	-2.8	-1.1	0.0	-3.8	-69.7	5.4	12.3	-52.0	14.0	-0.2	-34.5	-32.4
Mathare North	-16.9	-0.1	30.6	13.6	-0.3	0.0	0.0	-0.3	-76.1	3.0	0.0	-73.1	16.9	0.1	-21.3	-13.6
Mathare 4A	11.2	35.1	-15.2	31.1	-4.7	0.0	0.0	-4.7	-79.6	32.0	-32.0	-79.6	-11.2	-35.1	-8.0	-31.1
Mowlem	-1.1	25.5	39.7	64.2	-1.5	-0.3	0.0	-1.9	-48.3	-8.8	3.4	-53.7	1.1	-25.5	-36.1	-64.2
Kariobangi South	27.8	14.1	17.6	59.4	-0.4	-0.7	0.0	-1.1	-69.6	-2.1	2.1	-69.6	-27.8	-14.1	-16.8	-59.4
Njiru	0.5	19.9	23.8	44.2	-2.6	1.4	-1.1	-2.3	-22.1	-2.2	3.2	-21.1	-0.5	-19.9	-29.3	-44.2
Saika	18.2	31.9	29.8	79.9	-2.1	0.0	0.0	-2.1	-26.2	-3.9	1.3	-28.8	-18.2	-31.9	-29.5	-79.9
Mwiki	-2.1	0.6	37.1	35.7	-3.8	-1.5	-0.6	-5.9	-21.0	-1.1	2.4	-19.6	2.1	-0.6	-66.5	-35.7
Dandora B	4.8	11.5	11.2	27.5	-3.3	0.0	0.0	-3.3	-30.1	1.9	-2.5	-30.7	-4.8	-11.5	-16.7	-27.5
Dandora A	13.6	7.7	24.6	45.8	-3.7	-0.1	0.0	-3.8	-51.7	7.3	-2.1	-46.4	-13.6	-7.7	-17.9	-45.8
Korogocho	25.6	15.3	19.5	60.3	-16.7	0.0	0.0	-16.7	-64.1	-3.2	0.0	-67.2	-25.6	-15.3	-21.1	-60.3
Nyayo	38.4	-22.7	31.3	47.0	-18.4	0.0	0.0	-18.4	-57.6	-9.2	0.0	-66.7	-38.4	22.7	-33.3	-47.0
Gitathuru	8.0	10.3	15.6	33.9	-0.6	0.0	0.0	-0.6	-49.7	18.0	6.0	-25.7	-8.0	-10.3	6.0	-33.9
Kariobangi North	21.3	-2.2	7.2	26.3	-3.3	0.0	0.0	-3.3	-54.7	0.0	0.0	-54.7	-21.3	2.2	-32.1	-26.3
Ruaraka	-6.0	11.0	43.7	48.8	0.0	-0.6	-0.8	-1.4	-62.0	6.0	-1.0	-57.0	6.0	-11.0	-31.9	-48.8

Sublocations	Built-up area				Forest				Normalized Difference Vegetation index				Open Space Network			
	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018
Kasarani	-3.2	19.0	26.7	42.5	0.4	-1.3	-0.5	-1.4	-35.1	4.4	3.8	-26.9	3.2	-19.0	-40.5	-42.5
Muthaiga	-2.3	6.7	5.6	9.9	-11.9	-41.6	44.7	-8.8	-27.4	2.2	8.4	-16.9	2.3	-6.7	-5.5	-9.9
Lenana	-0.7	0.3	8.6	8.3	-6.1	6.4	-3.1	-2.8	-17.1	1.7	9.8	-5.6	0.7	-0.3	-20.2	-8.3
Mutuini	-1.5	1.3	7.3	7.2	-13.2	8.7	5.0	0.5	14.1	-26.0	6.7	-5.3	1.5	-1.3	-43.6	-7.2
Kirigu	0.8	0.1	15.8	16.7	-6.0	6.8	0.4	1.1	-18.0	10.6	10.5	3.1	-0.8	-0.1	-55.6	-16.7
Kabiria	-0.4	8.5	4.4	12.4	-21.2	6.4	-3.4	-18.2	-28.7	4.3	13.1	-11.4	0.4	-8.5	-12.4	-12.4
Kitisuru	-3.3	0.5	10.1	7.3	-26.2	9.8	0.4	-16.0	-15.9	-65.7	69.3	-12.3	3.3	-0.5	-23.4	-7.3
Spring Valley	-2.1	19.7	12.7	30.2	-13.9	12.0	-17.8	-19.8	-20.7	-14.4	10.8	-24.3	2.1	-19.7	0.0	-30.2
Upper Parklands	-2.1	33.3	17.3	48.5	-22.4	2.6	-8.5	-28.3	-13.8	-20.3	-16.6	-50.7	2.1	-33.3	-13.2	-48.5
Highridge	7.8	36.6	22.5	66.8	-7.5	2.4	-9.2	-14.4	-50.3	-19.4	20.9	-48.8	-7.8	-36.6	8.9	-66.8
Ngara West	35.6	-16.8	35.0	53.8	12.6	-4.3	-10.1	-1.8	-66.4	8.4	10.9	-47.2	-35.6	16.8	-7.8	-53.8
City Centre	9.9	17.4	25.2	52.6	-1.4	-1.9	-2.7	-6.0	-77.7	11.8	8.6	-57.3	-9.9	-17.4	-18.7	-52.6
City Square	6.2	27.7	14.2	48.2	3.3	-6.2	-9.8	-12.7	-62.1	0.8	12.2	-49.1	-6.2	-27.7	-8.4	-48.2
Nairobi West	8.0	1.7	25.7	35.4	-1.6	4.8	-3.1	0.1	-29.7	10.8	7.5	-11.4	-8.0	-1.7	-56.2	-35.4
Kenyatta Golf course	-0.6	6.1	30.9	36.4	-1.7	5.2	-3.6	-0.1	-59.8	5.1	8.5	-46.2	0.6	-6.1	-22.7	-36.4
Mugumoini	18.2	-8.5	26.6	36.3	-0.3	-5.1	-5.9	-11.3	-41.7	-0.1	-1.0	-42.8	-18.2	8.5	-57.0	-36.3
Laini Saba	-30.9	18.5	38.2	25.8	-1.2	0.0	0.0	-1.2	-38.6	10.5	7.9	-20.2	30.9	-18.5	-42.1	-25.8
Silanga	-9.4	6.4	21.5	18.6	0.0	0.0	0.0	0.0	-79.7	0.0	0.0	-79.7	9.4	-6.4	-26.9	-18.6
Olympic	-0.9	0.0	24.4	23.5	-0.2	-5.9	-42.1	-48.2	-7.1	12.3	-6.7	-1.5	0.9	0.0	-1.3	-23.5
Makina	2.7	17.5	53.4	73.6	19.8	-12.6	-35.4	-28.3	-24.2	2.8	-5.9	-27.3	-2.7	-17.5	-14.7	-73.6
Kibera	10.0	1.5	11.1	22.7	0.0	0.0	0.0	0.0	-51.6	0.0	0.0	-51.6	-10.0	-1.5	-27.8	-22.7
Soweto	-7.9	-16.2	42.4	18.4	0.8	-0.8	0.0	0.0	-56.7	21.6	-2.7	-37.8	7.9	16.2	-43.2	-18.4
Lindi	2.6	11.8	41.4	55.8	-0.9	0.0	0.0	-0.9	-76.2	4.3	0.0	-71.9	-2.6	-11.8	-52.9	-55.8

Sublocations	Built-up area				Forest				Normalized Difference Vegetation index				Open Space Network			
	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018	1988-1998	1998-2008	2008-2018	1988-2018
Gatwikira	-4.9	25.5	26.8	47.4	-10.3	-14.8	-21.4	-46.6	-33.2	-28.6	17.9	-43.9	4.9	-25.5	-10.7	-47.4
Uthiru	-5.5	0.2	12.8	7.5	-10.8	8.6	8.0	5.8	-32.2	15.0	4.5	-12.7	5.5	-0.2	-30.2	-7.5
Ruthimitu	-3.3	-0.1	20.7	17.4	-7.7	2.6	2.4	-2.7	-19.4	5.0	8.1	-6.4	3.3	0.1	-51.6	-17.4
Waithaka	0.5	2.3	17.0	19.7	-1.2	1.0	-0.7	-0.9	-55.4	19.0	14.9	-21.5	-0.5	-2.3	-25.0	-19.7
Loresho	-0.8	2.9	17.6	19.7	-13.6	-10.1	10.0	-13.7	-61.6	17.8	13.8	-29.9	0.8	-2.9	-26.8	-19.7
Kyuna	0.6	8.4	11.6	20.7	-3.7	2.6	2.6	1.4	-58.3	9.5	16.7	-32.1	-0.6	-8.4	-11.4	-20.7
Kilimani	4.6	26.1	20.8	51.4	2.5	-2.5	-2.2	-2.1	-58.4	-0.4	18.2	-40.7	-4.6	-26.1	-8.6	-51.4
Riruta	2.3	0.4	49.0	51.8	-11.3	3.2	-4.1	-12.1	-48.3	21.4	14.8	-12.1	-2.3	-0.4	-24.8	-51.8
Ngando	-0.2	5.6	22.2	27.6	-14.9	5.2	-0.4	-10.1	-16.0	-1.9	3.5	-14.4	0.2	-5.6	-14.3	-27.6
Kawangware	5.5	12.1	61.3	78.9	-1.0	0.1	0.6	-0.3	-65.2	12.4	16.0	-36.8	-5.5	-12.1	-28.8	-78.9
Gatina	0.2	28.5	24.7	53.4	-3.9	-0.7	0.0	-4.7	-59.8	-0.8	10.8	-49.7	-0.2	-28.5	-11.5	-53.4
Maziwa	6.4	-3.4	29.1	32.1	-5.2	-3.9	-1.8	-10.9	-55.2	-5.1	19.1	-41.2	-6.4	3.4	-36.2	-32.1
Muthangari	-0.5	10.1	9.2	18.9	-22.9	6.5	-7.1	-23.4	-52.4	7.1	14.6	-30.7	0.5	-10.1	-16.6	-18.9
Gichagi	-6.7	2.6	49.4	45.3	-1.3	87.2	-89.6	-3.7	-53.9	20.9	11.7	-21.3	6.7	-2.6	-17.0	-45.3
Kangemi	2.3	4.3	58.1	64.6	-10.2	2.5	-3.5	-11.2	-52.6	15.3	14.2	-23.1	-2.3	-4.3	-9.0	-64.6
Mountain View	-1.0	2.2	29.5	30.6	-13.0	5.5	6.8	-0.7	-44.2	14.9	12.7	-16.6	1.0	-2.2	-13.1	-30.6
Kileleshwa	-1.5	12.8	8.5	19.7	-10.3	-3.9	0.6	-13.5	-53.3	7.5	18.1	-27.7	1.5	-12.8	-12.9	-19.7
Woodley	-1.7	2.7	-9.3	-8.3	-26.0	4.8	2.6	-18.6	-18.0	-4.0	3.8	-18.1	1.7	-2.7	-23.5	8.3

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on the topic: *THE ROLE OF URBAN FORM IN CLIMATE CHANGE ADAPTATION IN CITIES. THE CASE OF NAIROBI*

for the period ending:
12th March,2019

Permit No : NACOSTI/P/18/45119/21681
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Director General
National Commission for Science, Technology & Innovation

Appendix XXI: Glossary of Key Terms as Applied in the Study

Biophysical: These are combination of natural and built-environment characteristics that influence how weather elements interact with urban surfaces. The natural elements include landcover, soil drainage properties, elevation, slope NDVI. The built-environment elements include population density and open space networks.

Climate Change Adaptation: The process of improving the resilience of a person, household, community, neighbourhood, or region to better manage the impacts and effects of climate change.

Climate change effects: These are the direct results of the global warming phenomena without looking at the possible hazards and risks, for example, extreme temperatures, sea-level rise, extreme precipitation, and intense winds.

Climate Change Impacts: The direct results and risks related to the effects of climate change like flooding, drought, and landslides associated with extreme precipitation; heatwaves, cold waves and thermal variability associated with extreme temperatures; hurricanes, cyclones, and tornadoes associated with intense winds and inundation associated with sea-level rise. The impacts are both direct and indirect and affect the different sectors of human life in different ways, intensities, and durations.

Climate change vulnerability: The degree to which a system is susceptible and unable to cope with the impacts and effects of climate change. It encompasses three components namely exposure, sensitivity, and adaptive capacity.

Climate change: The change in climate over time due to natural variability and human activities that persists for an extended period, typically decades or longer (IPCC, 2007c).

Climate variability: Variations in the mean state and other statistics of the climate on all temporal and spatial scales, beyond individual weather events

Climate: Climate is the aggregation of weather patterns over 30 to 35 years indicating seasonal trends in weather.

Open Space Networks (OSN): It is a combination of public and private green or bare ground open spaces. It can also be referred to all open spaces excluding streets and buildings.

Socioeconomic: They are housing and population census parameters of poverty levels, age, access to services, and gender.

Urban form elements: The main physical and non-physical elements that constitute the urban fabric. Broadly grouped under natural and built environment elements. Specifically, geology, landform, plants, streets, open spaces, buildings, and the relationship between these elements.