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URBAN HEAT ISLAND MITIGATION THROUGH URBAN FARMING USING REMOTE SENSING IN MAIDUGURI NIGERIA

LADAN TIJJANI ABUBAKAR

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THESIS PRESENTED TO QUALIFY FOR A DOCTOR OF PHILOSOPHY

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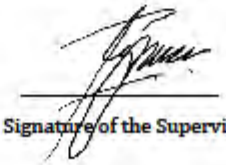


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ABSTRACT

Urban heat islands (UHI) present critical challenges to urban environments, intensifying heat-related health risks and reducing livability. This study evaluates the potential of urban farming to mitigate UHI effects in Maiduguri, Nigeria, by analyzing changes in land surface temperature (LST), land use/land cover (LULC), and vegetation cover over a 30- year period (1992–2022). Landsat satellite imagery processed through ArcGIS and Google Earth Engine was validated using ground truth observations collected with a Garmin eTrex
10 GPS device and supplemented by long-term climatic data from the Nigerian Meteorological Agency (NiMET). ENVI-met microclimate simulations quantified the impact of urban farming on surface temperature and humidity. Results show significant urban expansion accompanied by decreased vegetation, driving higher LST values and intensifying UHI impacts. By 2022, LST peaked at 32.98°C, with UHI intensity rising steadily throughout the study period. ENVI-met simulations indicate that increasing urban farming coverage leads to notable cooling effects and improved vegetation health, with a 0.5°C temperature reduction and a 2.0% humidity increase observed at 10% urban farming coverage. A survey of 400 residents revealed limited awareness of UHI but strong recognition of urban farming's benefits for food security and environmental sustainability. These findings underscore urban farming as an effective, nature-based strategy for UHI mitigation and advocate for its integration into urban planning to foster resilient, sustainable cities in rapidly urbanizing and arid regions such as Maiduguri.

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MITIGASI PULAU HABA BANDAR MELALUI PERTANIAN BANDAR MENGGUNAKAN PENDERIAN JAUH DI MADIDUGURI NIGERIA

ABSTRAK

Pulau haba bandar (UHI) memberikan cabaran kritikal kepada persekitaran bandar, meningkatkan risiko kesihatan berkaitan haba dan mengurangkan kebolehtinggalan. Kajian ini menilai potensi pertanian bandar untuk mengurangkan kesan UHI di Maiduguri, Nigeria, dengan menganalisis perubahan dalam suhu permukaan tanah (LST), guna tanah/litupan tanah (LULC), dan litupan tumbuh-tumbuhan dalam tempoh 30 tahun (1992– 2022). Imej satelit Landsat yang diproses melalui ArcGIS dan Enjin Google Earth telah disahkan menggunakan pemerhatian kebenaran tanah yang dikumpul dengan peranti GPS Garmin eTrex 10 dan ditambah dengan data iklim jangka panjang daripada Agensi Meteorologi Nigeria (NiMET). Simulasi iklim mikro yang dipenuhi ENVI mengukur kesan pertanian bandar terhadap suhu dan kelembapan permukaan. Keputusan menunjukkan pengembangan bandar yang ketara disertai dengan penurunan tumbuh- tumbuhan, memacu nilai LST yang lebih tinggi dan meningkatkan kesan UHI. Menjelang 2022, LST memuncak pada 32.98°C, dengan keamatan UHI meningkat secara berterusan sepanjang tempoh kajian. Simulasi ENVI-met menunjukkan bahawa peningkatan liputan pertanian bandar membawa kepada kesan penyejukan yang ketara dan kesihatan tumbuh- tumbuhan yang bertambah baik, dengan pengurangan suhu 0.5°C dan peningkatan kelembapan 2.0% diperhatikan pada liputan pertanian bandar sebanyak 10%. Tinjauan ke atas 400 penduduk mendedahkan kesedaran terhad tentang UHI tetapi pengiktirafan yang kukuh terhadap faedah pertanian bandar untuk keselamatan makanan dan kelestarian alam sekitar. Penemuan ini menekankan pertanian bandar sebagai strategi berasaskan alam semula jadi yang berkesan untuk mitigasi UHI dan menyokong penyepaduannya ke dalam perancangan bandar untuk memupuk bandar yang berdaya tahan, mampan di kawasan perbandaran yang pesat dan gersang seperti Maiduguri.

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CONTENTS

	Page
DECLARATION OF ORIGINAL WORK	ii
DECLARATION OF THESIS	iii
ACKNOWLEGEMENT	iv
ABSTRACT	v
ABSTRAK	vi
CONTENTS	vii
LIST OF TABLES	xiii
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xvii
LIST OF APPENDICES	xx
CHAPTER 1 INTRODUCTION	
1.1 Overview	1
1.2 Background of The Study	5
1.3 Rational of the Research	13
1.4 Statement of problem	20
1.5 Aim of the study	27
1.6 Objectives of the study	28
1.7 Research Questions	28

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

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1.8 Scope of the study 29

1.9 Operational Definition 29

1.10 Significance of the Study 32

1.11 Summary 33

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction 35

2.2 The Concept of Urban Heat Island 36

2.3 Types of Urban Heat Islands 42

2.4 Urban Heat Island and Human Health 43

2.5 Urban Heat Island Intensity 45

2.6 Urban Heat Island and Climate Change 47

2.7 Relationship between Urban Heat Island and Land Use/Land Cover 56

2.8 Urban Heat Island Studies in Nigeria 57

2.9 Issues Within UHI Communication 59

2.10 Urban heat island mitigation strategies, the blue, green and grey 61

2.10.1 Green Infrastructure 63

2.10.2 Urban Parks 63

2.10.3 Green and Cool Roof 65

2.10.4 Vertical Farming/Sky Farming 66

2.10.5 Trees 68

2.10.6 Urban Farming, Urban/Community Garden 70

2.10.7 Blue Infrastructure 72

2.10.8 Grey Infrastructure 77

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2.11 Remote Sensing and UHI 81

2.12 Landsat Sensors 84

2.13 The Origin of Urban farming/Urban agriculture 89

2.14 The Concept of Urban Farming 94

2.15 Types of Urban Farming 101

2.16 Significance of Urban Farming 105

2.17 The Imperative of Urban Farming in Maiduguri 114

2.18 Summary 121

CHAPTER 3 METHODOLOGY

3.1 Introduction 123

3.2 Historical Background of the Study Area 124

3.2.1 Study Area Location 128

3.2.2 Growth and Development of Borno State 132

3.2.3 Size and population 134

3.2.4 Weather and Climate 135

3.2.5 Soil 147

3.2.6 Landform Topography 148

3.2.7 Geology 153

3.2.8 Hydrogeology 154

3.2.9 Drainage System 157

3.2.10 Vegetation 160

3.2.11 Transport System 160

3.2.12 Land use 162

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

3.3 Research Design 166

3.4.1 Sources of Data 166

3.3.2 Data Assembly and Management 167

3.4.3 Image Pre-processing 168

3.4.4 Image Classification 170

3.4.5 Accuracy Assessment 171

3.4.6 Derivation of LST from Landsat and retrieval of brightness 171

3.4.6.1 Conversion of DN to TOA Spectral Radiance 174

3.4.6.2 Conversion to Brightness Temperature (BT) 174

3.4.6.3 Surface Emissivity and Final LST Estimation 175

3.4.7 Normalized Difference Vegetation Index (NDVI) 177

3.5 ENVI-met Simulation 180

3.5.1 ENVI-met Simulation Procedure 182

3.6. Population and Sampling 184

3.6.1 Sample 184

3.6.2 Sample Frame 185

3.6.3 Sample wards and sample size 190

3.6.4 Pilot study 191

3.6.5 Exploratory Factor Analysis 192

3.6.6 Data Source from 194

3.7 Data Analysis 197

3.7.1 Materials and Method for the Analysis of Objectives 197

3.8 Summary 200

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

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CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction 203

4.2 Data acquisition 108

4.3 Image Processing LULC Classification 211

4.4 LULC accuracy assessment 213

4.5 Changes in Magnitude, Trend Percentage, and Annual Change Rate 217

4.6 Land Surface Temperature (LST) Dynamics 223

4.7 Derivation of NDVI, from the Landsat Imagery 226

4.8 Urban Heat Islands Estimation 228

4.9 Spatiotemporal Pattern of LU/LC Dynamics 236

4.10 Relationship Between LST and Vegetation Cover 248

4.11 Urban Farming Practices in Maiduguri 250

4.11.1 Farm Site 1: Gamboru, Old Maiduguri, Gongulong 255

4.11.2 Farm Site 2: Bale Galtimari, Mairi 255

4.11.3 Farm Site 3: Maisandari 256

4.11.4 Farm Site 4: Mairi 256

4.12. ENVI-met Simulation Report 258

4.12.1 Simulation Results 261

4.12.2 Validation of ENVI-met Model Using NiMET and Ground 267

4.13 Urban Dwellers' Perspectives on Understanding and Perception 268

4.13.1 Urban Dwellers' Perception on UHI Phenomenon 268

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05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

4.13.2 Socio-demographic Characteristics of Respondents 269

4.13.3 Demographic characteristics of urban dwellers 273

4.13.4 Awareness and Understanding of UHI Phenomenon 279

4.13.5 Challenges and Barriers of UF for UHI Mitigation 306

4.14 Summary 325

CHAPTER 5 DISCUSSION, SUMMARY AND CONCLUSION

5.1 Introduction 327

5.2 Researcher's Discussion and Further Argument 329

5.2.1 Assessing the Level of UF Practice and the UHI 329

5.2.2 Analyzing Spatiotemporal Trends in LULC, LST, NDVI 332

5.2.3 Assessing Urban Residents' Knowledge and Perceptions 335

5.2.4 Evaluating the Effectiveness of UF in Reducing UHI 337

5.3 Summary 340

5.4 Implications and Recommendations 342

5.5 Conclusion 345

REFERENCES 347

APPENDICES 379

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

LIST OF TABLES

Table No.		Page
2.1	Summary of band designations and pixel size (m) for all Landsat satellites (LS) and sensors	87
2.2	Stages of the historical development of urban farming	93
2.3	Studies implementing urban farming as a strategy for Urban Heat Island mitigation	99
3.1	Spatial and Temporal Distribution of Average Temperatures in Maiduguri (1992–2022)	138
3.2	Distribution of Average Relative Humidity (%) in Maiduguri	142
3.3	Annual Rainfall (mm) in Maiduguri Wards (1992–2022)	146
3.4	Spectral Bands Used in the Study	176
3.5	Sample wards and sample size	190
3.6	Kaiser-Meyer-Olkin Measure of Sampling Adequacy and Bartlett's Test of Sphericity	192
4.1	Details of Landsat datasets of the study area, Maiduguri.	207
4.2	Area (km2) and percentage of Land Cover classes during the study period 1992 – 2022	209
4.3	The description and composition of the LULC types used in the study.	213
4.4	Land use land cover accuracy assessment.	216
4.5	Change Magnitude of Maiduguri Metropolis from 1992 – 2022.	219
4.6	The Trends of the LULC from 1992-2022	221

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

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4.7	The annual change rate of the LULC from 1992-2022	222
4.8	Summary of LST (°C) for Maiduguri Metropolis (1992–2022)	226
4.9	Urban Farming Sites: Size and Perimeter (2002-2022)	254
4.10	Total Area and Perimeter of Urban Farming Sites (2002-2022)	255
4.11	Baseline data used for the simulation	259
4.12	Scenario 1: 10% Urban Farming Coverage	260
4.13	Scenario 2: 20% Urban Farming Coverage	260
4.14	Scenario 3: 30% Urban Farming Coverage	260
4.15	Simulated result of different urban farming Scenario and how it reduces temperature and Humidity	261
4.16	Demographic Characteristics of Urban Dwellers	270
4.17	Environmental Impact and Lifestyle Choices of urban dwellers	276
4.18	Responses on Awareness and Understanding of Urban Heat Island Phenomenon	284
4.19	Perception and Attitude Towards UHI Mitigation and UF	266
4.20	Challenges and Barriers of Urban Farming for UHI Mitigation	306
4.21	Initiative and Adaptation Measures for UHI Mitigation	317

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LIST OF FIGURES

No.	Figures	Page
1.1	Figure 1.1 Research gap.	24
2.1	The formation of UHI and temperature profile.	38
2.2	Landsat mission series and management history.	86
2.3	Conceptual Framework for UHI Mitigation Using Urban Farming Potential.	120
3.1	Map of Borno State showing Maiduguri and its environs.	138
3.2	Annual Average Temperature Maps of Maiduguri	139
3.3	Annual Average Relative Humidity of Maiduguri (1992– 2022).	141
3.4	Annual Average Rainfall Map of Maiduguri (1992–2022).	144
3.5	Relief of Maiduguri Metropolitan Area.	150
3.6	Cross section of the multi-layered aquifer system	156
3.7	Drainage system in Maiduguri Metropolitan.	159
3.8	Types of Data Collected.	194
4.1	UHI Pattern of Maiduguri in 2002 with Raster-Based Tempt	232
4.2	UHI Pattern of Maiduguri in 2012 with Raster-Based Tempt	233
4.3	UHI Pattern of Maiduguri in 2022 with Raster-Based Tempt	235

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4.4	LULC distribution of Maiduguri Metropolis from 1992 to 2022	240
4.5	Classified LULC Maps; 1992, 2002, 2012, and 2022	243
4.6	LST Distribution of Maiduguri Metropolis in 1992, 2002, 2012, and 2022	245
4.7	NDVI Spatial Distribution of NDVI of Maiduguri Metropolis in 1992 – 2022.	247
4.8	Farm site Spatial Distribution of Maiduguri in 2002 -2022	252
4.9	Humidity ENVI-MET Simulation Results: Temperature Reduction and Increase	262
4.10	Graphic Presentation of Demographic Characteristics of urban dwellers	271
4.11	Graphic Presentation of Demographic Characteristics of urban Dwellers	272

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ANN	Artificial Neural Network
ArcGIS	Arc Geographic Information System Software by ESRI
BGI	Blue-Green Infrastructure
DN	Digital Number
EO	Earth Observation
ETM+	Enhanced Thematic Mapper Plus
ENVI-met	Environmental Meteorology
FAO	Food and Agriculture Organization
FCC	False Colour Composite
GIS	Geographic Information System
GPS	Global Positioning System
GRI	Green Resilient Infrastructure
IDP	Internally Displaced Person
IFAD	International Fund for Agricultural Development
ITOS	Information Technology Outsourcing Services

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LST	Land Surface Temperature
LULC	Land Use Land Cover
MLSICM	Maximum Likelihood Supervised Image Classification Method
MLC	Maximum Likelihood Classification
MSS	Multispectral Scanner
NDVI	Normalized Difference Vegetation Index
NESS	National Environmental Satellite System
NGO	Non-Governmental Organization
NIR	Near-Infrared
NOAA	National Oceanic and Atmospheric Administration
OLI	Operational Land Imager
OXFAM	Oxford Committee for Famine Relief
PCI	Park Cool Island
PV	Proportion of Vegetation
RED	Red Band (of the electromagnetic spectrum)
RF	Random Forest
RS	Remote Sensing
SAM	Spectral Angle Mapper
SGDs	Sustainable Development Goals
SPSS	Statistical Package for the Social Sciences
SUHI	Surface Urban Heat Island
SVM	Support Vector Machine

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SWIR	Shortwave Infrared
TIR	Thermal Infrared
TM	Thematic Mapper
TOA	Top of Atmosphere
UA	Urban Agriculture
UF	Urban Farming
UHI	Urban Heat Island
UN	United Nations
UPA	Urban and Peri-urban Agriculture
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WFP	World Food Programme
WGS84	WGS84 - World Geodetic System 1984

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LIST OF APPENDICES

A Respondents Questionnaire

B Respondent's Information Sheet and Informed Consent

C1 Ethical Compliance

C2 Ethical Compliance

D Reliability

E1 Validation of ENVI-met Model Outputs Using NiMET

E2 Accuracy Assessment of Landsat-Derived LULC Maps

E3 Surface Temperature and Land Use/Land Cover Using Ground Truth Data

F Publications

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CHAPTER 1

INTRODUCTION

1.1 Overview

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Today, there are over four billion urban residents worldwide, with over 863 million living in informal settlements, and this number is growing by approximately one million every ten days (Acuto et al., 2018; Elmqvist et al., 2019). Also, the number of large cities with populations of over five million urban dwellers is increasing, with over thirty "megacities" with inhabitants exceeding ten million (Saaroni et al., 2018). Studies have indicated that by 2020, the developing countries of Africa, Asia, and Latin America will be home to about three out of every four urban dwellers, as well as eight of the world's nine megacities (Azunre et al., 2019). This rapid urbanization and its attendant sprawl, in both the global north and south, endangers the urban climate's long-term viability. Given that cities are among the most complex man-made systems or mechanisms, the sustainability of the urban

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landscape and that of the urban dwellers is one of humanity's greatest concerns. Similarly, urban centers have emerged over the decade as critical to securing a long-term future. Economic, environmental, and social, urbanization now play a critical role in each of the three fundamental pillars of sustainability.

Rapid population growth is a worldwide phenomenon, Venter et al., (2020). The localized climatic phenomena known as the urban heat island, which is defined by higher temperatures within the city than in the rural environs, is one of the most notable environmental features bedeviling urban regions, (Saaroni et al., 2018). The intensity of this urban-rural temperature variation is impacted not only by the city's population figures, but also by its physical characteristics, such as the developed area's density, the materials used in its buildings and pavements, and the concentration of anthropogenic activities. (Elmqvist et al., 2019; Hwang et al., 2017; Noro & Lazzarin, 2015; Yao et al., 2018), Cities contribute more than 75% of national earnings, subsequently, generate about 75% of carbon emissions from global energy consumption, and are home to the majority of the world populace. Therefore, the twenty-first century should be appropriately termed the urban century, (Elmqvist et al., 2019). The Urban Heat Island is well known across cities around the world and it suffices to say that the phenomenon has spawned a plethora of literature from all regions of the globe (Noro & Lazzarin, 2015). Large surfaces of low albedo and high admittance components (primarily asphalt and concrete); reduced vegetation and pervious surfaces, which limit shade and evapotranspiration; high buildings and narrow roads, which reconfigure overall wind speeds and create urban canyons; and composition of heat-generating activities produced from combustion processes (including

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cars) and other anthropogenic activities are the main factors that contribute to UHI, (Noro & Lazzarin, 2015; Wanga et al., 2015; Zölch et al., 2016).

In this urban century, Humans have transformed the cityscape into the most sophisticated and typical socio-ecological system. The fundamental challenges of government and governance will be urban. As urban planners, policymakers, and researchers navigate into the new urban environment. This is due in part to a worldwide interest in urban resilience and sustainability (Zhang & Li, 2018). One of the greatest challenges of this era is the urban heat phenomenon, though it is not new the concept (UHIE) is a more recent threat according to (Richards & Edwards, 2018) that can lead cities to become unbearably hot, with significant economic repercussions. As a result, several communities have implemented measures to limit warming, and the UHIE is becoming a critical issue in academia, (Fatma et al., 2020; Kumari et al., 2017; Li et al., 2019; Narumi et al., 2021; Yusof et al., 2017).

Many scholars have presented an enormous literature on urban agriculture. However, (Ibharim & Salim, 2020) reported that an inquiry into association between urban farming activities that enhance the well-being of urban dwellers remains unexplored, and numerous scholars have underlined the advantages of urban farming from a global urban perspective, (Kuhn et al., 2019; Li et al., 2020; Orsini et al., 2013; Vandercasteelen et al., 2018) very few highlighted the significance of urban farming in mitigating the impact of urban heat islands in our cities. Therefore, this study will highlight the potential benefits, relevance, and unique characteristics of vegetated surfaces in the form of Urban Farming

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in the semi-arid region of Maiduguri Metropolis will be explored and employed to ameliorate the impact of heat island phenomena in the semiarid microclimate. (Kullu et al., 2020; Kumar et al., 2017; Li et al., 2020; Orsini et al., 2013; Yusoff et al., 2017).

Urban farming is seen by Kullu et al., (2020), as the practice of community gardening as an organizational strategy, a comprehensive approach to communities, pursuing economic growth through food production, promoting and engaging urban dwellers, improving neighbourhood safety through blight prevention, and introducing youth to intergenerational and neighbourhood interactions, advancing economic development through crop production, and encouraging independence and urban sustainability. Similarly, Rahdriawan and Arriani, (2020), reiterated that urban farming is the growing, processing, and delivery of food and other goods in municipalities and the surrounding area, as well as the recycling of land and resources and urban waste, to obtain a wide range of crops and livestock. It not only promotes local economies by producing jobs and providing access to good food, but it also significantly strengthens local microclimates by sequestering carbon and providing green spaces that add shade. Amidst miles of boring concretes and asphalt city roads, the sight of green spacing blooming an abundance of fresh fruits and vegetables is a sight to behold, which positively enhances environmental sustainability. (Filippini et al., 2018; Kullu et al., 2020; Poulsen et al., 2017; Ramaloo et al., 2018).

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1.2 Background of The Study

The urban heat island phenomenon is a highly technical concept that is specific to urban climatology, engineering, and urban planning, therefore, this concept is not readily understood by a non-specialist in the field. This phenomenon has been and continues to be an important area of investigation across numerous fields of study since it was first documented nearly two centuries ago, owing to its negative impacts on the urban natural ecosystem and the overall sustainability of cities (Estoque & Murayama, 2017). Urban heat islands affect more than 54% of the world's population (UHIs). Since this phenomenon was first identified in the nineteenth century, a plethora of studies have shown that it increases the use of energy and water resources, deteriorates urban ecosystems, and threatens the health of residents (Liu et al., 2021). The urban heat island can negatively affect the urban inhabitants and disrupt the urban ecosystem and their total well-being. Also, there are no known studies that identify the formation of urban heat islands and their dynamics, and also its mitigation measures in Maiduguri Metropolis. If left unchecked this hot and dry semi-arid environment which is already fragile and vulnerable to the complex interrelationship between human activities and climatic variability will further worsen and exacerbates the negative effects of the local climate change.

According to Stewart and Mills (2016), Luke Howard's work on the Climate of London, where the science of urban heat islands was conceptualized, was the foundation of heat island studies (which was first published in 1818). For 26 years, he and his family kept a daily record of the maximum and minimum air temperatures at various sites outside

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of the city to explain the climate of the area. When he examined his records to those held by the Royal Society in London, he discovered a systematic mismatch that he couldn't refute as observational inaccuracies. He concluded that the city's temperature should not be matched to the climate. His research revealed that the disparities were more pronounced during the winter season when the city was warmer, which he attributed to human heating of buildings, a lack of greenery to cool the air, and impediments to urban airflow. Steward & Mills further revealed that Before the 1970s, there were few measurements of surface temperature in cities due to the high cost and complexity of mounting thermal infrared (TIR) sensors. To examine the urban surface on a large scale, these sensors needed to be high enough to "see" a swath of the urban environment and aggregate the inputs of the ground, walls, and rooftops. TIR sensors that measure land surface temperature and allow detection of surface UHI have been included in satellite observation systems since the mid-1970s. Successive investigations in cities around the world have demonstrated that Howard's findings are applicable worldwide (Al-Marzooqi, 2019).

As Taslim et al., (2015) corroborate, Luke Howard’s findings showed that the urban centre of London was 2.1℃ warmer at night than the surrounding rural areas and that this warming was likely to expand by around 1℃ every decade. It was not, however, classified as a heat island. When isotherms were used to model the city, the name "island" was coined. When air temperatures are depicted using isotherms, the city seems to be an island in comparison to the surrounding countryside, which has lower temperatures (Musco, 2016). The concept of "urban heat island" was coined in the 1940s to describe the difference in temperature between a city's atmosphere and the surrounding urban areas.

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The sequential screen-height air temperature differential between urban and rural temperatures is commonly used to calculate the severity of the UHI. The phenomenon is an unanticipated consequence of urbanization that occurs practically in all metropolitan settings, potentially increasing energy needs and causing thermal discomfort (Wang et al., 2016).

It has been reported by numerous scholars that the most significantly influenced meteorological variable by urban growth and development is temperature. The temperature rise within cities and their environs has been well established (Santamouris, 2013; Santamouris, 2020; Stewart & Oke, 2012; Stewart & Mills, 2016; Valle-Dı´az et al., 2009). The term "urban heat island," which was first coined by Manley (1958), is now commonly accepted. The urban heat island has been examined in various cities since its conception and has been proven to cause temperature differences of several degrees between urban and rural areas (Valle-Dı´az et al., 2009). Moreover, modelling predicts that the temperature differential between urban and adjacent rural areas in some cities could reach 8 degrees Celsius by 2050. The extent of the urban heat island effect is determined by a variety of factors, including area climate, but it is projected to be greater in dry climates than in cold humid ones.

According to the World Meteorological Organization, the UHI effect can raise the air temperature in a city by 2 to 8°C (Mohajerani et al., 2017). Conversely, Santamouris, (2013) found that a more accurate range is between 5 and 15°C. The heat island effect is the result of a decline in vegetation and evapotranspiration, an increased frequency of dark

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surfaces with low albedo, and greater anthropogenic heat output as our cities continue to grow and develop. In their study on heat island mitigations Santamouris et al., (2019) presented results of hundreds of cities, details on the magnitude and characteristics of the urban heat island are provided. The magnitude of UHI varies between 0.5 and 11℃, with an average value close to 4.1℃, according to data obtained through mobile traverses in 101 Asian and Australian cities. A similar record of data from 110 European cities revealed that the magnitude of UHI varied between 1 C and 10 ℃, with an average maximum value of around 6℃. Looking at the findings of the above studies from West, Asia, and Australia studies on heat islands in Africa are lacking. Hence, there is the need to embark on such investigation to identify and proffer sustainable solutions to one of the most challenging climatic phenomena of the twenty-first century to keep abreast with the rest of the world for the sustainability of our cities and communities, which is one of the cardinal points of the United Nation sustainable development goals (UN SDGs).

Furthermore, changes in land use/land cover of cities can elevate the temperature of both the local air and surfaces, many degrees warmer than the surrounding locations at the same time. The interaction between human activity and the environment is characterized as LULC, and it has a significant impact on urban climate. Different UHI patterns are caused by various LULC types, which include surface material qualities such as albedo and emissivity, pollution (air), anthropogenic heating, and urban geometry, (Naserikia et al., 2019). Furthermore, various LULC features influence UHIs, including green biomass abundance, natural vegetation, desolate land, water, low/medium/high-

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density built-up regions, pavements, plant abundance, and impervious surface areas, the latter two being the most influential.

Two types of urban heat islands were identified; the atmospheric urban heat islands and the surface urban heat islands. The former addresses UHI effects in the canopy or boundary layers, whereas the latter considers the surface variation in radiative temperature. In general, atmospheric urban heat islands are observed and modelled using in-situ sensors (meteorological stations or towers), radiosondes, and aircraft. Although the devices generate more reliable air UHI measurements, they are more expensive to set up (Darshana & Yuji, 2021). Similarly, pioneer studies have revealed that investigations on the development of UHIs depended heavily on meteorological measurement (in situ) data and field observation data obtained in urban and suburban regions originally studied by Howard in 1833. However, the use of remote sensing technologies can enhance the precision of defining the UHI spatial distribution and lessen the amount of time needed for analysis (Liu et al., 2021).

Rapid globalization is intrinsically linked to urbanization, city expansion, and development. Although it benefits human society greatly, it also has negative consequences for the environment. In all the environmental consequences of urbanization, the threat it poses to the thermal environment is of major concern (Darshana & Yuji, 2021; Wang et al., 2010; Yao et al., 2018). In the same vein Stewart and Mills, (2016) affirm that the urban heat island, in all its ramifications, is a common consequence of urbanization.

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The temperature effect of urban environments has been investigated for almost 200 years, resulting in a vast body of knowledge with a wide range of content, spatial coverage, methodological approaches, and experimental rigour (Stewart & Mills, 2016). Similarly, Estoque and Murayama, (2017) reiterated that this phenomenon has been and continues to be an important area of investigation across numerous fields of study since it was first documented nearly two centuries ago, owing to its negative impacts on the urban natural ecosystem and the overall sustainability of cities.

The growth and development of cities, as well as industrialization, are intended to bring comfortability and well-being to city dwellers. However, amid the climate crisis, this development has resulted in various challenges as a result of human interactions in the environment. Cities' intensive anthropogenic activities consume well over two-thirds of the global energy demand and account for more than 70% of world carbon emissions. Cities, due to their complex nature and human activities, can have varied local climates that differ from the surrounding natural environment. The (UHI) effect is a well-known climate feature that occurs when urban centers are relatively warmer than their surroundings, as documented in numerous cities across the world (Wang et al., 2021b). UHI is caused mostly by the use of building materials, complex urban morphology, a lack of vegetation, and anthropogenic heat sources.

It is now a common knowledge that more than half of the world population now live in urban areas (Bassett et al., 2020; Li et al., 2019; Weng et al., 2019). In the next decade it is projected that more 60% of the world population will live in urban areas

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(Ibharim & Salim, 2020). It is on record that in 1980, 1.7 billion people (39%) lived in urban areas. In 2014, the number has risen to 7.3 billion (54%) and it is projected that, the world urban population will rise to 9.7 billion (66%) by 2050. This projection indicates that more than (90%) of urbanization until 2050 will occur in Africa and Asia. Today the global urban population is expected to be growing at approximately 1.84% per year up to the year 2020, 1.63% between 2020 and 2025, and 1.44% per year between 2025 and 2030. In Nigeria 84 million people were living in cities in 2014; by 2050 it is projected to rise to 295 million (World Bank, 2016). Similarly, Bloch et al.,(2015) asserted that in Nigeria urban population has risen rapidly over the past 50 years and will continue to grow relatively fast in the coming decades. A report indicated that Nigeria has seven cities with more than a million people and Maiduguri the study area is one of them with a population of 1,112,449 people. Worldpopulationreview, (2019) Urbanization leads to the alteration of local climate and in particular creates urban heat (Folorunsho et al., 2017; Ohwo & Abotutu, 2015).

In many societies across the world, there is a growing interest in crop production in and around cities covering a variety of forms, backgrounds, and interests. There is also a correspondent increase in literature and discussions among academia and the media on the upscaling interest in Urban Farming (UF) Pölling et al., (2017), observe that, like Urban Agriculture (UA), Urban Farming is defined as 'Small-to large-scale agriculture, which mainly cultivates agricultural land on the urban fringe It is primarily economically motivated and managed by professionals with medium to large distribution networks from direct marketing to global value chains. Many scholars use different terms to explain the

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agricultural practice in towns and cities, like ‘urban agriculture ‘professional urban agriculture’ ‘professional farms’ ‘peri-urban agriculture’ ‘metropolitan agriculture’ and ‘urban fringe agriculture’ (Opitz et al., 2016; Pölling et al., 2017). In their work, on the role of a community in urban farming activities Yusof et al., (2017) described urban farming as food or livestock production or processes that are carried out within the urban area or around the urban centres to generate income. Thus, urban agriculture in the same vain refers to the growth, processing, and distribution of food and other products through intensive plant cultivation and animal husbandry, horticulture, aquaculture, and other practices, for producing fresh food in and around cities to feed local population (Game & Primus, 2015; Tornaghi, 2014; Yusoff et al., 2017). This definition according to Game and Primus, (2015) describes both (UPA) urban and peri-urban agriculture. The UPA was introduced by the United Nations Food and Agricultural Organization (UN FAO) as a means of planting crops and growing livestock in and around cities (FAO, 2011). It is worth noting that in Sub-Saharan Africa urban farmers contribute greatly to food security as they produce 80% of what they consume (Shabu, 2019).

The urge of humans to explore the environments and create new settlements transformed mankind's needs, which resulted in the formation of villages, towns, and cities to meet the requirements of humans regarding society, economy, culture, and comfort (Yusoff et al., 2017). As towns and cities grow and develop, there will always be consequences as a result of this urbanization to the urban environment and the urban dwellers, thus (Yao et al., 2018), in their study on surface urban heat island intensity and associated drivers in China described urban heat islands as a major detrimental

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consequence of urbanization. Similarly, (Mohajerani et al., 2017) affirms that The main causes of the UHI are increased use of manmade materials and increased heat generated by human activities. As a result, it's now widely accepted that the fundamental cause of the urban heat island is growing urbanization.

1.3 Rational of the Research

The increasing number of people in our cities and towns, participating in various anthropogenic activities, combined with urbanization and industrialization, improves our material lives and comfort; however, it also causes many problems for humans, such as rising temperature, industrial effluents, and carbon emissions. Besides the negative environmental consequences, they have an impact on regional urban areas as well as local climates. Urban areas are more seriously affected by industrial activities and the heavy use of synthetic concrete structures. As a result, the natural environment and ecology have been greatly impacted, and the requisite balance has been lost (Kumar et al., 2017). He maintained that urbanization is a complex concept that is linked to some severe environmental concerns.

Similarly, it also reported that urban growth is speedily destroying biodiversity and, with it, the Earth's ability to support life on this planet. Despite the steady depletion of human civilization's fabric, the mainstream is struggling to grasp the magnitude of this loss. While there are numerous proposed solutions, their current scale of successful execution

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does not match the persistent progression of biodiversity loss and other serious threats associated with continuous expansion. Significant delays between environmental deterioration and socioeconomic consequences, such as climate disruption that includes rising temperatures in cities, impede identification of the enormity of the challenging task and timely intervention required (Bradshaw et al., 2021; Yao et al., 2018). The ability of a town or city to develop a higher temperature than its surrounding rural areas is now widely recognized. This is one of the most well-documented climatological consequences of man's alteration of the urban atmosphere.

Globally, urbanization is accelerating, particularly in developing countries, where air pollution and other urbanization-related problems are becoming increasingly severe and attracting increased attention. Holistic assessments of the environmental impact of urbanization on the urban environment are necessary. This research work seeks to better understand the generation, determination, and mitigation of UHI through urban farming. The concept is intriguing and the researcher would like to learn more about it. In particular, I would like to investigate the development of the phenomenon and how urban farming can be used to mitigate the impacts in the already dry and warm critical ecosystem of semi-arid cities. The urban heat island phenomenon which is one of the major negative effects of urbanisation, refers to higher temperatures in cities than in rural areas. UHIs have several negative effects on natural ecosystem (for example, net primary production), human health (for example, worsening respiratory disease and even fatal consequences), and the urban landscape (e.g. pollution) (Yao et al., 2018).

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The ability of a town or city to develop a higher temperature than its surrounding rural areas is now widely recognized. This is one of the most well-documented climatological consequences of man's alteration of the urban atmosphere (Chen et al., 2006; Waffle et al., 2017; Weng, 2009). According to emerging literature, UHI dynamics are more complex and difficult for dryland cities, which include arid, semi-arid, and Mediterranean climates. Although many studies focus on temperate regions, there are far fewer that emphasize dryland regions, and even fewer that do a worldwide correlation (Dialesandro et al., 2019). This assertion by Dialesandro et al that dry regions experience even more complex challenges than other areas makes it imperative for the researcher to embark on this endeavour as the study area is coincidentally situated in the dry semi-arid region of West Africa to understand the dynamics of the phenomenon.

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Consequently, after looking at length on some available literature from multiple sources and some interactions with some critical stakeholders within the research community, the researcher chose to focus on these three distinct areas. First, the researcher will look at the formation of the phenomenon to identify and establish its status. Secondly, the study will look at the trend, pattern and or magnitude of the concept. Finally, this piece of work will aim to explore how urban farming can help ameliorate the impact of urban heat island. Numerous sources of databases will be utilized, though a primary source of data will be acquired directly in the field, the study is hinged on remote sensed data from USGS.

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According to a study in one of the Asian cities revealed that, the occurrence of the UHIs and SUHIs is commonly associated with urban sprawl and increased industrial and human activity; however, geographical location, climatic condition, urban materials, seasonal changes, and times of day and night can all have differential influences (Haashemi et al., 2016). This finding suggests the need to identify the complexities of the phenomenon in various parts of the globe and provide appropriate measures required by them for the sustainability of cities, as it is evident that each environment is with its own peculiarities. A study on urbanization's contribution to climate warming in Great Britain, by Bassett et al., (2020) also agrees with Haashemi's statement, reaffirming that, UHI research is mainly limited to the city of interest.

Numerous regions are grappling with the urban heat Island effect, and so much research has been devoted to improving those conditions. Several scholars have discussed vegetation as part of mitigating factor, but few studies have proposed using it, especially in the west African sub region. This study looks into the potential for growing food crops and urban farming in general in hot urban microclimates of this area as a heat island mitigation strategy. According to UN Habitat's report on the state of African cities with the theme "Re-imagining sustainable urban transitions," the UN body highlighted that, in 2011, West Africa's total urban population was 140.1 million (44.9%). The sub-region was indeed projected to reach an urban majority of 196 million residents shortly after 2020. After Eastern Africa, Western Africa is the continent's fastest urbanizing region. The West Africa's population is expected to rise from 49.9% in 2020 to 65.7% by 2050. As a result, all countries in the sub region are confronted with accelerating city growth rates and the

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resulting increase in demand for affordable housing and all basic amenities (UN-Habitat, 2014). As a result, it increases the pressure on the critical urban ecosystem and the scarce resource, with negative environmental consequences. This threat to the urban environment and its inhabitants must be addressed immediately.

Western Africa is one of the world's poorest, least urbanized and least industrialized sub-regions (Ofoezie et al., 2022; UN-Habitat, 2014). In the region and the whole of Africa Nigeria is the most populous country, this as a result of its share number, may also have serious consequences for regional urbanization estimates and the environment (UN-Habitat, 2014).

With nearly all of the world's demographic growth concentrated in developing nations, rising urban population is becoming a defining characteristic of the developing world. As useful as they are as demographic absorbers, metropolitan regions create complex and multifaceted problems on unprecedented scales. The consequences of this population dynamics, particularly in African cities, resulted in threats that are quite difficult to embrace. Most major African cities, including those in Nigeria, are dealing with severely compromised physical and living conditions. Informal settlements, urban sprawl, and squatter settlements are examples of deterioration, as are increased temperatures, traffic congestion, flooding and erosion, deteriorating infrastructure, and shortfalls in service delivery (Olujimi, 2009).

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Man continues sustenance on Earth, and the quality of his life is heavily influenced by the environment. The major environmental components-air, water, and land-are man's supporting pillars, on which he relies directly or indirectly for his survival and well-being. However, man appears to be at conflict with his environment, as evidenced by overuse and ineffective management of the environment's basic components. This unsustainable exploitation of the natural environment as a result of anthropogenic activities has created significant challenges and a substantial threat to Nigeria's biophysical environment including the urban micro climate and particularly rising urban temperatures (Ohwo & Abotutu, 2015).

The advent of cities and other large metropolitan areas in developing nation takes a different trajectory than the developed world experience. While urbanisation in developed countries is the result of massive industrialization and quite well urban planning management system, the situation in the poorer countries, including Nigeria, is the result of "urban involution," or the advent of cities as a result of mass migration from rural areas to "assumed cities" that lack sufficient plan, design, infrastructural facilities, basic amenities, sanitary conditions, and a structure of economic systems to provide the for need of the urban dwellers (Udoh et al., 2020).

Nigeria's urbanization and urban population have increased significantly in the last 20 years and the trend is expected to continue (Ezeudu, 2020). Similarly, it has also been observed that, Since the second half of the twentieth century, the rate of urbanisation has been increasing dramatically. The environmental impact of urbanisation has attracted a lot

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of attention (Ikporukpo, 2018). Most cities in Nigeria, have expanded in an uncontrolled and unsupervised manner, resulting in a variety of environmental issues such as overcrowding, heavy traffic, carbon emissions, unstable housing, unemployment, urban blight, and deterioration of urban amenities (Ezeudu, 2020; Ikporukpo, 2018; Olujimi, 2009). Basically, it further worsens the already fragile urban climate as well as other existential threats in the cities often these cities' operation, togetherness, wellbeing, and sustainability are in doubt. The preceding has prompted concerns and calls from various groups and stakeholders in the built environment for progressive changes in policies, laws, technologies, and development strategies aimed at improving urban quality (Udoh et al., 2020). These can only be attained by objectively understanding the dynamics of these challenges through novel research and effective implementation of the findings and also by engaging all stakeholders.

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Furthermore, the study revealed that, since 2010, the Nigerian urban population has been rapidly increasing, and it is expected to reach nearly 300 million by 2050. This rapid increase in urban population in Nigeria has resulted in what is known as "false urbanisation," a situation in which urban growth outpaces economic growth and increasingly outpaces the ability of the country's healthcare systems to provide reasonable and relevant care. Slums, overcrowding, indecent shelter, heavy traffic, open dumpsites in city centers, job losses, flooding, infrastructural decay, and general decline in the standard of living of urban inhabitants are all manifestations of false urbanisation in Nigeria. All of these functions and procedures aggravate the already fragile urban ecosystems and, in

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particular, the urban microclimate by raising the temperature of the atmosphere, necessitating immediate action (Udoh et al., 2020).

This is the unique case of the study area, which has been devastated by the decade-long Boko Haram insurgency that has severely damaged the region, with Maiduguri being the worst hit area as the epicentre of the violent conflict. As a result, all nearby towns and villages have been forced to migrate into the Metropolis, threatening the already stressed urban ecosystem beyond limits. Therefore, it is critical that a study that seeks to understand the dynamics of this environment's microclimate be conducted, especially in the wake of rising urban temperatures, which can result in several unintended consequences for the urban inhabitants and the environment.

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1.4 Statement of problem

Rapid urbanization over the past few decades has resulted in a significant decrease in urban vegetation cover (VC), raising land surface temperature (LST) and making the environment less sustainable. Urban green space is one of the most crucial elements in promoting ecological balance and environmental sustainability (Rahaman et al., 2022). Urban sprawl is gradually displacing these green spaces, which speeds up carbon emissions, increases land surface temperature, and leads to global warming (Kafy et al., 2021; Santamouris, 2020; Tian et al., 2021; Yu et al., 2020).

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Many studies have shown that increasing LST significantly contributes to local, regional, and global warming impacts, paving the way for the global emergence of the Urban Heat Island problem. The UHI is a well-documented consequence of urbanization, defined as higher temperatures in city areas as compared to surrounding rural areas (Hwang et al., 2017; Imran et al., 2019; Mohd et al., 2019; Oke, 2006; Rahaman et al., 2022; Santamouris, 2013; Schatz & Kucharik, 2014; Yao et al., 2019). Current empirical results from Asia, Europe, the United States, Africa, and Amazonia demonstrated that lower vegetated surfaces eventually led to global-scale warming and were linked to a rise in LST (Rahaman et al., 2022). This critical situation hastens the dire environmental consequences by undermining local societies' sustainability in the face of massive urbanization and contributing to significant local and global climate changes (Beaumont et al., 2022; Rahaman et al., 2022; Santamouris, 2020).

The UHI effect can worsen health effects by altering the micro-climate in the city, and rainfall patterns, interacting with air pollution to make it worse, elevating the risk of flooding, and reducing water quality. Exposure to higher temperatures is the UHI's most significant influence on human health (Aflaki, et al, 2017; Heaviside et al., 2017; Ningrum, 2018; Santamouris, 2020). It plays a significant role in the worsening of the effects of global warming (Aflaki, et al, 2017), and climate change (Beaumont et al., 2022; Santamouris, 2020). Furthermore, the adverse health effects of heat exposure range from the escalation of minor health conditions to an elevated risk of increased morbidity and mortality. Heat is frequently a contributing factor to deaths and morbidity from other causes, such as respiratory illness, rather than being the only cause of death from heat

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stroke. Although health effects are most serious when temperatures are extremely high or during heat waves, this threat has been observed to be substantial at even moderately high temperatures (Heaviside et al., 2017; Santamouris, 2020).

In its State of the Climate in Nigeria report, the Nigerian Meteorological Agency (NiMet) remarked that Maiduguri recorded temperatures of 45.8 °C in 2019 and 2020 and 43.9°C in 2021 (NiMet, 2022). Similarly, the agency NiMet, in its high-temperature outlook signed by the Director-General, Prof. Mansur Matazu, predicted that most Northern cities would experience temperatures ranging from 35°C to 40°C. However, Borno state is expected to have temperatures above 40°C. The report further states that Maiduguri is likely to experience high thermal discomfort (Falaju, 2022; Gabriel, 2022; Yakubu, 2022). Furthermore, the trend continued this year as the highest temperature value in the nation was recorded in Maiduguri in April at 43.9°C. Maiduguri endured this severe condition for 69 days with a daytime temperature greater than 40°C. During this period, over 475 suspected cases of Measles were reported in 22 states from January to June. (NiMet, 2022). The same report indicated that high temperatures leading to extreme weather events have resulted in the prolonged heatwave in March, April, and May across Nigeria and the Nigerian Centre for Disease Control (NCDC) recorded.

Similarly, the NCDC recorded Cerebrospinal Meningitis - 175 suspected cases with 11 confirmed cases and 3 fatalities. Measles - 17,541 suspected cases, with 816 confirmed and 204 fatalities. Malaria - is one of the leading causes of illnesses and deaths in Nigeria. The (WHO) reports that Nigeria accounted for 27% of the Malaria cases and 23% of deaths

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due to Malaria Globally. It is estimated that Nigeria loses up to one billion USD yearly due to Malaria-related absenteeism and production losses (NiMet, 2022).Urban sprawl and rising temperatures have been linked to food insecurity and health issues such as meningitis, discomfort, and heat stroke. Therefore, is essential not only for regulating the urban microclimate but also for providing food and promoting a healthier life for city residents (Carolan, 2020; Nkwocha et al., 2020; Grebitus et al., 2020; Hairy et al., 2020). NiMet, (2022) also corroborated and warned about acute food insecurity in this region, a report by the agency shows that 12.9 million people were in severe acute food insecurity between (October – December 2021) of whom two million are in Adamawa, Borno, and Yobe states. These figures are projected to increase to 18 million and 3,5 million, respectively, during the peak of next year's rainy season (June to August 2022), including 13,550 people likely to face catastrophic conditions if food assistance along with resilience interventions are not urgently intensified and sustained (NiMet, 2022).

Despite rising urban temperatures and obvious evidence of fast land use change in Maiduguri, no previous research has specifically recognized, evaluated, or mapped the city's UHI, leaving a significant gap in localized climatic knowledge. Urban farming has grown informally in response to socioeconomic pressures, but its impact in alleviating UHI and regulating microclimates has not been investigated empirically using geospatial analysis. Existing research rarely combines biophysical data (e.g., LST, plant cover) with socioeconomic factors like community perception and land-use behaviour. There is also a scarcity of research that examines urban farming as a dual instrument for livelihood support and environmental regulation. This study aims to fills crucial gaps by conducting long-

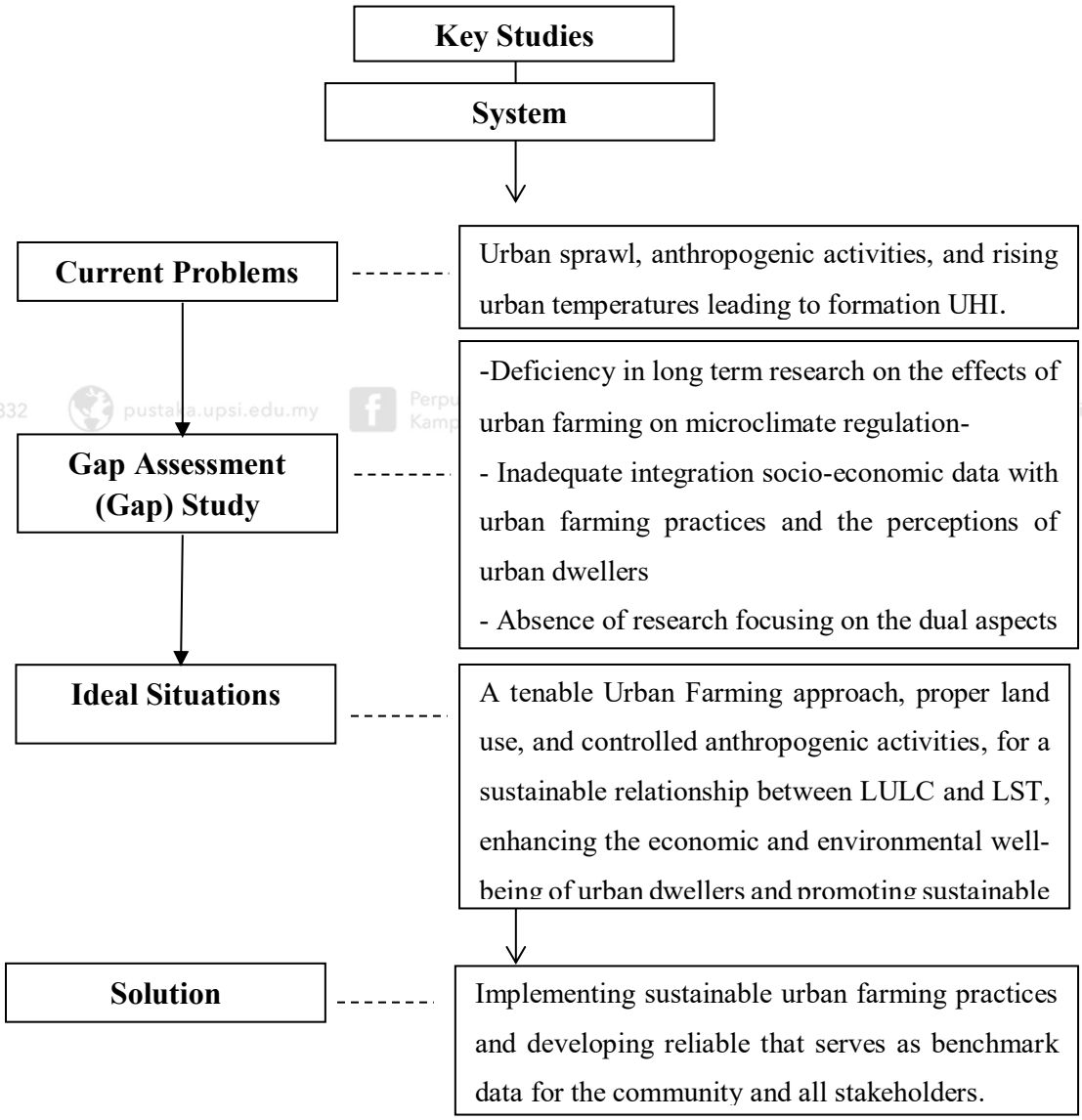
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term UHI analysis in Maiduguri, integrating urban farming trends with cooling effects and community perspectives to support sustainable urban development.

Figure 1.1

Research gap



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Numerous strategies have been examined to minimize the impacts of UHI on cities worldwide. Urban vegetation, a form of urban farming, is crucial for enhancing human thermal comfort within cities. Researchers in Melbourne, Australia, found that street trees can lower the daytime Universal Thermal Climate Index (UTCI) by 6 degrees Celsius during the summer, reducing thermal stress from very strong (UTCI > 38 °C) to strong (UTCI 32 °C) (Imran et al., 2019). The same study further reports that urban vegetation reduces UHI and improves human thermal comfort (HTC) during the day in Melbourne, especially during heatwaves. However, due to lower ground/storage heat flux at night and minimal cooling during the day, the combination of urban vegetation and cool roofs provides the maximum cooling benefit. Similarly, Taher et al., (2019) report that Urban vegetation is much more than just an extravagance or an improvement in aesthetics for cities. It should be regarded as an essential component of urban planning. Due to the evapotranspiration process and the reduction of surface temperatures between 5 to 20 °C due to shading, urban greenery such as trees and parks was proposed as an effective way to improve the harsh urban climates through building structures within the local or regional scale.

Taher et al., (2019) in the same vein highlighted those other strategies used to include urban farms which are used in Europe, cool roofs that are used in California, large urban gardens used in Singapore, and central parks used in New York. It is amazing how different, intricate, and diverse possible adaptation strategies cities provide in response to population growth and climatic changes. To reduce UHI. Others include phase-changing materials and reflective pavements. Also, the effects of rice and soybean

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cultivation and the urban garden on UHI were assessed and were found to be effective (Guo-yu et al., 2013). Conversely, in their study on temporal temperature variation in urban gardens Nolte et al., (2022) observed that urban environments have a significant impact on the night-time temperature range, and the inner composition of gardens does not have the same impact on temperature regulation as the composition of the surrounding landscape. In particular, for vulnerable populations where bioclimatic stressors are most severe, these results point to the potential for using urban gardens as green infrastructure to develop cooling islands within the impervious landscape.

For these reasons, academia, city planners,' policymakers, and development partners are paying more and more attention to the connection between land use and the urban environment as they work to identify, create, and ultimately implement growth strategies that aim to improve the well-being of urban populations. Maiduguri the study area with its current estimate at over one million urban dwellers, the city's population continues to rise (Abdul-Azeez, 2018; Nkwocha et al., 2020). Consequently, this leads to environmental challenges such as the urban heat island effect among others. There are enormous studies on heat islands in the global north and south. However, it is pertinent to note that, an investigation that specifically explores the impact of the urban heat island in Maiduguri and its environs remains unexplored. Hence, a better understanding of the mechanism leading to the development of the phenomenon is required to develop and implement a mitigation measure that the researcher believes could be found, among others, in urban farming.

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Therefore, this study intends to evaluate the potential of urban farming which is part of the green infrastructure (areas with a high concentration of vegetation) in mitigating the impact of urban heat islands and ultimately minimizing its effect on the environment and its impact on the urban dwellers such as the risks of heat-related illness from high urban temperatures especially among the most vulnerable populations (e.g. children and aging population and many with chronic health conditions, impoverished or otherwise disadvantaged minorities). By providing adequate details on the status, causes, and effects of urban heat islands, the study will be of great significance. Moreover, the potential contributions of urban farming to the control of the urban microclimate. This will act as a framework for the government, academic institutions, urban farmers and residents, urban planning board, engineers, architects, other field researchers, development partners, and all other stakeholders who are concerned with the sustainability of the urban landscape and its inhabitants, in particular to those who are concerned with urban climate. The study will primarily focus on Maiduguri and its surroundings, as well as portions of the Jere, Konduga, and Mafa local governments.

1.5 Aim of the study

This study aims to identify and assess the Spatio-temporal dynamics of the urban heat island phenomenon in Maiduguri Metropolis and its environs.

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1.6 Objectives of the study

The specific objective of the study is to:

i. Determine the level of urban farming practice and the phenomena of the urban heat island of Maiduguri between 1992 to 2022.
ii. Analyze the spatiotemporal trends and the magnitude of Land Surface Temperature and Land Use Land Cover changes in Maiduguri between 1992 and 2022.
iii. Examine the urban residence knowledge and perceptions of urban heat islands and their mitigation through urban farming.
iv. Determine the effectiveness of urban farming as a mitigation approach to reduce the impact of urban heat islands in Maiduguri.

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1.7 Research Questions

i. What is the extent of evolution in urban farming practices, and what are the characteristics of the urban heat island effect in Maiduguri over the past three decades?
ii. What are the spatiotemporal trends and magnitudes of land surface temperature and land use/land cover changes in Maiduguri between 1992 and 2022?
iii. What is the level of knowledge and what are the perceptions of urban residents in Maiduguri regarding urban heat islands and their potential mitigation through urban farming?

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iv. How effective is urban farming as a mitigation strategy in reducing the impact of urban heat islands in Maiduguri?

1.8 Scope of the study

The study examined the spatio-temporal dynamics of the Urban Heat Island in Maiduguri metropolis, Borno state, North Eastern Nigeria, from 1992 to 2022, as well as the possibilities for urban farming to minimize its effects on the environment and rural residents. It encompassed Maiduguri and its surroundings, as well as portions of the local governments of Jere, Konduga, and Mafa. A quantitative technique was implemented, including remote sensing and GIS analysis. An environmental model (ENVI-met) was used to analyze urban farming's potential for UHI mitigation, and Google Earth Pro was utilized to track the growth of urban farming practices. A survey of 400 urban inhabitants was also undertaken to collect information on their socioeconomic status and awareness of UHI.

1.9 Operational Definition

Urban Heat Island

Urban Heat Island refers to the spatial variation in land surface temperatures between densely built-up urban areas and adjacent vegetated or less-developed zones within Maiduguri. This phenomenon is quantified using satellite-derived thermal data, producing

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continuous raster surfaces that facilitate the assessment of UHI intensity and its temporal distribution across the urban landscape.

Urban Farming

Urban farming refers to the practice of cultivating crops, engaging in horticultural activities (including the growth of fruits, vegetables, and ornamental plants), and planting or maintaining trees within the urban boundaries of Maiduguri. These activities are conducted in various urban spaces such as home gardens, vacant lots, community gardens, and along streets or riverbanks. Urban farming serves multiple purposes, including enhancing food security, promoting environmental sustainability, and contributing to the urban green infrastructure. By increasing vegetation cover, urban farming plays a significant role in mitigating the UHI effect, improving air quality, and fostering ecological balance within the city.

Urban Heat Island Mitigation

Urban Heat Island Mitigation refers to the reduction of elevated urban temperatures through the implementation of urban farming practices within Maiduguri's urban landscape. Urban farming activities including the cultivation of crops, horticulture, and tree planting in spaces such as home gardens, vacant lots, community gardens, and along streets or riverbanks serve as green infrastructure that enhances vegetation cover. This increased greenery facilitates natural cooling processes like evapotranspiration and shading, thereby lowering land surface temperatures and alleviating the UHI effect.

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Green Infrastructure

In this study, green infrastructure refers to natural and human-managed vegetative systems that contribute to urban environmental quality, particularly temperature regulation. Urban farming is treated as a key form of green infrastructure, with its cooling potential assessed through its spatial extent and vegetation density. The distribution and effectiveness of these green spaces are quantified using satellite-derived vegetation indices, primarily the Normalized Difference Vegetation Index, to evaluate their role in mitigating UHI effects across Maiduguri.

Land Surface Temperature

Land Surface Temperature is operationally defined in this study as the temperature emitted from the Earth's surface, captured through thermal infrared satellite sensors (e.g., Landsat 4, 7, and 8). LST is used as the primary indicator of surface heat conditions across Maiduguri and is analyzed to detect urban heat patterns. Variations in LST across different land uses, especially between urban farming zones and built-up areas, are used to evaluate the cooling impact of vegetation and assess the severity of the UHI phenomenon.

Normalized Difference Vegetation Index

Normalized Difference Vegetation Index is a satellite-derived indicator used to measure the presence, density, and health of vegetation cover. In this study, NDVI is applied to analyze spatiotemporal changes in vegetation in Maiduguri from 1992 to 2022, serving as a proxy for green infrastructure and contributing to the assessment of vegetation's role in UHI mitigation.

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1.10 Significance of the Study

The advent of the urban century brings with it a unique set of concerns. The urban population now exceeds more than half of the world's population (Bassett et al., 2020; Bloch et al., 2015; Hussain et al., 2019; Ulpiani, 2021; Yao et al., 2018). Among the challenges of this era is the urban heat island phenomenon, which may be largely attributed to urbanization, population growth, and climate change (Meriam et al., 2019; Singer, 2022; Weng, 2018). The state of this urban environment is extremely important to everyone. The sustainable development of cities and communities, as one of the 17 United Nations Sustainable Development Goals, should be regarded as an essential component of the approach to combating UHI and addressing climate change (Echendu, 2020; Tian et al., 2021).

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Under a warming climate and an increasingly growing urban environment, the UHI effect and its impacts are projected to be more significant. This is especially true in China, India, and Nigeria, where the urban population is expected to account for 35% of the world by 2050 (Martin-Moreau & Ménascé (dir.), 2019; Zhou et al., 2019). Despite all the commitment by government and scholars across the global north and south as demonstrated by the array of literature available on the concept of the urban heat island, there has not been an inquiry highlighting the phenomenon of urban heat island effects and its impact on human and the environment in (Maiduguri) the study area and it environs. Therefore, this study aims to identify the urban heat island phenomenon and its impacts on the urban populace. It is also expected to examine the existing urban farming practices as a mitigating

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strategy on the consequences of the urban heat island effect. The findings of the study will serve as a baseline for reference for urban planners, academia, policymakers, and all stallholders concerned with the sustainability of the delicate urban environment. Appropriate mitigation and adaptation strategies to reduce the UHI intensity to improve urban sustainability will also be highlighted by the findings. The study will help in no small measure by providing sufficient information on the causes and effects of urban heat islands, will serve as a framework for the government, urban farmers/dwellers, urban board planners, engineers, architects other field researchers, development partners and all stakeholders that are concerned with the sustainability of the urban landscape and its inhabitants and specifically to those who are concerned with urban climate. Primarily, the study will cover Maiduguri and its surrounding area, parts of Jere, Konduga, and Mafa local government.

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1.11 Summary

The foundation for a thorough investigation of the Urban Heat Island (UHI) phenomenon in Maiduguri, Nigeria a semi-arid region with hot, dry weather has been established in this Chapter. The dearth of empirical research on urban heat islands (UHI) within this complex environmental framework highlights the importance of this study, establishing it as a fundamental baseline for every stakeholder engaged in urban planning, environmental sustainability, and community welfare. This study aims to provide important insights into the dynamics of UHI by clearly defining its objectives and research questions. It focuses

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on the spatiotemporal aspects of changes in Land Surface Temperature and Land Use/Land Cover from 1992 to 2022. Because of Maiduguri's distinct environmental conditions including its pre-existing hot and dry climate addressing rising temperatures presents additional challenges. For the region's resilience and sustainable development, investigating UHI mitigation strategies is therefore even more important.

In addition to offering a historical context, a spatiotemporal analysis of UHI in Maiduguri will lay the groundwork for comprehending the extent and current impact of the UHI effect in the area. Furthermore, the evaluation of urban farming as a viable mitigation strategy presents a novel way to deal with the issues raised by UHI and provides a long-lasting, neighbourhood-focused resolution. This study acknowledges the significance of assessing urban dwellers' attitudes and knowledge about UHI and urban farming. A thorough assessment of the complex elements of UHI mitigation is made possible by the research's addition of a social dimension through the inclusion of public awareness and engagement.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents an understanding of the various terms that constituted the research problem; it brings to the fore specific terms or concepts related to the urban heat island phenomenon. This study reviewed several related pieces of literature on the urban heat island effects in different regions of the globe in both developed and developing nations in the global north and south. It centrally stresses the semi-arid region of West Africa where this study is being undertaken. Efficient and prudent use of the Earth's resources, as well as enhanced conservation and preservation of vulnerable and endangered habitats, are dependent on timely information and correct analysis of those resources.

In the late 1960s, it was widely assumed that Earth-orbiting satellites could give continuous and virtually comprehensive coverage of terrestrial resources, making them the greatest means of obtaining needed data. Such coverage would be particularly beneficial for understanding and analysing Earth-system phenomena at regional,

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national, continental, or global scales (Zhou et al., 2019). Today, satellite images have immeasurably contributed to our understanding of the Earth's systems and their attributes for the sustainability of the Earth's ecosystem and its different components, particularly the urban climates.

This section also highlights the significance of the applications of satellite remote sensing in urban climatology and specifically urban heat island studies and further explains the potential of Landsat sensors in this course. The impact of the urban heat island effect, its associated environmental and social challenges, and some benefits of urban farming in alleviating these impacts are explained. Various researchers have proposed various mitigation measures, which can be divided into those that can only be implemented during the design and planning stages and those that can be incorporated after the planning and design stages.

2.2 The Concept of Urban Heat Island

The most heavily influenced meteorological variable by urban growth is temperature. The temperature rises within cities and their environs have been thoroughly established, and the concept of "urban heat island," which was first coined by Manley in 1958, (Aflaki,. et al, 2017) is now universally accepted. The urban heat island has been examined in multiple cities since it was initially conceived, and it has been demonstrated to cause temperature variations of several degrees between urban and rural areas. The urban heat island is the

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most reported climate change event. It refers to a rise in air temperature in dense urban areas relative to compared to rural locations nearby. In more than 400 towns throughout the world, urban overheating has been extensively observed using different techniques. The intensity of the phenomena could be greater than 5 ^{0}C, and in certain circumstances, urban heat island intensities of more than 10 ^{0}C have been documented (Santamouris et al., 2019).

It has been reported by numerous scholars that the most significantly influenced meteorological variable by urban growth and development is temperature. The temperature rise within cities and their environs has been well-established (Stewart & Mills, 2016; Santamouris, 2020; Santamouris, 2013; Stewart., & Oke, 2012). Moreover, modeling predicts that the temperature differential between urban and adjacent rural areas in some cities could reach 8 ^{0}C by 2050. The extent of the urban heat island effect is determined by a variety of factors, including area climate, but it is projected to be greater in dry climates than in cold humid ones.

The concept of urban heat island is a pervasive and entrenched consequence of urbanization in all of its ramifications (Stewart & Mills, 2016). The impact of temperature on cities and towns has been studied for over 200 years, producing an enormous literature that is remarkably diverse in terms of content, geographical coverage, methodology, and experimental rigour (Azmi et al., 2021; Dialesandro, 2021; Shi et al., 2021; Weng, 2018). However, it was only in the last decade that it received media attention (Azmi et al., 2021). The study of urban heat islands encompasses two of the twentieth century's most critical environmental challenges, rapid population and climate change. This helps to explain why

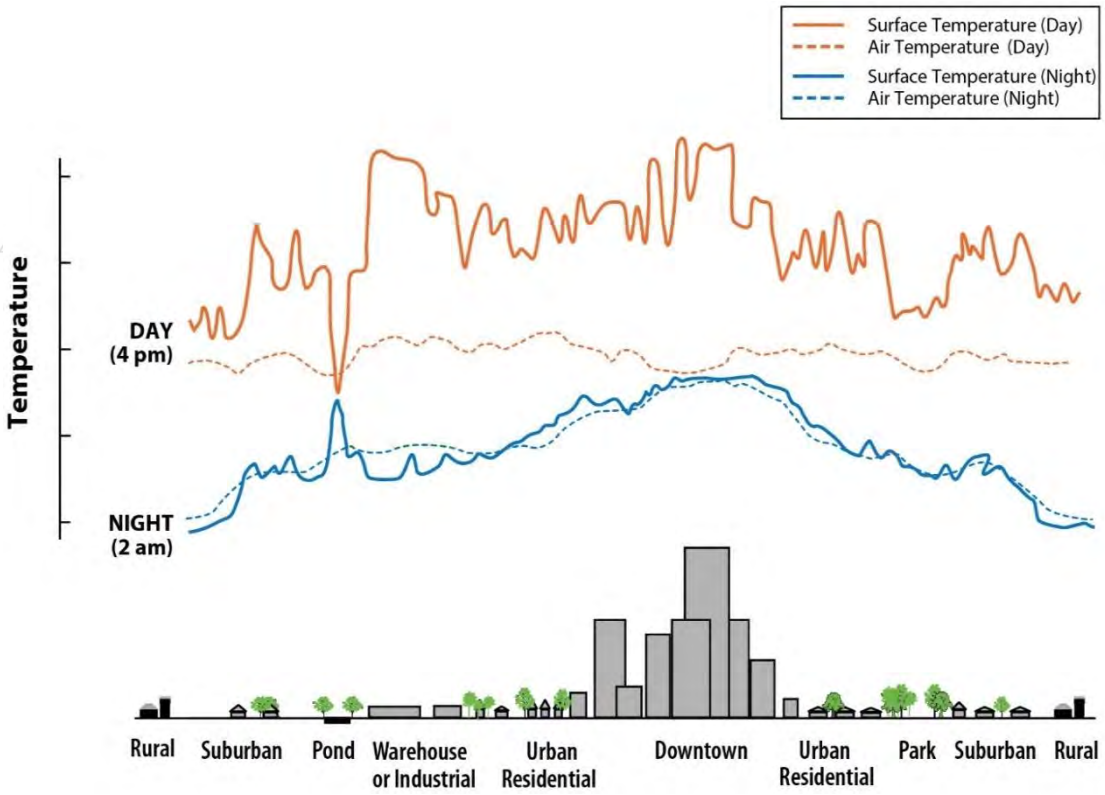
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the global shares of heat island studies have increased so dramatically over the last decade. Cities of all cultural and physical descriptions have been the subject of formal heat island investigations ranging from both the global north and south (Azmi et al., 2021; Stewart & Oke, 2012).

Figure 2.1

The formation of the UHI and the temperature profile in different areas



Adapted from Almeida et al., 2021.

The concept, of urban heat island (UHI) in its simplest term refers to a difference in the relative temperatures of the city (and its parts) and the surrounding natural

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environment (rural area) (Stewart & Oke, 2012; Stewart & Mills, 2016). An urban heat island (UHI) is a process that occurs when the air temperature in a city is relatively higher than in the surrounding rural area as a result of anthropogenic sources (Hwang et al., 2017). Similarly, the term urban heat island is described as a phenomenon in which urban areas are comparatively warmer than their surroundings, which has been observed in many cities around the world. This concept according to Stewart & Oke, (2012) can be found in almost any urban area, large or small, in warm or cold climates.

Climate variability or change, according to growing scientific data, poses severe threats to people living in cities in both developing and developed countries across the world, the adverse impacts of the UHI on cities are universally recognized. Exposure to high ambient temperatures is widely accepted as a serious health hazard (Abur et al., 2018; Santamouris, 2020). It has also been observed by World Bank, (2015), that Human health is enormously affected by climate and weather. Cole et al., (2008) observes that higher air pollution levels reduced nighttime cooling, and increased daytime surface temperature related to urban heat islands can negatively influence human health, causing general discomfort, exhaustion, respiration problems, headaches, non-fatal heat stroke, heat cramps, and heat-related mortality. Similarly, (Wong et al., 2018) highlighted that many studies have revealed a high rate of psychological distress namely anxiety, depression, and aggressive behaviours, including physical health impacts such as heat exhaustion, respiratory problems, and heat stroke are associated with the heat island effect. Block et al., (2012), also stressed that heat-related sickness and mortality will be more common among vulnerable population groups across all social strata and geographical regions,

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especially the very young, the frail old, and those with a pre-existing physical or mental condition. Waffle et al., (2017), also indicated that, urban heat island can affect the growth cycle of plants when compared to their growth in rural areas.

Leveraging the foundational concept of the Urban Heat Island (UHI), measurement methods have evolved from early ground-based observations and manual temperature surveys to more advanced techniques. These include the application of boundary-layer theory and surface energy balance modeling (Almeida et al., 2021), as well as the integration of numerical models, satellite remote sensing, and standardized urban climate classifications such as Local Climate Zones (Mills et al., 2022; Stewart & Oke, 2012). This evolution reflects the growing need for accurate tools to assess urban thermal dynamics.

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Furthermore, the study of the UHI phenomenon has advanced enormously over the last two centuries, owing to innovations in technology and evolving scientific views. Early research, long before the introduction of Geographic Information Systems (GIS) and remote sensing (RS), relied on simple yet insightful ground-based observations. These early approaches, as described by He et al., (2023), established the foundation for UHI science using tools such as mercury thermometers, mobile transects, and fixed weather stations. Luke Howard's pioneering work in the early 1800s represented this era, in which temperature data were painstakingly gathered along urban-rural gradients to capture thermal variations.

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In the mid-twentieth century, UHI measurements expanded to encompass mobile and aerial surveys. Thermometers installed on vehicles and infrared sensors aboard aircraft allowed researchers to collect more spatially diverse data, but analysis remained mainly analog. The introduction of digital thermometers and data recorders in the 1960s and 1980s signalled a trend toward more continuous and dependable time-series measurements. However, the spatial component of UHI was difficult to quantify until the combination of computer models and digital mapping techniques (He et al., 2023).

Stewart & Mills, (2016) trace the advancement of UHI research from simple observational studies to comprehensive urban climatology frameworks. Their research demonstrates how temperature measurements evolved from in situ monitoring of canopy UHI (CUHI) to simulation of boundary-layer (BUHI) and surface urban heat islands (SUHI) using enhanced surface energy budget (SEB) techniques. This trend also included the creation of urban microclimate models, such as the urban canyon idea, and the use of eddy covariance techniques to detect turbulent heat fluxes (Mills et al., 2022).

The shift to satellite-based RS in the late twentieth century, particularly through platforms such as Landsat, was a milestone. It enabled large-scale, temporally logical, and georeferenced surface temperature mapping, ushering in the SUHI era (Oppelt, N., & Muhuri, 2024; Stewart & Mills, 2016) When combined with GIS, these techniques now enable the spatial synthesis of land use, vegetation indices (e.g., NDVI), and albedo, all of which are crucial for comprehending UHI dynamics at both city and regional scales.

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2.3 Types of Urban Heat Islands

UHI can be divided into two main categories, according to Rasul et al., (2016), these include atmospheric urban heat islands and surface urban heat islands. The first takes into account UHI effects in the canopy or boundary layers, while the latter takes into account the change in radiative temperature at the surface. In general, in situ sensors (weather stations or towers), radiosondes, drones, and aeroplanes are used to monitor and model atmospheric urban heat islands. Surface UHI is becoming more prominent, with satellite-based surface UHI being used for consistent spatiotemporal assessments at local, regional, and global level. Surface UHI is also crucial in thermal anisotropy. Surface UHI varies according to season, sun intensity, land cover, and weather. Additionally, surface UHIs vary substantially between day and night. Because of the incoming solar radiation, daytime surface UHI is higher than nighttime surface UHI.

Stewart & Mills, (2016) in their book The Heat Island a Guide book identified four distinct types of urban heat islands, these include;

i. The canopy-level UHI (CUHI) is based on the near-surface air temperature measured below roof height;
ii. The boundary-level UHI (BUHI) is based on air temperature measured well above the height of buildings in cities;
iii. The surface UHI (SUHI) is based on the temperature of the three-dimensional urban surface, that is, the ground, walls, and rooftops;

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iv. The substrate UHI (GUHI) is based on the temperature of the soil below the ground surface.

2.4 Urban Heat Island and Human Health

Climate change, expansion of cities, and an aging population are all likely to increase the health risks associated with UHI, notably high-temperature exposure, across cities on the entire planet. Furthermore, an increased concentration of people with more pervasive UHI effects tends to result in more frequent and severe heat waves in urban areas than in rural areas. Heat waves in cities and surrounding areas will be aggravated by the UHI effect, negatively impacting residents' health and well-being (Shi et al., 2021). Similarly, the design of a city has a significant impact on the urban climate. Cities can suffer from urban heat island intensification, as well as strong and intense winds in some areas and stagnant air in many others, if careful planning is not implemented. These can have an impact on the safety, health, and well-being of urban dwellers (Lenzholzer et al., 2020).

UHI has a direct or indirect impact on the health and livelihood of city dwellers. High temperatures put undue stress on the human body, heat islands can have a detrimental effect on health. Temperature and precipitation changes, including severe weather events, can lead to deaths directly or indirectly by changing the environment, leading to an increased incidence of contagious diseases. Higher temperatures and humidity can aggravate air pollution. The UHI effect increases the possibility of smog formation, which

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is caused by photochemical processes of pollutants in the atmosphere. The development of smog is heavily temperature-sensitive because photochemical processes are much more likely to form and increase at higher temperatures (Shahmohamadi et al., 2011).

According to Shi et al., (2021) a study on the heat waves in the UK's West Midlands, identified urban heat islands as responsible for roughly half of all heat-related deaths. The study indicated that the mortality and morbidity threats of diabetic patients were slightly increased by about 18% for fatalities and 10% for overall morbidity during the heat wave. High temperatures were discovered to dramatically enhance the rate of death in the Jinan, China population. The majority of studies on this issue employ both weather station and in-person measurements to investigate the health effects of UHI. Shi maintains that in a similar study, the finding revealed that different locations (city centre or surroundings) have experienced varying degrees of warming as a consequence of rapid urbanization. It is also reported that the greatest direct consequence of UHI on health is heat risk, which is worsened in urban centers, notably during heat waves (Heaviside et al., 2017).

Exposure to high ambient temperatures is widely accepted as a serious health hazard (Santamouris, 2020). It has also been observed by World Bank, (2015), that Human health is enormously affected by climate and weather. Cole et al., (2008) observes that higher air pollution levels reduced nighttime cooling, and increased daytime surface temperature related to urban heat islands can negatively influence human health, causing general discomfort, exhaustion, respiration problems, headaches, non-fatal heat stroke,

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heat cramps, and heat-related mortality. Similarly, (Wong et al., 2018) highlighted that studies have revealed a high rate of psychological distress namely anxiety, depression, and aggressive behaviours, including physical health impacts such as heat exhaustion, respiratory problems, and heat stroke are associated with the heat island effect.

2.5 Urban Heat Island Intensity

The urban heat island intensity (UHII) is used to define the size of the UHI and signifies the degree of temperature differential between the urban and rural areas. Furthermore, the UHIIs of various urban regions within the same city varies due to differences in urban design and the level of human activity (Hwang et al., 2017; Weng et al., 2019). The issue with the UHI is in its intensity, which has been growing steadily in recent decades due to global warming. There are huge differences in the intensity of the UHI between cities based on their geographic position (longitude appears to have a greater influence on its intensity than latitude), the distance of the city from the sea, and the patterns of land use (proportion of grey and green areas, flora and fauna, etc.), and the type of planning policies (Mancebo, 2018). In a similar study, (Yao et al., 2018), looked at the interannual variations in surface heat island intensity and their relationships with climate variability and urbanization in 31 Chinese cities from 2001 to 2015. Significant increases in SUHII were detected in 71.0%, 58.1%, 25.8%, and 54.8% of the cities, during summer days, summer nights, winter days, and winter nights respectively. Yao et. al maintained that the intensity variation of the surface urban heat island had never been consistent over time and in

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different geographic locations, or the intensity variation had been diverse in spatial and temporal dimensions. However, it is important to highlight that across the globe, there has been a tremendous decline in the intensity of urban heat islands across many cities as a result of the Covid 19 Pandemic which led to the shutdown of many activities particularly anthropogenic ones.

In an urban heat island study in the Emirates Alqasemi et al., (2021), observed that the partial or full nationwide lockdown, which resulted in the suspension of anthropogenic activities and sources of heat emissions such as industrial processes, power plants, aircraft, and transportation, resulted in a decline in SUHII levels. Over this time frame, nighttime SUHII levels were lower than in 2019. The trend was observed in all over the Emirates, ranging from 12.3 percent to 28.6 %, with an average drop of 19.2 %. Chakraborty et al., (2021), further stressed that, the reduction in anthropogenic activities caused by the lockdown could affect natural variability, cloud cover, and rainfall, which in turn could affect the NDVI/LST. It is evident from these studies that, the intensity of the urban heat island varies based on the time, day, month, and year. Studies on urban heat island intensity variations according to (Weng et al., 2019), contributes to a better understanding of the impact of urbanization on surface climate and, as a result, to better urban design thus, a sustainable cities.

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2.6 Urban Heat Island and Climate Change

There is significant concern that global average temperatures and sea levels will continue to rise throughout the twenty-first century, (Abaje, 2019; Arroyo, 2016; Alhaji Mukhtar et al., 2021; Narumi et al., 2021; Santamouris et al., 2015; Shi et al., 2021). Studies have shown that the trend of global warming has been remarkable over the last century. Temperatures on the earth's surface have risen globally, with regional variations, as indicated by an instrumental observation over the last 157 years. The global average of both land and sea surface temperature, as assessed by a linear trend, clearly demonstrates warming of 0.85°C from 1880 to 2012, and 0.72°C from 1951 to 2012. 1998 and 2005 are the warmest years in recorded history of global surface temperatures (Abaje, 2019). According to a study by the Goddard Institute for Space Studies (GISS), the global surface temperature in 2018 was the fourth highest during the period of instrumental measurements.

The global temperature in 2018 was +1.1°C (2°F) higher than it was in the 1880-1920 benchmark, which (Hansen et al., 2019) used as an estimate of 'pre-industrial' temperature. This record further confirms the earlier studies that the earth’s surface temperature is on the rise. Remarkably, the researchers reported that the last four years, 2015-2018, have been the four warmest in the GISS record. According to another report by (Azunui, 2021), reiterated that global temperatures have risen over the last 30 years, with 2001-2010 being the warmest on record ever. A plethora of studies researchers have demonstrated that the earth is warming; this study found that the years 2000 to 2009 were

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hotter than any other decade in the previous 1,300 years. However, according to a study by Samue citing the World Health Organization, stated that, about 92,000 people will die each year from heat waves by 2030, with Sub-Saharan Africa, South America, and Southeast Asia being the most affected. In the same vein the World Meteorological Organization (WMO), observed that the period between (2011-and 2020) has been the warmest decade on record, with the last six years (2015-2020) being the hottest years on record (Azunui, 2021; Emeka & Samuel, 2022).

Various scholars have contributed tremendously to the urban climate studies in cities around the world and have shown that temperatures are rising in urban areas (Wong et al., 2018) in Kuala Lumpur and many cities in Malaysia, (Kondo et al., 2021) in Fukuoka and many cities in Japan, (Yao et al., 2018) in more than 16 cities in China, (Isioye & Akomolafe, 2020) in Abuja and many cities in Nigeria. The rising temperatures in these cities have demonstrated significant spatial and seasonal heterogeneity. However, it all establishes the occurrence of the phenomena in these towns and cities. It is also reported by Dubbeling, (2015), that urban centers are responsible for a considerable portion of global greenhouse gas emissions, putting them at the forefront of climate change drivers. As cities expand, so do the environmental challenges they create, particularly in the form of rising temperatures and more severe weather occurrences. These changes disproportionately impact the city populations and infrastructure, increasing vulnerability. The Urban Heat Island (UHI) effect, which is a direct result of urban growth and diminished greenery, exacerbates these dangers. Addressing UHI is thus critical not only for reducing heat stress, but also for improving urban climate resilience. Integrating UHI

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mitigation into city design is critical to creating sustainable and adaptable urban environments.

Similarly, urban centres can be up to 10 degrees Fahrenheit warmer than surrounding rural areas, and they can continue to be that way all night. Cities' buildings and asphalt entrap heat. High-rise buildings reduce the amount of convection cooling. Trees and other vegetation that provide shade and increase cooling through evaporation may be largely missing in urban centers. As a result, compared to rural or suburban dwellers, urban residents may experience longer and more severe periods of intense heat (Luber & Mcgeehin, 2008; WHO, 2015). Similarly, urban residents are at risk of increased heating as a result of climate change, which is exacerbated by the urban heat island effect. This is compounded by urbanisation processes, which worsens the already existing warming trends (Kondo et al., 2021).

According to Abaje, (2019), the relationship between climate change and the frequency and severity of extreme heat events is now more well established than ever, according to a study. Extreme weather events will become more common and more severe as a result of climate change, global climate models, especially in higher latitudes, affecting major urban centers that are not well adapted to them. Extreme heat is already a major public health concern in the United States, and it is the leading cause of weather-related illness and death. As Abaje, (2019) further explains a warming climate and urban heat island effects are among the drivers of heat related illnesses and even death. The rise in global temperatures is due to an increase in greenhouse gases (GHGs) caused by human

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activities such as industrial pollution, habitat degradation, fossil fuel emission and combustion, and chemical use, among others. GHGs emitted as a result of these activities includes, Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halocarbons are examples of these gases. Global warming has resulted from the rapid increase in these GHGs since the Industrial Revolution (Abaje, 2019).

As a consequence of global warming, the world is witnessing more extreme weather, including climate variability, heat and cold waves, and increased floods and droughts, all of which have an adverse effect on the environment, its sustainability as well as lives of the urban dwellers (Abaje, 2019; Dipeolu et al., 2020; Narumi et al., 2021; Taslim et al., 2015; WONG et al., 2018; Yusof et al., 2017). At both the local and regional levels, climate change, urban heat island (UHI), and urbanisation are becoming intimately intertwined, leading to various of ecological impact (such as heat stress, resource depletion, fire hazard, heating up water due to runoff, and compromised air quality). this UHI related impacts are also regarded to as (UHIRIP) UHI regional impacts (Shi et al., 2021).

A study on Nigerian climate revealed that, rising temperatures as a consequence of climate change have already been shown to have an influence on the environment and sustainable livelihoods in Nigeria. In various ecological zones within the nation, temperature increases of about 0.2 – 0.3°C per decade have been recorded. On every degree of global warming, tropical humid zones can expect precipitation increases of about 2% to 3%. (Abaje, 2019). Heat waves are becoming more prevalent across many locations, Nigeria is not an exception, as the earth warms, a 1.5°C increase in global

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temperature above pre-industrial levels can have a significant impact on land, ecosystems, and biodiversity in general, including habitat loss and extinction. Consequently, wellbeing, food security, water systems Heat, livelihood, food security, water system, peace building, and economic expansion will all be compromised as a result.

Similarly, another study on the heatwave in north eastern Nigeria reported that, in Maiduguri, more than 60 people died as a result of a three-days heatwave. The weather in this region situated in the semi-arid zone, usually between March to June, is characterised by hot weather. This extreme weather event can lead to heat exhaustion and coronary heart disease. He argued that excessive exposure to high levels of ultra-violet radiation can compromise the immune systems of animals and human beings. (Emeka & Samuel, 2022) This extreme temperature events in north-eastern Nigeria, particularly in Yobe and Borno states, are the manifestation of the impact of climate change (Emeka & Samuel, 2022).

Numerous studies have indicated that urban climate change and UHIs in a metropolitan area could have a synergistic effect. Without appropriate consideration of urban climate change, urban designs may adversely affect the ambient temperature for city dwellers. As a result, the potential interaction between global and urban climate change and UHIs has yet to be fully investigated. A study highlighted the threats of extreme heat or extreme weather events in Nigeria and observed that, it is generally ignored and quite often misconstrued, particularly in developing countries like Nigeria. Intense temperatures have had a serious impact on Nigeria's north-eastern region over the last decade, however most of the developments have gone unreported due to a lack of awareness. An urban

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design methodology that incorporates these findings must be developed and implemented (Kelbaugh & Goldie, 2020). Planners, urban designers, architects, engineers, and climatologists must work together more closely. How to deal with the potential expansion of cities' physical footprints should be a research priority to pave way for sustainability of cities.

The Urban heat islands phenomena and rising temperatures as a result of global climate change will both significantly raise energy use and greenhouse gas emissions, as well as have an impact on ambient air quality, human and animal health, and thermal comfort. And hence, addressing UHI issues can help mitigate the effects of GCCs and increase adaptive capacities at the local level. These actions can also improve environmental sustainability (Estoque & Murayama, 2017). It's also worth noting that urban heat islands increase the risk of heat-related mortality as a result of global climate change, because the intensity of UHIs tends to vary with population density and mean annual precipitation, scholars must provide a unified understanding and explanation for this variation, which will help mitigate this climatic challenge, which is exacerbated by anthropogenic sources, (Manoli et al., 2019).

In cities, the rise in near-surface ambient temperature is well established (Hwang et al., 2017; Narumi et al., 2021; Santamouris et al., 2015). Urban overheating is the result of a combination of the urban heat island, which occurs primarily in cities with a positive thermal balance, and global warming, which affects the urban climate as well. However, the impact of urban heat islands has been extensively studied but, the specific impact of

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global warming on urban climate is not fully grasped (Hwang et al., 2017). There appears to be widespread agreement that global warming has no direct effect on UHI. On the other hand, due to the growing incidence and duration of supportive macroclimatic conditions, its occurrence and length appear to be increasing. More anticyclonic patterns, such as a rise in sea-level pressure, promote UHI, whereas more cyclonic patterns, such as a drop in sea-level pressure, decrease it (Mika et al., 2018).

Furthermore, in his study on addressing sustainability and adapting to global warming through urban agriculture (Mancebo, 2018), also concurred the above assertion, stressing that, it is worth noting that UHIs are neither the cause nor the consequence of global warming. However, (Hwang et al., 2017), indicated that the UHI effect and global warming intensify the urban ambient temperature, resulting in changes in building energy demands. Therefore, the increase in summer cooling demand is far greater than the decrease in winter heating demand, building energy consumption is significantly higher in cooling-dominant regions such as hot-and-humid Taiwan. In the same vein (Hwang et al., 2017), observed that urban heat island is one of the most significant climate change phenomena in urban areas, with potentially serious consequences for flora, pollutant concentrations, air quality, energy and water consumption, human health, environmental and socioeconomic impacts, and even global warming.

Narumi et al., (2021), highlighted that, Extreme temperature rise in some major cities could be attributed to both urban heat island and global warming, but UHIE is currently having a greater impact in countries like Japan than GW. On the basis of past

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trends, it is reasonable to expect that the temperature rise will continue for some time. UHIE and GW have a wide range of effects on urban dwellers, including changes in energy and resource availability, human health, and air pollution. As a result, we must take steps to address these two issues.

This portion additionally discusses the impact of Urban Heat Island (UHI) on atmospheric pollution, acknowledging it as an important aspect of rising urban temperatures in the wider context of climate change. Climate change is expected to alter circulation and radiation effects, influencing the properties of urban air pollution (UAP) and urban heat island (UHI). The UHI effect and high pollution levels are the two most harmful factors affecting the urban population at the same time. According to Dubbeling, (2015), rising urban temperatures increase energy demand, greenhouse gas emissions, and air pollution levels. Elevated heat stimulates the development of ground-level ozone, exacerbating smog and public health problems, especially among vulnerable populations. The lack of green spaces reduces natural cooling and pollution absorption, resulting in a chain reaction that exacerbates both urban heat and air quality degradation, increasing climate-related vulnerabilities.

The health effects of high temperatures during extreme weather and high pollution densities are combined in the urban landscape index, (Mika et al., 2018). In several ways, urban dwellers are more biologically sensitive to climate-related health concerns than earlier communities were. Heat waves and extreme weather are more dangerous to the elderly, but air pollution also presents significant health risks. Also, (Li et al., 2019; Yao

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et al., 2018), observed that, UHIs have a devastating effect on ecosystems, including the aggravation of respiratory illnesses and even death, as well as the disrupting the environment (air and water pollution).

The use of fossil fuels, which contributes to air pollution in urban areas, is the most common cause of urban heat island. It is well understood that rapid urbanisation, particularly in developing countries, adds to the environmental burden and exacerbates the problem, (Feizizadeh & Blaschke, 2013). This study found a significant correlation between UHI and air pollution, implying that increase in the intensity of urban heat island would also increase the rate of air pollution in the urban environment. Similarly, (Li et al., 2020), Observed that, in urban centers, the continuous fossil fuel combustion, and daily domestic activities in the urban region, the urban atmosphere typically has higher aerosol concentrations than the surrounding rural atmosphere; the elevated concentrations of air pollutants in cities are referred to as “Urban Pollution Island (UPI).” The “Urban Aerosol Pollution Island” is also defined as an area with higher amounts of urban aerosol pollutants (UAPI). Aerosol concentration levels in urban areas are hazardous to human health.

In their study on "Assessing climate risk to support urban forests in a changing climate," Esperon-Rodriguez et al., (2022) emphasize the role of green infrastructure in mitigating UHI effects and pollution, while also addressing climate change challenges. This supports the present study's focus on nature-based solutions, such as urban farming, which, like urban forests, provide crucial ecosystem services including temperature regulation, pollutant absorption, and enhanced climate resilience. According to Esperon-

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Rodriguez et al., (2022), strategically employing urban forests can significantly lower surface temperatures and improve air quality in densely urbanized areas. Their call for systematic planning and long-term monitoring aligns with the study's recommendation for consistent, data-driven interventions to mitigate UHI, manage rising urban temperatures, and promote environmental sustainability in cities.

2.7 Relationship between Urban Heat Island and Land Use/Land Cover Changes

The impact of LULC on UHI in urban centers, has been subjected to scrutiny by many scholars, to understand the magnitude of their relationship for the sustainability of our cities. Feizizadeh & Blaschke, (2013), in their study, examined the relationship between the UHI and LULC, and the comparison revealed a positive correlation with both LST and UHI zones controlled by Land use. It is reported by (Isioye, et al., 2020), in a study in Abuja, Nigeria's capital city, that, a phenomenal influx of immigrants into the city over the years, has resulted in alteration of the urban environment and changes made in the LULC and the growth of satellite towns whereby the city is sprawling. As a result, more vegetal covers are being modified for urban infrastructure, resulting in microclimate change and increased UHI.

It is reported by (Koko et al., 2021), that rapid urbanization is associated with significant changes in land use/land cover patterns and the alteration of various biophysical climatic conditions, most notably the Surface Urban Heat Island. The conversion of

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wetlands, vegetation, and agricultural lands into built-up and impervious surfaces can have a significant impact on land surface temperature. Due to the unique qualities (i.e., surface reflectance and roughness) attributed to each LULC category in terms of its radiation and absorption energy, land use/land cover change dynamics are critical factors influencing surface UHI. Similarly, a study by (Naserikia et al., 2019), revealed that changes in urban land use and land cover can raise the temperature of the local air and surfaces. The urban climate is significantly influenced. Various LULC types and surface material properties are responsible for the formation of different UHI patterns. Furthermore, the enormous amount of green biomass, natural vegetation, barren land, water, built-up areas, impervious surfaces, vegetation abundance, and impervious surfaces are LULC parameters that influence UHIs. Li et al., (2020), in a study highlighted that the biophysical composition of a city, including the vegetation cover and moisture dynamics, has a significant impact on the thermal character and Surface Urban Heat Island intensity. As a result, biophysical indices are extremely sensitive to changes in land use and cover. However, the relationship between these variables and land surface temperature varies greatly across regions.

2.8 Urban Heat Island Studies in Nigeria

Like in any other part of the of globe, researchers and or scientist have explored extensively on Nigerian cities urban microclimate and specifically on urban heat island effects, aimed at understanding the phenomena and mitigating its impact on the urban environment and the urban dwellers. In a study on the dynamics of urban heat island in south west Nigeria,

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(Adewara et al., 2019), reported that, one of the most effective UHI mitigation strategies in the study area is to increase the amount of vegetation cover by planting trees. Growing trees reduces the heat island effect through evapotranspiration. Unlike other studies, (Abur et al., 2018), looked at cool pavement as a mitigating strategy, indicated that, in order to mitigate UHI, most existing research on cool pavements tends to focus on solar reflectance, which is the main indicator of a material's optimum surface temperature. More of the incoming solar radiation would be reflected back if urban surfaces were lighter in colour, cooling the surfaces and air temperature. Cooler surfaces and air reduce the demand for air conditioning, saving energy and lowering emissions from power plants. Cooler air can also help to reduce pollution by slowing down the chemical reactions that cause smog.

In another study, on an assessment of the urban heat island over Ibadan Metropolis, (Folorunsho et al., 2017), analyzed the changing patterns of land use types, revealing that, the most noticeable change being the decrease in forest cover. Modifying the environment from natural ecosystem to building and paving covers causes significant changes in geophysical attributes of the earth's surface, such as surface albedo, infiltration capacity, runoff, evaporation, and so on, all of which can be influenced by LST. The LST and the amount of vegetative area have a negative relationship. This relationship between urban temperature and land cover types aids in determining the best solutions for improving urban environment quality and developing heat island mitigation strategies. A study of Lokoja town discovered a significant urban heat island effect and identified vegetation's role as a regulatory cooling feature in the urban environment, (Oluseyi, 2010).

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Many studies on the Nigerian urban environment have explored the interplay between anthropogenic activities and the natural ecosystems leading to the disruption of these ecosystems. Consequently, forming phenomena like the urban heat islands, urban pollution islands, etc. which greatly influences the urban microclimate of the urban centers.

2.9 Issues Within UHI Communication

Improved communication within the field of urban climate, as well as communication among both urban climate and associated fields, is required to both connect the subject internally and to more effectively move it into multidisciplinary interplay (Oke, 2006), This will contribute to a greater understanding of the challenges the discipline aimed to address, as well as a greater sense of cohesion and collaborative effort toward attempting to solve the threat to the urban environment. A growing body of research on urban heat in both the global north and south has thoroughly examined the genesis, main causes, and mitigation strategies of UHI using in-situ methods, remote sensing applications, and statistical and physical models (Meriam et al., 2019; Lenzholzer et al., 2020; Kim & Brown, 2021) one of the 17 targets of the United Nations Sustainable Development Goals, the sustainable development of towns and neighbourhoods should be regarded as an essential component of the solution to UHI and climate change.

Diverse UHI mitigation schemes have been developed and analyse in global cities in both developed and developing countries over the last few decades to minimize surface

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and air temperatures, particularly during hot seasons (Kim & Brown, 2021; C. Wang et al., 2021b). However, in today's urban environment or among scholars concerned with urban climate and specifically UHI, the main issue is the implementation of these studies' findings in towns and cities to reap the benefits of these massive scientific investigations, as evidenced by numerous available literatures that many stakeholders themselves lack proper knowledge of the concept of the UHI. As a result, the implementation of these findings will be severely hampered.

Another critical issue in urban heat island studies is the rural-urban divide, which has the potential to lead to miscommunication. Conventionally, Sites are categorized as either urban or rural, and temperature differences between them are used to determine the magnitude of the heat island. Researchers have devised a simple framework to distinguish the effects of city and country on the local climate categorizing measurement sites as urban or rural. Recent studies, however, shows that the methods and communication in heat island literature have suffered significantly as a result of this popular use of urban rural classification.

The terms urban and rural are ambiguous and can refer to different things to different people (Stewart & Oke, 2012), to avoid such misconception Steward and Oke propose the use of seventeen 'local climate zones,' which are detailed descriptions of different types of rural and urban areas that can be used to facilitate clear communication about the urban/rural conundrum. Their primary aim is to provide a simple, coherent classification model that is universal enough to be adopted in most places, and this will

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offer a more in-depth understanding of the complexities of UHI. However, in their study (Simwanda, et al, 2019) concludes that, to this day there is no agreement on how to develop a precise definition centered on any single set of characteristics to define the rural and urban areas.

2.10 Urban Heat Island Mitigation Strategies, The Blue, Green and Grey Infrastructures

In recent years, the Urban Heat Island effect as posited earlier, has become a focal point of intensive research, driven by the recognition of its escalating impact amidst the challenges posed by climate change and rapid urbanization. This phenomenon, wherein urban areas experience significantly higher temperatures compared to their rural surroundings, has raised concerns about its adverse effects on human health, energy consumption, and overall urban comfort. Consequently, a concerted effort has been made to devise effective strategies to mitigate the UHI effect and alleviate its consequences (Aleksandrowicz et al., 2017; Guo-yu et al., 2013). Crucially, gaining a profound understanding of the available and viable approaches for addressing the intricate issues of urban microclimates has emerged as a top priority in this domain. Researchers and urban planners alike recognize that successful UHI mitigation hinges on informed decisions encompassing both "adaptation" strategies, aimed at adapting to the changing climate conditions, and "mitigation" strategies, aimed at reducing the root causes of the UHI effect itself (Aleksandrowicz et al., 2017).

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A pivotal milestone in the field of UHI mitigation Aleksandrowicz et al. argued, was the ground breaking work of Hashem Akbari, Arthur Rosenfeld, and Haider Taha at the Lawrence Berkeley National Laboratory, who played a pioneering role in introducing the term "mitigation" and popularizing its use concerning the UHI phenomenon. Their research shed light on the potential for actively reducing the UHI effect through deliberate and sustainable interventions, garnering global attention and catalysing further studies in this area. Among the proactive strategies gaining momentum are those that prioritize environmental friendliness and sustainability. Urban planners are now incorporating innovative and ecologically sensitive approaches, such as sustainable infrastructure design and cutting-edge urban landscape architecture, to curtail the adverse thermal stress inflicted by the UHI effect (Aleksandrowicz et al., 2017; Hoang et al., 2021). By fostering green spaces, rooftop gardens, and tree-lined streets, these strategies not only help in cooling the urban environment but also enhance the overall quality of life for city dwellers (Aleksandrowicz et al., 2017).

The concept of UHI mitigation can be translated into a plethora of distinct measures for intervention that differ in measure and extent, as well as the viability and compatibility with the local environment as such experts have explored the blue, green and grey infrastructure for the sustainability of urban dwellers and the environment.

Urban Heat Island mitigation strategies involve implementing various measures to counteract the excessive heat accumulation in urban areas compared to their rural surroundings. These strategies can be broadly categorized into two types: blue

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infrastructure and green infrastructure, with grey infrastructure often playing a supporting role. Let's explore each of these infrastructure types in the context of UHI mitigation:

2.10.1 Green Infrastructure

Green infrastructure involves incorporating natural elements, such as vegetation and open spaces, into urban planning and design. This approach aims to increase vegetation cover, which provides shade, reduces surface temperatures through evapotranspiration, and enhances air quality. Examples of green infrastructure for UHI mitigation include Urban Parks and Green Spaces: Designing and creating parks, green roofs, and vertical gardens in urban areas to provide shaded and cooler areas.

2.10.2 Urban Parks

Urban parks typically consist of a diverse array of vegetation, including grass, trees, and various types of low-growing shrubs. Among these features, large expanses covered by trees, often referred to as "urban forests," exhibit notable efficiency in cooling, particularly during daylight hours. Sizeable grassy sections within parks also play a role in nighttime cooling. However, if these grassy areas lack adequate irrigation, they can become warmer than their surroundings during the day (Atri et al., 2021; Saaroni et al., 2018; Wong et al., 2021). In a similar vein, a study by Shao and Kim, (2022) underscores the benefits of urban

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parks. This study demonstrated how a wooded park covering 100 square meters within a city block bordered by 15-meter-tall buildings managed to decrease air temperatures on a nearby canyon street by as much as 10 degrees Celsius. Additionally, Shao and Kim's research highlights how urban parks exert control over temperatures in neighbouring urban zones, thereby enhancing thermal comfort and reducing energy consumption.

Furthermore, a study by Meerow et al., (2021) on the performance of green infrastructure in arid and semi-arid urban environments revealed that various park attributes, such as size, layout, and amount of foliage, significantly influence cooling effects. Parks with more extensive coverage and greater canopy density were associated with a more pronounced cooling impact, extending beyond the physical confines of the park itself. In sum, urban parks, with their mix of greenery, trees, and other elements, are pivotal in the mitigation of Urban Heat Island effects (Fatma et al., 2020). The cooling benefits provided by urban forests and well-maintained grassy spaces, along with the influence of park characteristics on temperature regulation, highlight the vital role of such parks in creating more comfortable and energy-efficient urban environments.

The cooling effects of parks go beyond their boundaries, positively impacting surrounding areas and improving the overall urban microclimate. As cities continue to face the challenges of rising temperatures and urbanization, the integration of well-designed and maintained urban parks becomes essential for creating more comfortable and sustainable living environments.

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2.10.3 Green and Cool Roof

Within the ongoing discussions on the efficacy of green and cool roofs in mitigating the Urban Heat Island phenomenon, the literature accentuates three fundamental strategies: the cultivation of trees in public spaces and along streets, the adoption of vegetated roofs (living roofs/green roofs), and the augmentation of reflectivity on built surfaces. The core objective of these strategies is to counterbalance heat accumulation and foster more temperate urban settings. Moreover, Imran, (2018) emphasizes the pivotal role played by factors like prevailing wind patterns, street alignment, width, and the physical attributes and arrangement of streets in determining the potency of these strategies. At the urban level, (Heaviside et al., 2017) presented two primary categories of mitigation strategies. The first involves enhancing solar reflectivity through the use of "cool" or reflective materials for surfaces and structures. The second centers around boosting evapotranspiration by increasing the presence of green vegetation and improving water accessibility. This strategy encompasses both green infrastructure, which involves planting trees and creating green spaces, and blue infrastructure, which involves managing water bodies to enhance cooling effects and moisture release (Chidambaram et al., 2022; Sahnoune et al., 2021).

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2.10.4 Vertical Farming/Sky Farming

Vertical farming contributes to sustainability across social, economic, and environmental dimensions. Achieving these sustainability goals hinges on selecting appropriate locations for vertical farms. Notably, vertical farms play a pivotal role in the ecological sphere, acting as green spaces within urban landscapes (Albadal & Ali, 2022; Kalantari et al., 2020). This function reduces the urban heat island effect, while also rejuvenating the local atmosphere through the exchange of oxygen and carbon dioxide between the indoor farming environment and the outdoors. This is complemented by the remarkable capability of vertical gardens to decrease temperatures around buildings by around 8°C (Putri et al., 2015). The broader environmental impact of vertical farming is significant; it provides a cultivation space that doesn't encroach upon natural lands or disrupt existing ecosystems like traditional farming methods do. As a result, the natural environment can regenerate autonomously, fostering tree growth and facilitating a healthier surrounding ambiance. This process ultimately enhances air quality by supporting a greater diversity of animals and plant species (Albadal & Ali, 2022).

Vertical or sky farming, utilizing aeroponics and hydroponics, offers a promising solution for mitigating Urban Heat Island effects in urban areas. By cultivating crops indoors or in misty environments with nutrient solutions instead of soil, it boosts vegetation and modifies surfaces. This enhances heat absorption, shade, and evapotranspiration, collectively minimising the UHIE (Shah & Wu, 2019) Utilising urban structures for vertical farming reduces heat-retaining surfaces, while energy-efficient practices and

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reduced produce transportation contribute to UHI mitigation by curbing energy consumption and emissions. Moreover, cleaner air quality and minimized transportation distances further combat UHI. In sum, vertical farming emerges as a comprehensive strategy addressing UHI through increased greenery, surface modification, energy efficiency, improved air quality, and reduced transportation-induced heat (Putri et al., 2015; Shah & Wu, 2019).

The utilization of green walls as a cladding technique presents a multifaceted approach to mitigate the Urban Heat Island effect. Unlike dense building materials like concrete, masonry, and asphalt that absorb and retain heat, green walls counteract this by offering shading and insulation, effectively cooling the urban environment. This passive cooling method not only reduces the need for energy-intensive air conditioning systems but also promotes energy efficiency (Albadal & Ali, 2022; Kalantari et al., 2017, 2020). By moderating temperatures and providing shade, green walls contribute to sustainable building operations and energy savings. Vertical farming systems have gained significant recognition over the years due to their potential for greater energy efficiency in food production when compared to conventional horizontal farming methods (Game & Primus, 2015; Kalantari et al., 2020). Overall, this cladding strategy not only offers practical benefits but also contributes to enhancing urban environments. By introducing greenery and vegetation, it restores vital natural elements to urban surroundings. Additionally, it brings an aesthetic dimension to existing structures, fostering a more natural and visually appealing urban landscape. This transformation contributes to making urban areas more comfortable and environmentally friendly (Albadal & Ali, 2022).

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It's noteworthy to emphasize that the concept of "Sky farming," while it might seem modern, has deep historical roots dating back to as early as 600 BC. Elghonaimy, (2022) traces its inception to the Hanging Gardens of Babylon, demonstrating that the idea of cultivating vegetation in vertical spaces is rooted in ancient history. This historical precedent underscores that the idea of cultivating crops in vertical structures has been present for centuries, illustrating the enduring nature of innovative agricultural practices.

The innovative concept of sky farming presents a transformative approach that synergistically addresses urban sustainability, resilience, and air quality enhancement. By efficiently using vertical spaces for food production, sky farming conserves land, promotes resource efficiency, and ensures local food security. Its role in mitigating the urban heat island effect and improving air quality adds further dimensions to its urban benefits. As cities face ever-increasing challenges related to population growth, environmental pressures, and resilience, sky farming emerges as a holistic solution that contributes to creating liveable, sustainable, and resilient urban environments.

2.10.5 Trees

Planting trees along streets and sidewalks to provide shade and reduce heat absorption by pavement. Trees stand as a cornerstone within the realm of green infrastructure, bearing significant importance. The broader practice of urban greening, with a specific focus on urban trees and forests, is widely recognized as the foremost approach for efficacious urban cooling. These methodologies principally encompass shading and the moderation of

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ground-level temperatures. Occasional instances involve evapotranspiration, with the most effective cooling trees often characterized by their substantial, dense crowns (Saaroni et al., 2018). Within urban forests, shade trees yield cooling benefits through the process of evapotranspiration. Notably, trees, when adorned with leaves, concurrently curtail wind speed. Correspondingly, trees are hailed as the premier strategy within the realm of green infrastructure. A study by Wong et al. (2020) substantiates this perspective, revealing an array of studies demonstrating the consistent temperature reduction and concurrent enhancement of human comfort stemming from this strategy. The canopy of a tree provides shading that attenuates direct solar radiation. This shading effect is further augmented by the moisture release of evapotranspiration, contributing to heightened relative humidity levels.

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Evidence posits that trees, whether in isolation or groups, confer substantial daytime cooling effects to their surroundings due to evapotranspiration and the cast shadow. Almaaitah et al., (2021) reinforce this notion, affirming that tree shade remarkably curbs solar radiation by a substantial 96.5%, thereby augmenting the cooling impact. Remarkably, a solitary tree in the front yard is noted to induce a 1 to 1.5°C reduction in Physiological Equivalent Temperature (PET). Additionally, an all-encompassing tree planting initiative within cities could potentially lead to a 1.7°C dip in maximum daily summer air temperatures (Saaroni et al., 2018).

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Furthermore, when gauging water utilization, shade trees emerge as superior in comparison to other vegetative counterparts, such as grass, for mitigating urban heat (Meerow et al., 2021). Moreover, the same study by Meerow et al. underscores the significant variation in cooling effects among tree species. Nonetheless, an overarching observation asserts a 0.2°C decrease in air temperature per each percentage increment in total tree canopy cover.

2.10.6 Urban Farming, Urban/Community Garden

Urban agriculture serves as a vital tool in mitigating the Urban Heat Island effect by fostering cooler and cleaner urban environments through shade provision and enhanced evapotranspiration (Azunre et al., 2019). Notably, research from the University of Manchester highlights that a mere 10% expansion in urban greenery through agricultural practices could yield a substantial reduction of up to 4°C in surface temperatures within urban centers (Azunre et al., 2019). Diverse forms of urban agriculture, ranging from gardens and agricultural lands, contribute to diminishing solar radiation, amplifying evapotranspiration, and fostering cooling effects via shading. Crucially, the ecosystem services furnished by urban agriculture, encompassing air purification, carbon sequestration, microclimate enhancement, and UHI alleviation, emerge as pivotal assets in addressing the challenges posed by climate change (Mancebo, 2018).

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Urban farming, urban gardening, and urban agriculture collectively encompass the cultivation, processing, and supply of food within or close to urban areas. These practices extend beyond economic functions, also encompassing valuable social and environmental roles. Among the environmental contributions are enhancements in air and water quality, as well as pivotal roles in pollination and biological control (Azunre et al., 2019; Mancebo, 2018). The multifaceted benefits of urban agriculture include its potential to mitigate the adverse effects of urban heat islands. By furnishing shade and augmenting evapotranspiration, urban agriculture contributes to amplified cooling and cleaner air. A study from the University of Manchester reveals that augmenting green space by 10% through urban agriculture could potentially lead to a reduction of up to 4°C in surface temperatures within urban cores (Azunre et al., 2019). Urban gardens, agricultural lands, fruit and street trees, parks, and forests all forms of urban agriculture hold the potential to curtail solar radiation, escalate evapotranspiration, and consequently diminish temperatures via shading and moisture release (Mancebo, 2018).

A study by Gaxiola, (2018) underscores urban agriculture's substantial contribution to mitigating the Urban Heat Island effect through strategic design and implementation. Employing digital techniques, Gaxiola's research demonstrates that integrating vegetated cover, water features, and shading in outdoor spaces not only modifies microclimates but also offers direct evaporative cooling and optimized thermal regulation (Gaxiola, 2018). Urban agriculture's role in scaling up these cooling strategies for urban environments, coupled with its multifunctional benefits including food security, improved air quality, and reduced energy demand, underscores its potential to foster more sustainable, comfortable,

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and resilient cities in the face of rising temperatures and UHI challenges. Urban gardens play a vital role in enhancing the well-being of city residents, particularly in terms of human thermal comfort (Gasperi, 2017). These green spaces, integrated around buildings and within underutilized urban areas, have a significant impact on the urban microclimate. They achieve this by leveraging vegetation to increase humidity levels, reduce temperatures, provide shelter from wind, intercept excessive solar radiation, and create shaded, comfortable areas. Additionally, urban gardens have a positive influence on urban biodiversity, collectively improving the urban environment and fostering a more pleasant and sustainable living environment for city dwellers (Gasperi, 2017; Lal, 2020).

Promoting urban agriculture in cities presents a host of environmental and social advantages. However, the persistence and expansion of these green spaces face considerable challenges amidst competing urban dynamics. To overcome these hurdles and garner support, it's crucial to identify win-win opportunities for urban farming. These are areas where both environmental and social benefits can be maximized, often on underutilized land. Such strategies are essential for building social and political acceptance of urban farming systems. By demonstrating how these initiatives can simultaneously enhance the environment and benefit the community, we can encourage their growth and integration into urban landscapes (Lin et al., 2017).

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2.10.7 Blue Infrastructure

Blue infrastructure focuses on water-related solutions that help mitigate UHI effects by utilizing water bodies and water management techniques to cool the urban environment. Examples of blue infrastructure for UHI mitigation include:

Urban Lakes and Ponds: Creating or enhancing water bodies that can absorb heat during the day and release it slowly at night, moderating temperature fluctuations. Artificial blue spaces, encompassing elements like pools and fishponds, hold the potential to combat the Urban Heat Island effect by leveraging two key mechanisms: evaporation and reflection. The presence of man-made water bodies increases opportunities for evaporation, effectively cooling the immediate surroundings. Additionally, water surfaces possess high reflectivity, redirecting a significant portion of incoming solar radiation back into the atmosphere. This reflective quality prevents excess heat absorption, contributing to localized cooling effects within urban areas (Almaaitah et al., 2021). In the pursuit of mitigating UHI, the integration of artificial blue spaces emerges as a practical strategy. By facilitating evaporation and harnessing reflective surfaces, such as pools and fishponds, urban planners can foster a more balanced thermal environment. However, considerations regarding water sustainability, maintenance, and ecosystem impact remain integral to the effective implementation of these cooling measures.

The cooling impact of water has been confirmed through a study by Li et al. (2022), which demonstrated temperature reductions spanning from -9.2°C to -0.9°C. This outcome

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underscores the notable cooling potential of water bodies within urban blue spaces as a means to mitigate the Urban Heat Island effect. Nonetheless, the extent of this cooling influence hinges on a range of environmental factors, encompassing microclimate, urban development, wind patterns, temperature, and humidity. In light of these findings, optimizing strategies for UHI mitigation would benefit from the strategic incorporation of water features within the urban landscape, taking advantage of their adaptable cooling capabilities across various seasons. In the same vein, Probst et al., (2022) In their study reported that historically, conventional drainage systems prioritized rapid stormwater removal, while modern strategies focus on moderating runoff through attenuation, infiltration, and retention, enhancing evapotranspiration and cooling urban surfaces. Furthermore, recognizing the importance of green spaces and water bodies for human health, aesthetics, and ecosystems underscores their role in mitigating Urban Heat Island effects. These approaches collectively contribute to UHI mitigation by reducing heat-absorbing surfaces, increasing local cooling, and promoting shaded urban environments.

Water bodies like ponds and lakes act as thermal buffers within urban areas effectively reducing land surface temperatures in their vicinity and disrupting heat source connectivity Bach et al., (2014). Their cooling impact is more pronounced when combined with greenery. However, debates persist regarding their overall influence on air temperature and human comfort, especially due to night time warming effects and increased humidity. Bach et al. maintained that, the cooling effect of water bodies is size-dependent, with larger bodies offering localized cooling benefits, while smaller, shallow ponds spaced at regular intervals can be several degrees cooler than the surrounding urban area, in a feature known

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as the Park Cool Island (PCI). PCI intensity is often largest at night (like the UHI) and tends to increase with park size. Parks with extensive tree coverage tend to be cooler during the afternoon due to shading can have a neighbourhood-scale impact, particularly if positioned to align with prevailing wind directions (Bach et al., 2014).

Gaxiola, (2018), in his study observed that, water bodies, whether natural or constructed (like lakes, rivers, wetlands, and fountains), provide aesthetic appeal and sustainable drainage. Their cooling effect on surroundings has sparked debates due to day-night temperature distinctions. Water's heat capacity cools in the day but warms at night, influenced by factors such as size, quantity, proximity to warmth, and wind patterns. Addressing these complexities requires better assessments of day-night cooling effects, comparisons among water features, and integrating them with urban greenery for optimized heat mitigation. This integration leverages Blue Green Systems' added benefits like biodiversity enhancement, carbon sequestration, and stormwater management (Gaxiola, 2018).

The traditional isolated approach to urban water management can impact Urban Heat Island mitigation efforts. To effectively reduce UHI effects, a comprehensive understanding of urban systems, including water management, is essential. Integrating water management into UHI strategies, such as incorporating green water infrastructure and enhancing microclimates, allows cities to harness synergies between water management goals and UHI reduction efforts, emphasizing the interconnectedness of urban water systems in developing effective UHI mitigation strategies (Bach et al., 2014).

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It is reported that irrigation had a significant impact on reducing surface heating in the studied areas. Irrigation, in particular, was observed to contribute to the cooling of surfaces during the day (Coutts, 2013). Early afternoon air temperatures were significantly cooler in irrigation-implemented regions, than in non-irrigated zones and urban areas. Unlike irrigation, Stormwater harvesting contributes to (UHI) mitigation (Coutts, 2013). By collecting and storing runoff, this practice prevents excess water from contributing to heat build-up and flooding in urban areas. It helps maintain soil moisture levels, supporting green spaces and vegetation that contribute to cooling through evapotranspiration. Additionally, utilizing harvested stormwater for irrigation reduces the demand on potable water sources, ensuring more sustainable water usage for landscaping. Incorporating stormwater harvesting systems aligns with strategies to enhance urban resilience to UHI effects while promoting water conservation and greener urban environments (Coutts, 2013).

The integration of Blue Infrastructure in urban planning for Urban Heat Island mitigation comes with both benefits and potential risks. While BGI can effectively cool urban environments and enhance public health, it must be thoughtfully designed to avoid unintended consequences. Inappropriately designed blue spaces can exacerbate heat stress and pose risks related to flooding and vector-borne diseases, especially under changing climate conditions. To maximize the positive impact of BGI on public health, urban planners should incorporate public health awareness and interventions from the early stages of planning. This proactive approach ensures that BGI not only mitigates UHI effects but

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also safeguards public health, creating more resilient and liveable urban environments (Li et al., 2022).

2.10.8 Grey Infrastructure

Grey infrastructure (GREI) includes man-made structures and technologies that play a role in UHI mitigation alongside green and blue infrastructure. These solutions are often more traditional and engineered in nature. Examples include:

To effectively assess the performance of Grey Infrastructure in mitigating the Urban Heat Island effect, a clear understanding of its definition and classification in relation to urban temperatures is crucial (Qi et al., 2019). Grey infrastructure refers to all other infrastructures that lack visual greenery or natural life and are typically man-made as a result of extensive human modifications to the natural environment (Qi et al., 2019; Zhang et al., 2022). GREI is defined through a comparative approach, contrasting it with green and blue infrastructures, and encompasses the human-engineered physical elements within urban landscapes that do not possess inherent green or natural characteristics (Qi et al., 2019).

Grey infrastructure's contribution to mitigating the Urban Heat Island effect is underscored in the study by Zhang et al., (2022), wherein a predictive model is formulated to evaluate local surface temperatures while considering the interaction between grey and

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green spaces, leveraging landscape and vegetation indices. This model equips urban planners with insights into surface temperature distribution, empowering UHI reduction strategies during urban design. The study also delves into the role of building construction materials, emphasizing their influence on thermal comfort. The classification of building patches based on material type yields robust predictive capabilities for urban surface temperature, with distinct impacts from coloured steel buildings, as revealed by (Zhang et al., 2022). These findings collectively enrich the understanding of grey infrastructure's interplay with building materials, providing a comprehensive framework for enhancing UHI mitigation and urban planning strategies, as elucidated by (Zhang et al., 2022).

While the effectiveness of green and blue infrastructures in alleviating the Urban Heat Island effect is well-established and garners public favour, it's essential to recognize the coexistence of another crucial player: GREIs despite constituting over 60% of urban surfaces, pavements and roofs predominantly fall under the category of GREIs (Akbari & Levinson, 2008; Qi et al., 2019; Zhang et al., 2022) and their significance in the broader UHI mitigation strategy should not be overlooked. Grey infrastructures, which encompass man-made elements with limited natural characteristics, play a pivotal role in shaping urban landscapes and interacting with the surrounding environment.

The reality of urban development necessitates the integration of GREIs into the discourse of UHI mitigation. While green and blue infrastructures offer invaluable cooling effects and aesthetic benefits, a comprehensive approach must consider the vast expanse covered by grey infrastructures. These structures, often consisting of concrete, asphalt, and

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built environments, significantly impact local temperature dynamics, energy consumption, and the overall urban microclimate. By addressing the specific challenges posed by GREIs, such as heat absorption and radiation, urban planners and policymakers can strategically harness their potential to counterbalance the UHI effect. The synergy between green, blue, and grey infrastructures becomes essential to build urban resilience against rising temperatures and ensure a holistic strategy that encompasses the diverse components shaping our urban environments.

Research into urban heat island mitigation increasingly considers grey infrastructure, recognizing that over 60% of urban surfaces consist of pavements and rooftops, typically composed of GREIs (Akbari & Levinson, 2008). While green and blue infrastructures are recognized for their effectiveness, the significance of grey infrastructure should not be overlooked, especially given its dominance in urban landscapes (Qi et al., 2019; Santamouris, 2013; Wang et al., 2021a). Recent investigations have focused on the synergy between green-grey and grey-blue infrastructures as strategies for enhancing urban resilience and combating UHIs. Cool pavements have also gained attention, with the development of reflective coatings, infrared-reflective pigments, and high-albedo materials showing promise in reducing surface temperatures. Permeable and water-retentive pavements, more suitable for rainy regions, are being explored, with their thermal performance contingent on water availability. Though laboratory advancements have been made, comprehensive, large-scale demonstrations are needed to fully understand how grey infrastructure solutions can effectively modify local microclimates, improve thermal comfort, and reduce energy consumption.

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Similarly, in their study on grey, green, and blue infrastructure Taher and Kader, (2022), define grey infrastructure as encompassing structures such as dams, seawalls, highways, pipelines, and water treatment facilities. These constructed solutions are integrated within watersheds or coastal ecosystems, where their functioning is influenced by the hydrological and environmental characteristics of the surrounding area. In the realm of Urban Heat Island mitigation, Green Infrastructure focuses on integrating natural elements for cooling, Blue Infrastructure harnesses water-related solutions like water bodies and management, and Grey Infrastructure includes engineered structures.

However, a comprehensive UHI mitigation strategy is most effective when these approaches are combined synergistically. Integrating greenery with water bodies, strategically modifying grey infrastructure, and implementing reflective and water-retentive features can create a holistic solution. This combined strategy addresses various UHI dimensions, fostering cooler microclimates, improved air quality, water conservation, and enhanced urban livability. As urbanization and climate change challenge cities, this integrated approach emerges as a powerful tool, safeguarding well-being, promoting sustainability, and creating vibrant, resilient urban environments for present and future generations.

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2.11 Remote Sensing and UHI

Traditionally, urban studies use demographic or geographic information to describe the condition of the urban environment, the attributes of the urban landscape, the modifications that have occurred over time, and the pressures on the urban area. This information must be rich in both space and time, which necessitates the use of monitoring networks or special experiments capable of adequately reflecting the area under investigation. Several satellite sensors have been sent into orbit to examine and analyze the Planet's surface and its surroundings since the early 1960s. Technology has advanced tremendously, and satellite missions have multiplied; more importantly, conceptions of the potential and applicability of satellite remote sensing have significantly changed (Lauer et al., 1997; Weng, 2009; Gallo, 2018).

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The use of remote sensing technologies is currently a key component of Earth observation. There are many different types of Earth observation sensors and remote sensing platforms. They're used to collect high-precision, high-resolution data on a global scale, allowing scientists to develop a better understanding of the environment from both a spatial and temporal perspective (Ge et al., 2020). Satellite-based observations have been recognised as a critical in using these data to detect, quantify, and track changes in the Earth's ecosystems, land processes and attributes over time (Gallo, 2018). Thus, it is clear that advances in remote sensing and spatial science have greatly enhanced the quantity and quality of SUHI studies that make up the majority of the urban heat island research during the last few decades.

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The United States developed the first remote sensing satellites, which is a significant milestone in Earth observation history that cannot be over emphasized. In August 1960, the military successfully launched its first Earth-observing satellite. It was named the discoverer was and intended to be an unclassified system that would contribute to the biomedical investigation and Earth observations (Lauer et al., 1997).

Remote sensing is seen as the science of obtaining information about an object or phenomena of interest by measuring emitted and reflected radiation (Lushnikov et al., 2020). In the same vein Adiri et al., (2020) reported that remote sensing is the practice of detecting and monitoring an object or an area's physical attributes by assessing its reflected and outgoing radiation from a distance. Shirazi et al., (2018) However, observed that, in contrast to on-site observation, remote sensing is the obtaining of objects of interest or phenomenon without making physical contact with the object. Similarly, (Arroyo, 2016) stressed that the ability to measure a target's properties without touching them is referred to as remote sensing.

Although remote sensing appears to be a very specific application, it is all around us, from snapping a photo with a camera, in which the picture is the product of the light photons that reach the camera sensor over time, to estimate the speed of the Universe expansion by assessing the Doppler signature of all Spectral objects earth’s Atmosphere (astronomy). This indicates that because the target is not directly touched, its properties are not altered, and the measurement recorded is more accurate, reliable, and original. Shirazi et al., (2018) in their study on remote sensing in South Khorasan, Iran, narrowed the

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definition to mean the use of satellite or aircraft-based sensor devices to detect and characterize objects on Earth, which include those on the surface, in the surrounding air, and in the oceans, focused primarily on propagated signals (e.g., electromagnetic radiation). However, this definition excludes procedures that employed data or information acquisition using vehicles or other handheld instruments.

It is paramount to highlight the significant feet attained in our understanding of the phenomena which can be seen in the work of P. Krishna Rao, a research physical scientist with the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite Service (NESS), was the pioneer to use satellite thermal data to study SUHI. In the Eastern United States, he discovered clear urban signatures on ITOS-1 thermal images, enhancing the ability of thermal remote sensing in SUHI studies (Zhou et al., 2019). This piece of work prompted more research into the subject and broadened our understanding of the concept. It is also imperative to mention the contributions of the private sector to the field of remote sensing is expanding at a rapid pace. As a result, commercial firms have launched cube satellites with amazing spatial and temporal resolutions at the consequence of low orbital stability and radiometric accuracy (Hemati et al., 2021).

In terms of studies involving large coverage of a town or a city only remotely sensed TIR data can provide an uninterrupted and continuous view of an entire city, which is critical for extensive analysis of city's microclimate (Weng, 2009; Gallo, 2018). Remote sensing techniques have been extensively used in urban climate studies. The most

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significant benefit of using remote sensing thermal data is that it provides comprehensive coverage of UHI patterns, which can be used for spatiotemporal assessment. Gallo, (2018) also affirms that, Continuity and consistency of observations are the most significant characteristics of monitoring activities employing EO (Earth Observation) satellites. Moreover, the application of remote sensing techniques in urban studies is popular among researchers because it allows for the acquisition and analysis of spectral signatures over relatively broad areas of interest in a relatively quick and cost-effective manner, (Adiri et al., 2020).

2.12 Landsat Sensors

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The Landsat mission is one of the longest-running satellite program for Earth observation from space (Irons et al., 2013; Zhu et al., 2019; Guo et al., 2020). It is made up of a group of eight operational Earth-observing satellites that use embedded sensors to collect data and image our planet as part of the USGS's National Land Imaging (NLI) Program. Landsat is a name for a series of satellites that have featured a variety of sensors, ranging from the low-resolution Multispectral Scanner (MSS) in the 1970s to the Thematic Mapper with Landsat-4 in 1982, Landsat-5 in 1993, Enhanced Thematic Mapper Plus with Landsat-7 in 1999, and the Operational Land Imager (OLI) and Thermal Infrared (TIR) sensors on-board Landsat-8. On July 23, 1972, Landsat-1 was launched, heralding the beginning of modern satellite-borne Earth observation. It presented international science organizations with an

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advent of high-resolution Earth image database (Lauer et al., 1997; Irons et al., 2013; Guo et al., 2020).

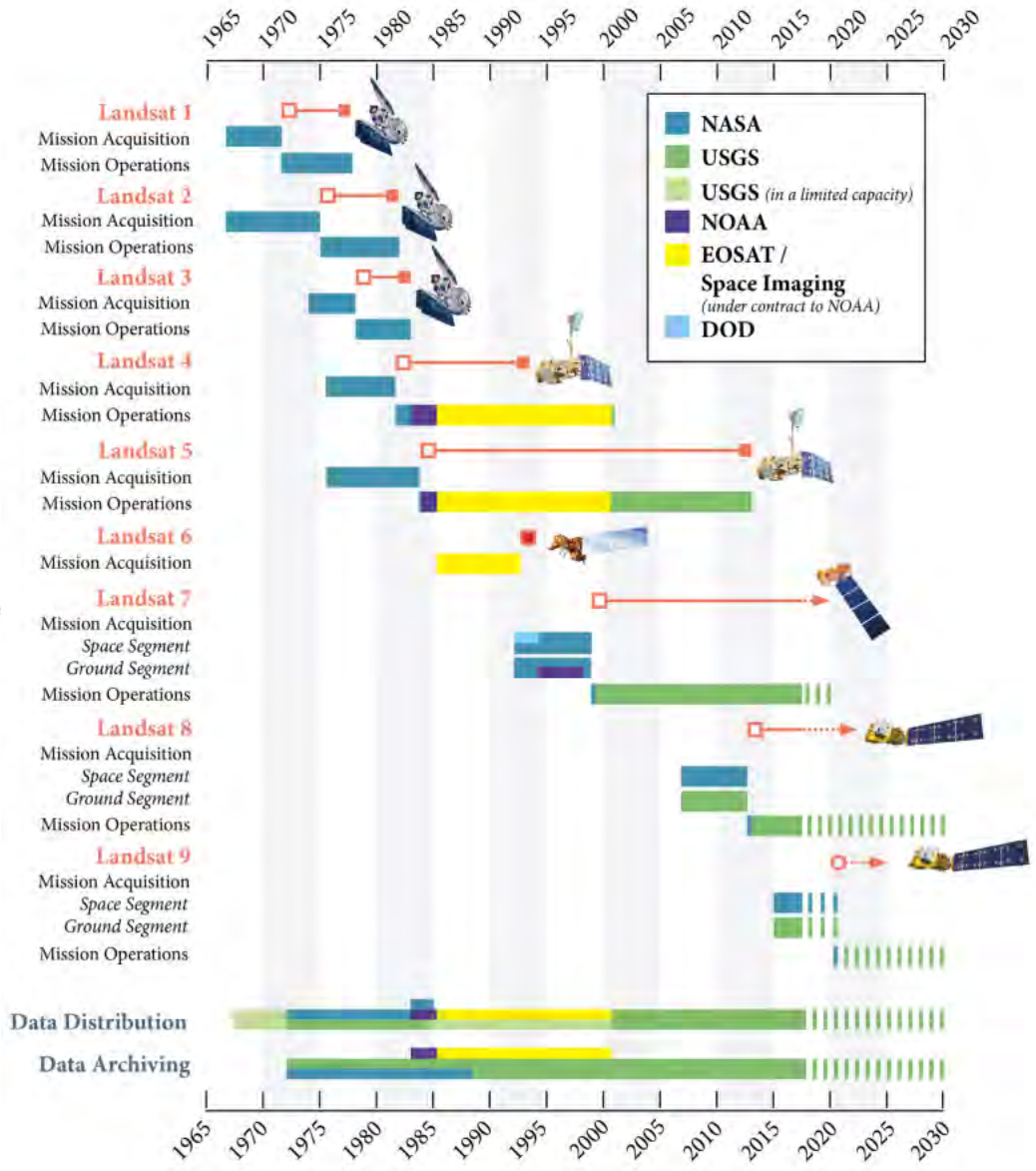
In the history and evolution of the Landsat a significant milestone was attained. The United States Geological Survey (USGS) adopted a free and open Landsat data policy in 2008 (Hemati et al., 2021), which resulted in a significant increase on use of Landsat data, which has tremendously benefited many segments of society. Operational developments, research data, and discoveries informed by analyses of high volumes of Landsat images have all benefited greatly from this policy. For instance, using all available Landsat observations from 2000 to 2012, a global mapping of annual forest change was completed, revealing a net forest loss of 1.5 million km^2 (Zhu et al., 2019), the loss of these vegetation no doubt had a significant impact on the micro climate and specifically on the land surface temperature of the affected regions.

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Figure 2.2

Landsat mission series and management history. Six decades of program management responsibilities.



Adapted from Wulder et al., 2019

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Table 2.1

Summary of band designations and pixel size (m) for all Landsat satellites (LS) and sensors

Landsat sensor	LS 1-5 MSS	LS 4-5 TM	LS 7 ETM+	LS 8 OLI/TIR	Pixel size (m)
Coastal aerosol				B1 (0.43-0.45)	30
Blue		B1 (0.45-0.52)	B1 (0.45-0.52)	B2 (0.45-0.51)	30
Green	B1 (0.5-0.6)	B2 (0.52–0.60)	B2 (0.52–0.60)	B3 (0.53-0.59)	30 (60† for MSS)
Red	B2 (0.6-0.7)	B3 (0.63–0.69)	B3 (0.63–0.69)	B4 (0.64-0.67)	30 (60† for MSS)
NIR 1	B3 (0.7-0.8)				60
NIR 2	B4 (0.8-1.1)	B4 (0.77-0.90)	B4 (0.77-0.90)	B5 (0.85-0.88)	30 (60† for MSS)
SWIR 1		B5 (155 - 1.75)	B5 (155 -1.75)	B6 (1.57-1.65)	30
SWIR 2		B7 (2.09-2.35)	B7 (2.09-2.35)	B7 (2.11-2.29)	30
Thermal		B8 (0.52-0.90)	B6^{+}(10.40-12.50)	B10(10.60-11.19) B11(11,50-12.51)	30†
Pan-Chromatic			B8 (0.52-0.90)	B8 (0.50-0.68)	15
Cirrus				B9 (1.36-1.38)	30

Source: Adapted from Young et al., 2017

The importance of Landsat's free and open data policy in 2008 cannot be overstated, as it has been evident in studies as a defining moment in the number and nature of change detection studies. The average number of Landsat images used in research skyrocketed from 10 images in 2008 to 100,000 images in 2020 (Hemati et al., 2021). With the new Landsat 9 in operation, this figure is expected to tremendously increase. The launch of

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Landsat-9 in September 2021, combined with the continued operation of Landsat-8 and integration with Sentinel-2, significantly enhances possibilities for better monitoring of change over increasingly larger areas with greater climate variability frequency (Hemati et al., 2021). Hence, researchers, urban planners, and all stakeholders concern with the earth ecosystem will be better informed on its status and work toward the sustainability of environment and its biodiversity.

The Landsat Global Archive Consolidation (LGAC) has worked hard to ensure that all images acquired at international receiving stations are recorded, processed, saved, and made accessible via the Landsat data archive of the USGS. The Landsat archive is now more complete than it has ever been (Hemati et al., 2021).

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Landsat has provided new perspectives on geologic, agricultural, and land-use surveys, as well as potential opportunities for resource exploration It has made significant contributions to our understanding of the Planet and its terrestrial ecosystems, as well as land processes (Lauer et al., 1997; Chen et al., 2006; Irons et al., 2013; Guo et al., 2020). It also sparked novel strategies for data analysis and scientific research, as well as strong international collaborations focusing on science and technology, including a crucial one on how to operate Landsat. As a result, the Earth-observing system is now highly efficient and easier to chart and positively advances human understanding and sustainable resource management on the planet.

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2.13 The Origin of Urban farming/Urban agriculture

Humanity is undergoing an extraordinary adventure at the end of the twentieth century; we are transforming into an urban species. Urban centers, rather than villages and towns, are increasingly becoming our primary homes. The landscape across the globe and mankind is changing in response to urbanization (Deelstra & Girardet, 2000). According to published findings, the world population (now around 7 billion) is projected to expand and will surpass 9 billion by the mid-twentieth century, with developing countries (particularly Asian countries) growing at a faster rate. The population of highly developed countries, on the other hand, is predicted to remain nearly stable (Miccoli et al., 2016). Global urban populations have risen from 15% to 50% of the total population in a century, from 1.5 to roughly 6 billion people, thereby ushering in the urban century. As shown in another study, more than 60% of the world's population would live in cities by 2030 (Ibharim & Salim, 2020). Today, 54 percent of the world's population lives in cities. As earlier stated in 2007, the global urban population surpassed the rural population for the first time in history, and it is anticipated that by 2050, more than two-thirds of the world's population (70%) will be dwelling in urban centers (Miccoli et al., 2016; Coccolo et al., 2018; Elmqvist et al., 2019; Gelan & Girma, 2021).

Traditionally, farming is not often synonymous with cities. It's more of a rural than an urban hobby. However, this long-held belief may be about to change, since agriculture is on the verge of being reintroduced into our cities. New technology, combined with innovative design concepts, is challenging the long-held belief. Growing food in cities is

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not a strange idea, and urban farming is as old as cities themselves. Since the advent of urbanization, farming has been practiced all over the world. Indeed, farming and urbanization are linked, with cities requiring farming to support their populations and farming enabling the construction of cities. As a result, urban farming contributes to the social, economic, and environmental sustainability of cities in a variety of ways (Manikas et al., 2020).

The notion of farming in the city dates back to the most primitive kinds of urban agriculture discovered in Mesopotamia between 4000 and 600 BC. Rooftop greenery and the growing of shrubs and trees on aboveground terraces were hallmarks of the Sumerian, Babylonian, and Assyrian huge temple complexes (Ziggurats). The Suspended Gardens of Babylon are regarded as one of the Seven Wonders of the Ancient World, despite debate about whether they actually or were purely poetic inventions (Dieleman, 2016). This fact is further buttressed by the findings of a similar study which adds to the rich historical development of urban farming by affirming that, farming in cities is not a new concept. In 700 BCE, the Assyrian king Sennacherib planted date palm and tamarisk in the 'Hanging Gardens,' a vertical garden watered using aqua ducts and Archimedean screws. UA has flourished in most cities for thousands of years in the most basic forms, like family and community gardens. According to a recent mathematical modeling study, UA accounts for 5–10% of the global supply of legumes, tuber crops, and leafy vegetables. UA is a critical source of nutrition and income for the urban inhabitants in some underdeveloped cities (Sullivan et al., 2019).

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Agricultural activities have a longstanding tradition, and they are tied to people's abilities to not only take food from the natural environment but also to grow and harvest it purposely, both plants and animals. People in many parts of the world (originally Asia and Africa) began to learn agricultural techniques around 10-5 thousand years BC, according to historical records. Farming activities from the Arabian Peninsula were also spread to European soil (Dobele & Zvirbule, 2020).

Two more early instances dated from the 1400s A.D. in the Western Hemisphere. The nutritionally self-sufficient city of Machu Picchu in Peru is a famous example. "Scarce water was re-used over and over as it made its way down the hillside, one step at a time." The bio-intensive vegetable beds were created to take advantage of the afternoon sun and extend the growing season. To withstand the regular alpine frosts, water, and land crops were combined." The Aztec civilization is another important historical landmark in the evolution of urban farming (Pacey & Bray, 2021). In growing crops near the cities on lakes, they used "chinampa," or floating islands. When the Aztecs sought to support their people but couldn't capture more territory, the island became a crucial part of their expansion. Similarly, In and around the cities of ancient civilizations, Mougeot, (2006) reported that archaeologists often unearth the remnants of remarkable massive earth and water works. In those regions, farming activities have been documented for a variety of purposes, including food and fodder, construction materials, fortification, and even medicinal plants. From ancient Persia's fortified gardens to Roman colonies in Algeria and Morocco, from Europe's medieval monastic towns to Aztec city-states and the terraced terraces of Machu Picchu high in the Peruvian Andes (Mougeot, 2006).

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In the same vein Pacey and Bray, (2021) corroborate that the creation of artificial islands, or chinampas, in freshwater lakes was a particularly noteworthy Aztec farming method. These islands or elevated fields were created by either heaping soil onto a trellis made of willow rods and reeds put level in shallow water or building canals around small sections of swampy land. Since roughly the year 1000, kingdoms in the Mexican Basin had been constructing chinampa systems. When the Aztecs came to power in 1428, they created seventy square kilometers of chinampas around their island city of Tenochtitlan, converting lake fringes into very productive farmland.

Furthermore, it is critical to underscore that the growth and development of ancient cities are directly related to the city's ability to support sustainable food production systems supported by their environment. Therefore, Dobele and Zvirbule, (2020) in their study on the historical development of urban agriculture asserts that, earliest cities were developed when the ability to grow and store food improved, and the human population continued to increase and began to combine in the fairly dense social centres of a given area. Food was a crucial aspect in the establishment and development of cities, since it gave geographical autonomy and independence from surrounding areas. People have been growing food in cities since the beginning of civilization for two reasons: 1) People moved their agricultural knowledge to emerging cities to feed themselves, their families, and the urban population, and 2) most of the earliest cities were created and developed around cultivated agricultural fields.

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Table 2.2

Stages of the historical development of urban farming.

The development stage of urban farming	Influencing factors	Period
Urban farming – the basic principle for urban planning	- formation of cities - the need for territorial autonomy - population growth	3,5. thousand years. BC-17th century
Changing functions of urban agriculture	- industrialization - the economic stratification of society - economic migration to cities	18th -19th century
	- a period in time of World Wars - economic and social depression - insufficiency of resources	The first half of the 20th century
The renaissance of urban farming	- the concept of sustainable development - science and research activities - technological development - changing the values of society	Second half of 20th century - now

Adopted and modified from Dobele & Zvirbule, 2020

Urban farming is defined as food or livestock production or processes carried out within or near urban areas in order to generate income (Yusoff et al., 2017). Similarly, (Pölling et al., 2017) opined that the term "urban farming" refers to "small- to large-scale agriculture that takes place in cities." primarily cultivates agricultural land on the outskirts of cities It is mostly driven by economic considerations and is managed by professionals with medium to large distribution channels ranging from direct marketing to global value chains. But, (Poulsen et al., 2017), sees urban farming, as a type of urban agriculture cantered on entrepreneurial food production that serves a variety of functions in communities. A study

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by (Mahmood et al., 2020) reveals that with a predominance of shorter-cycle, higher-value market commodities, urban farming is intensive and makes the best use of space. It makes good use of both horizontal and vertical areas by using multi-cropping and integrated farming practices (through such techniques as chicken coops on shelves, multi-species fish ponds, and container farming). Urban farming uses water more efficiently than rural farming since water is expensive and generally in short supply.

2.14 The Concept of Urban Farming

In recent decades, one aspect that has dominated the urban discourse and that is frequently investigated and recognized in cities is urban farming or urban agriculture, this concept has been interchangeably used by many scholars for instance (Aisyah Salim et al., 2019; Kalantari et al., 2017; Kuhns et al., 2019; Lin et al., 2017; Muhammad et al., 2020; Opitz et al., 2016; Pasha et al., 2014; Ur Rehman, 2019) which is gaining worldwide popularity. Urban agriculture (UA) is popular throughout continents, with hundreds of hectares of urban gardens in many cities in the global north and south, and such green spaces provide a variety of environmental and social purposes for city residents. On long-term and global dimensions, urban farming is seen as a vital component of broader urban support systems (Lin et al., 2017).

In scientific research, four concepts are most typically used to describe urban agriculture: , urban farming, urban gardening, urban horticulture, and, urban agriculture

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(Dobele & Zvirbule, 2020). In the same vein a study reported that, besides Urban farming, many scholars use different terms for commercial farm businesses situated in urbanized areas, like 'urban agriculture', 'professional urban agriculture', 'professional farms, 'metropolitan agriculture' , and 'urban fringe agriculture (Pölling et al., 2017).

The term urban farming or urban agriculture can best be defined as an enterprise situated within (intra-urban) or on the outskirts (peri-urban) of a city, town, or metropolitan area that grows and enhances, processes, and delivers a variety of food and non-food commodities, (re-)using primarily human and physical resources, goods, and services discovered in or around the urban environment, and in turn providing human and other resources, goods, and services to that urban environment (Kuhns et al., 2019). This is the most commonly cited definition of urban farming which is also reported by (Dobele & Zvirbule, 2020; Opitz et al., 2016; Pölling et al., 2017; Veehuizen, 2006), However, according to a survey, there is a distinction between UA and PUA. In their study on Contributing to Food Security in urban areas: differences between urban agriculture and peri-urban agriculture in the Global North, Opitz et al., (2016) have undertaken a comprehensive study on urban and peri-urban agriculture as they have a direct and indirect impact on the urban food system, as well as distribution and consumption levels. While examining UA and PUA, they look at the underlying spatial, ecological, economic, and social conditions, as well as how UA and PUA practitioners manage these concepts.

Urban farming Kuhn et al maintain that it includes the following:

i. Crop farming, animal husbandry, and fish production in or around cities

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ii. Production of food as well as non-food commodities (for example, flowers, trees, and houseplants)

iii. Food and non-food goods grown in and around urban centers including processing and marketing of these products

iv. Manure and Compost and also (treated or untreated) municipal wastewater are used as resources.

v. It might occur in the city's open spaces, as well as in people's gardens or on rooftops.

Many scholars have Small- to large-scale agriculture that cultivates agricultural land mostly on the outskirts of cities is classified as urban farming. It is primarily driven by economic considerations and is managed by experts with medium to large channels of distribution ranging from direct marketing to global value chains.' (Pölling et al., 2017).

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Urban farming, according to the FAO, is a multipurpose system that links conventional farming activities with the benefits of human health, community well-being, financial viability, recreational activities, landscape, and environmental safety concerns (Ramaloo et al., 2018). Another similar definition of the concept was reported by Muhammad et al., (2020) who described urban farming as an agricultural activity in which crops and livestock are grown using ecologically friendly systems and techniques. This concept, which is integrated into the urban environment, provides food to the urban inhabitants and their surrounding community. Because food sources are close by, energy and transportation costs, as well as their negative consequences, can be minimized.

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An earlier survey presented a simple but, comprehensive description of the concept which postulates that "the growing of plants and the raising of animals for food and other uses within and around cities and towns, and related activities such as the production and delivery of inputs, and the processing and marketing of products. Urban agriculture is located within or on the fringe of a city and comprises a variety of production systems, ranging from subsistence production and processing at the household level to fully commercialized agriculture" (Veehuizen, 2006).

Food production in and near cities has been practiced in a variety of forms, backgrounds, and goals, and is gaining popularity in civilizations around the world, although it is not a new concept. This growing interest in urban farming is reflected in an increasing number of talks, projects, and publications in the media and academia (Pölling et al., 2017). The practice of urban farming is now implemented in practically every corner of the world. In many developing countries, urban and peri-urban farmers produce 80 to 90 percent of fresh vegetables and about 40 percent of eggs consumed in cities (Dieleman, 2016). Similarly, another survey indicated that worldwide about 60 percent of irrigated croplands and 35 percent of rain-fed croplands are located in cities of at least 50,000 people, with 20 km buffers surrounding these city boundaries (Pölling et al., 2017).

According to the several authors mentioned above, urban farming is distinguished by proximity to markets, high demand for land, scarcity of land, utilization of urban resources such as organic solid wastes and wastewater, low degree of farmer organization,

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predominantly perishable items, high-level of areas of expertise (Grebitus et al., 2020; Poulsen et al., 2017; Veehuizen, 2006).

Urban farming is becoming increasingly recognized not just for its contribution to food production, but also as a viable technique for mitigating the Urban Heat Island effect. Numerous studies have demonstrated that incorporating vegetation into urban structures such as gardens, horticultural plots, rooftops, facades, and tiny residential areas can considerably reduce surface and ambient temperatures via processes such as shade and evapotranspiration. Table 2.3 provides a succinct review of selected studies that have implemented various urban farming systems specifically for UHI mitigation, highlighting the methods used, locations, and cooling outcomes.

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A growing of research highlights the crucial significance of urban farming in mitigating UHI effects across varied geographic and climatic situations. Numerous empirical and modeling-based research have shown that incorporating plants into urban surfaces (rooftops, facades, gardens, and open spaces) can significantly lower land surface temperatures while increasing thermal comfort. For example, Ling et al., (2025) showed that integrating VF on building facades and agrivoltaics (AV) systems on rooftops in Singapore reduced heat transfer into buildings while also increasing photovoltaic panel efficiency, contributing to climate resilience and energy sustainability. Similarly, Tsilini et al., (2015) demonstrated using ENVI-met simulations in Chania, Greece, that UG could reduce surface temperatures by up to 10°C when compared to non-vegetated surfaces.

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Table 2.3

Studies implementing urban farming as a strategy for Urban Heat Island mitigation

Study	Farming Type	Research Type	Key Results	Location
Eom et al., 2012	Urban forests, parks, lawns	Field measurements (1 year, 17 sites)	Forests and parks reduced temperature year-round; lawns more effective in cooler seasons	Seoul, South Korea
Tsilini et al., 2015	Urban garden	Simulation (ENVI-met, 4 scenarios)	Urban gardens reduced surface temps by up to 10 °C	Chania, Greece
Kumar et al., 2017	Irrigated green areas	Modeling (MODIS, GSOD, CLM4)	Daytime UCI in 60%+ cities; nighttime UHI in 90%; vegetation and irrigation key drivers	Pan-India
Dwivedi & Mohan, 2018	Terrace gardens	15-month field experiment	Roof and ceiling temps reduced by 2–7°C; heat gain lowered via shading and evapotranspiration	Greater Noida, India
Maru Abebaw Berhanu & Akola, 2014	VF farming green roofs, terraces, parks	Remote sensing + ENVI-met	UHI reduction via greening; terraces should be mandated green; lakes/vegetated areas cooler	Mumbai, India
Chidambaram et al., 2022	Residential rooftop gardens	Field experiment	Reduced LST by 2–7°C; increased shading and evapotranspiration	India
Demisse Negesse et al., 2024	Urban green spaces (vegetation cover)	Remote sensing + statistical analysis	Green spaces ≥4.5 ha significantly reduce LST and support microclimate regulation	Addis Ababa, Ethiopia
Wirastri et al., 2024	Urban farming modules	Simulation (SketchUp + ENVI-met)	Modules reduced MRT by up to 3.9°C; locally effective	Yogyakarta, Indonesia
Mohapatra et al., 2024	Kitchen gardening / urban horticulture	Conceptual analytical review	Cools urban areas; boosts food security and SDGs; increases greenery and community engagement	India
Ling et al., 2025	VF on facades, AV on rooftops	Simulation-based study	VF lowers heat transfer; AV improves PV efficiency; both enhance climate resilience	Singapore

Experimental Studies conducted in India confirmed that rooftop gardens reduced ceiling and roof surface temperatures by 2-7°C, resulting in lower energy demand and enhanced indoor comfort. (Chidambaram et al., 2022; Dwivedi & Mohan, 2018). Aside from thermal control, urban farming has been acknowledged for its socio-ecological benefits, especially in resource-constrained and fast urbanizing regions. Mohapatra et al., (2024) demonstrated

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how kitchen gardening in Indian cities can act as a dual solution, decreasing UHI effects through increased green cover while simultaneously addressing nutritional insecurity by improving access to fresh vegetables.

Large-scale remote sensing studies, such as Kumar et al. (2017), support the cooling potential of irrigated vegetation in urban areas, reporting that more than 60% of Indian cities experience daytime cooling due to urban vegetation and irrigation when compared to their surrounding rural landscapes. Similarly, Demisse Negesse et al., (2024) discovered that green spaces larger than 4.5 hectares in Addis Abeba considerably lowered LST, highlighting the need of strategic spatial design in urban greening efforts. These findings emphasize the link between environmental performance and human well-being, emphasizing the importance of green infrastructure in urban policy.

Furthermore, the evaluated papers provide practical insights that are consistent with the goals and scope of this study on Maiduguri. Wirastri et al., (2024) in Yogyakarta, Indonesia, and Maru Abebaw Berhanu & Akola, (2014) in Debre Markos Town, Ethiopia, found that urban farming modules and mixed agricultural practices can significantly moderate microclimates while also supporting biodiversity and community resilience.

These studies demonstrate the need of carefully choosing vegetation whether on facades, rooftops, or in open lots to maximize local cooling effects. As Maiduguri continues to suffer rapid urbanization and increased sensitivity to excessive heat, evidence from these worldwide case studies supports the potential of urban farming as a locally adapted UHI

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mitigation technique. Thus, this thesis draws on a solid basis of global research to assess how urban farming might function as both a climate adaptation mechanism and a strategy for improving urban sustainability in Maiduguri, Nigeria.

2.15 Types of Urban Farming

The utilization of urban farming varies based on the region, habitat, and needs of the urban dwellers. studies have shown that urban farming is not new and has already been practiced across all cultures on the grounds, balconies, and rooftops of buildings, as well as vertical walls, in a variety of cities in various climatic environments, including high-density cities such as the United States of America, Japan, Singapore, and other developing countries (Yusoff et al., 2017). They further highlighted urban farming to include community farming, rooftop farming, and vertical farming. Each farm has similar techniques and goals, yet due to space organization and boundaries, each has its unique qualities.

Traditionally, city dwellers employed a variety of methods to cultivate food crops or flowers in their homes, such as in pots. Breeding and raising animals, bees, aquaculture (fish farming), aquaponics (fish farming alongside vegetables), and non-food goods such as planting flowers and growing seeds are all examples of urban farming. (Muhammad et al., 2020).

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Among numerous existing Urban Agriculture approaches, the following six systems are presented by (Camacho, 2016; Philips, 2013).

i. Vegetated roofs.
ii. Hydroponics.
iii. Aquaponics.
iv. Greenhouse.
v. PFAL (Plant Factort with Artificial Light).
vi. Remote sky lighting.

Similarly, Felser, (2019) broadly identified three broad categories of urban farming these include, Individual and family-based urban farming can be undertaken where people are solely concerned with their sustenance rather than making a profit. The most famous term for this classification is "urban gardening".

Urban farms, this type Felser maintains could be used for relaxation and leisure activities, with the primary goals of teaching urban inhabitants and integrating them into agriculture. Community gardening, both in communities and as part of schools, universities, and so on, guerrilla gardening, urban allotment farm or gardening, and basic city gardening programs are all examples of projects that aim to serve the economy, ecosystem, health, and well-being of cities' dwellers. This is the most common kind of urban agriculture and may be found in every modern city, particularly in European cities.

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The other form of urban farming is the corporate base which can be implemented on a market-oriented basis, with products sold either directly to clients or through middlemen. This form is typically organized by micro-enterprises or larger organizations. Consequently, farming projects typically dedicate themselves to commercial entity categories, employing a variety of farming techniques (Felser, 2019; Liu et al., 2015).

In their work on the differences in motivations and social impacts across urban agriculture types (Hawes et al., 2021) identified the following types of urban farming which include allotment gardens, home gardens, home farms, community gardens, hybrid community gardens, community farms, hybrid working farms, and working farms. Conversely another study by Huzeima et al., (2020) presented other benefits of urban farming are a greener environment, recycling organic waste, reducing the ecological footprint, mitigating urban heat islands, and Improved urban stormwater management. Azunre et al., (2019) argue that the general conclusion is that the nature of agriculture in cities should be decided by the key attributes of the city. As a result, overexploitation of the crucial environment is averted, and adequate and effective crops or vegetation are grown at the proper season. Because of its importance in the sustainable-city rhetoric, this will ensure that the concept endures in the landscapes of these cities.

As highlighted above as, urban farming can take several forms, including backyard gardening, community gardens, container farming, rooftop farming, and vertical farming, each of which provides distinct spatial and environmental benefits in urban areas. These activities help to improve food security, expand green spaces, and regulate microclimates

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in cities. However, while some of these methods are used in Maiduguri, such as backyard, open space, and peri-urban farming. Rooftop and vertical farming are not widely adopted. This is primarily owing to the structural qualities of local structures, which frequently lack the engineering capability and design elements required to support such systems.

It is reported that one of the primary goals of sustainable development of towns and cities is to provide safe and sufficient food for urban populations. The fact that approximately eight million people go hungry every day, that 12.9 percent of people in the third world are undernourished, that one in every six children in the developing world is underweight, and that poor nutrition accounts for 45 percent of child mortality (World Food Programme) forces us to consider ways to ensure food security for (Zeeuw & Drechsel, 2015). Through the various types of urban farming highlighted, urban farming can significantly contribute to the needs of urban residents without jeopardizing urban ecosystems.

2.16 Significance of Urban Farming

Many cities throughout the world have championed urban farming as a solution to a variety of concerns, ranging from food poverty in urban areas to jobs and ecological sustainability. Urban farming is now seen as a long-term solution to food security and environmental sustainability (Othman et al., 2019). The value of urban vegetation as "natural capital" is obvious, and its significance in delivering heat stress reduction at the neighbourhood scale

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is commonly acknowledged (Kapaniaris & Varvounis, 2019). Many experts have emphasized the potential of urban farming. Veehuizen, (2006), categorized the benefits into four, including environmental management, economic dependence, social improvement, and health and nutrition. Similarly, it reduces the cost of household expenditure and Improves landscape, food supply, and community engagement. While, Carolan, (2020) identified six categories of benefits from urban food production: improved food access, improved health, increased income, increased skills, improved community development, and combating structural imbalances. Urban farming is also viewed as a viable means of increasing green areas, vegetative fields, and gardens for leisure and urban rejuvenation purposes.

It is an approach in the form of "shifting cultivation" by generating new open spaces from largely unused land. By managing the landscapes, it will improve and preserve the ecological balance and environment of the city (Mohd et al., 2019). For people of all income levels, urban farming is an easy-in, easy-out entrepreneurial venture. It gives good access to food for the impoverished. It provides a source of income as well as low-cost, high-quality food for the steady poor. It allows middle-income families to save money and get a return on their investment in urban real estate. It is a profitable enterprise for both small and large business owners. (Muhammad et al., 2020). It cannot be overemphasized that urban farming is an important strategy for ensuring the long-term viability of cities.

As earlier mentioned, towns and cities are now home to at least 55 percent of the world's population, and 80 percent of all food produced globally is earmarked for urban

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consumers. Food management programs in urban and peri-urban areas would have a tremendous impact on social, economic, and sustainable development, as well as the development of urban health and nutrition. Ibharim and Salim,(2020) reported that, while cities are plagued with environmental concerns, it is critical to make the urban environment robust, sustainable, and comfortable to live in. The ability of the city system to safeguard social and ecological services, such as providing locations for leisure, clean water and air, and healthy and locally grown crops and vegetables, is fundamental to the city's resilience.

Many experts have classified the advantages or benefits of urban farming into four categories: environmental sustainability, economic independence, human health and healthy diet,(Caputo et al., 2021; Hawes et al., 2021; Pölling et al., 2017; Veehuizen, 2006; Yusoff et al., 2017). Several sources have reported that urban farming is also an investment plan in developed countries to reconnect urban people with nature, enlighten the urban populace on the global environmental challenges, and educate youngsters about environmental sustainability. Furthermore, urban farming is viewed as an excellent means of increasing green areas, vegetation farms, and gardens for recreational purposes as well as urban regeneration. It is a "shifting cultivation" method that involves producing new open spaces from underdeveloped land (Veehuizen, 2006; and Yusoff et al., 2017). Similarly, Yusoff reiterated that, by controlling the land surfaces, the city's ecological integrity and environment will be improved and preserved.

Urban farming has been connected to a variety of health advantages, in addition to its potential for boosting food security among city dwellers. Providing inexpensive access

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to fresh produce, particularly in areas with few grocery stores or supermarkets, may not only encourage people to try new meals but may also help them consume fewer processed foods (Orum & Michelle Glowa, 2017). It is also reported by Caputo et al., (2021) that, in its recent framework for the Urban Food Agenda, FAO stresses the importance of urban farming, primarily for its potential to alleviate food poverty, but it can also be a workable alternative to complex urban issues such as climate change, food shortage, wildlife habitat and ecosystem services, human health, and resource conservation.

Green spaces in cities provide multifaceted benefits that can help to alleviate some of the city's problems. Stormwater conservation, urban heat island effect reduction, food supply, improved air quality, and biodiversity are some of the natural environmental resources they produce. Actively engaging urban inhabitants in urban greenery improves physical and mental health, ameliorates social and economic challenges, and promotes community resilience (Caputo et al., 2021; Hawes et al., 2021). A study in Europe on the success factors of urban farming projects highlighted one of the most significant benefits of vegetation in cities noting that, Increased evapotranspiration given by more vegetated surfaces, produce by different types of urban agricultural activities such as community gardens, roof gardens, home gardens, and aquaculture, can help to reduce heat gains that contribute to the Urban Heat Island effect (Felser, 2019).

In relation to the environmental issue, the major impact of the UA can be summed as lower greenhouse gas emissions, energy efficiency, and, as a result, a lessened influence on global warming. The advent of "farm-to-table" foodstuffs into the urban market reduces

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consumption of goods and services stored and supplied via high-energy-intensive systems. Moreover, localized agricultural production in major cities overcomes the issue of food waste. Today, 30-40% of agricultural production is lost owing to inefficiencies in the delivery, preservation, and supply chain. Finally, several urban communities have been completely restored and revitalized as a result of UA's reuse of vacant, abandoned, or underutilized regions. In terms of social impact, UA meets the expectations (Miccoli et al., 2016).

Furthermore, the benefits of vegetation in urban centers that is attributed to urban agriculture cannot be overemphasized as it can contribute significantly to a city's environmental sustainability. Urban farms and community food gardens, as a type of green infrastructure, can substantially reduce urban heat island effects, ameliorate urban stormwater effects, and reduce the energy inherent in food delivery. Increasing the amount of vegetation in an urban area is one of the more prominent strategies for minimizing UHI via changing a city's heat balance. shelter belt provided by vegetation filters and redistributes the incoming radiation from the sun, as well as diffuses light reflected from neighbouring urban surfaces, that would have otherwise been reflected or re-radiated as heat transfer by urban surfaces. Evapotranspiration functions as a heat sink in vegetated areas, resulting in lower atmospheric and surface temperatures than in city centers devoid of vegetation (Poulsen et al., 2017).

Our cities will find it difficult to become completely self-sufficient; however, as we have seen, they can become greener, fresher, healthier, and more stable as we have

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witnessed. Since the alternative is unthinkable disaster and squalor. Moreover, u Urban agriculture is not a panacea for the problems that urban centers will face in the future, but it is an important part of any programme intended to make those cities more sustainable and improve the lives of urban inhabitants (Miccoli et al., 2016). The advantages of urban agriculture, particularly in terms of ecological and social aspects, have been grossly undervalued. As a result, researchers like Veehuizen, (2006), observed that urban agriculture's contributions to sustainable cities have been exaggerated. Moreover, the study finds that urban agriculture can help many regions, particularly those in the Global South, achieve sustainable development. Climate, landscape, the increasing rate of rapid urbanization, land commodification, and scarcity all influence the course of farming activities (Azunre et al., 2019). As a result, of this Azunre suggests that zoning these areas that are already used for urban agriculture could work in two ways of protecting them while also sustaining urban agriculture. The emphasis is on sustainable agriculture practices, which will protect the ecosystem roles of these land uses to a large extent. The government and city authorities must acquire urban green spaces and ecologically sensitive areas that will be zoned for agricultural purposes by paying the fair compensation to the property owners. This will contribute to addressing the issue of land commodification by local leaders and other landholders (Azunre et al., 2019).

Urban farming has gained popularity worldwide as a potential strategy for microclimate mitigation. As earlier stated, urbanization is a worldwide phenomenon, with the number of global urban dwellers rising from 30% in 1950 to 55% in 2018, and expected to reach 68% by 2050 (X. Li et al., 2022). Despite being the least urbanized continent,

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Africa has one of the world's highest urban development rates. Africa's urban population increased from 28% in 1980 to 43% in 2018, with forecasts of roughly 60% by 2050 (Simwanda et al., 2019). This fast urban growth, especially in Africa, exacerbates the Urban Heat Island (UHI) effect by replacing natural landscapes with impervious surfaces, resulting in higher urban temperatures. In this context, urban agriculture appears to be an important option for UHI reduction. Urban farming, which introduces greenery into densely populated areas, not only cools the climate but also increases urban resilience, making it an important component of sustainable urban development.

Urban Heat Islands is a major concern for cities across the globe, as rising temperatures worsen environmental and health problems. Numerous studies have shown that urban farming may lower surface temperatures and improve air quality, making it an important technique for minimizing the UHI impact. Beyond its environmental benefits, urban farming addresses various concerns, including food security, job creation, and ecological sustainability. Recognized as "natural capital," urban vegetation, a component of urban farming is vital in reducing heat stress at the neighbourhood scale, making urban farming a comprehensive solution for sustainable urban development (Kapaniaris & Varvounis, 2019; Othman et al., 2019).

Further illustrating this point, specific practices within urban farming, such as vertical gardens, have been shown to reduce surrounding temperatures by approximately ±8°C through shading and evapotranspiration (Putri et al., 2015). These gardens not only mitigate the UHI effect but also capture dust, increase oxygen, and reduce noise levels,

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enhancing urban air quality. Similarly, increasing vegetation by just 10% can result in a 0.6K temperature drop, underscoring the critical role of urban farming in regulating urban environments through evapotranspiration (Soytong et al., 2018). Supporting these findings, a UHI mitigation study conducted in Korea reveals the cooling effects of urban farming over three decades. The warmest urban air average temperature was recorded at 35.03°C, yet rice and soybean cultivation reduced this by 10.5°C and 3.0°C, respectively. With evapotranspiration rates of 6.86 and 6.00 mm/day, urban gardens further decreased the urban air average temperature (UAAT) by 2.0°C and building surface temperatures by 14.5°C. These plants also absorbed CO2, released O2, and lowered ozone concentrations, demonstrating urban farming's effectiveness as a UHI mitigation technique (Eom et al., 2012).

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Various urban farming systems have shown substantial promise in mitigating the Urban Heat Island impact. Block et al., (2012) highlighted that 'Vertical Green Systems (VGS) as a component of urban farming are vital for mitigating the Urban Heat Island effect, especially in climates prioritizing cooling and energy efficiency. In Mediterranean and arid regions, VGS can significantly lower surface temperatures, providing both environmental and economic benefits. Expanding VGS in cities like those in Australia could enhance urban sustainability by improving energy efficiency and reducing reliance on artificial cooling.

Sartina et al., (2023) further support this by showing that integrating green roofs and walls in high-rise buildings in Makassar City can enhance comfort and lower

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temperatures by 1.05–2.2℃. Urban farming methods, including the use of organic plants and green spaces, play a crucial role in reducing surface temperatures through shading and evapotranspiration. Additionally, incorporating pedestrian lanes and green open spaces can further mitigate UHI effects by reducing CO^2 emissions and heat absorption.

Humaida et al., (2023) found that urban gardening, such as vertical and rooftop gardens, effectively mitigates UHI by lowering surface temperatures through shading and evapotranspiration. This type of urban farming not only reduces energy consumption for cooling but also improves air quality and contributes to a healthier urban climate. Similarly, Albadal & Ali, (2022) emphasize that vertical farms and the strategic selection of specific plants, like leafy greens and herbs, enhance UHI mitigation by improving air quality, reducing resource consumption, and offering flexibility in market adaptation.

Complementing these findings, Athukorala & Murayama, (2020) discovered that trees and forested areas in Accra significantly reduce the UHI effect. Their study revealed that mean Land Surface Temperature (LST) dropped considerably in areas with natural environments, such as the Densu Delta and Achimota Forest. Vegetation in these areas produced an albedo 15% higher than built-up surfaces, which reduces heat absorption and increases reflective longwave radiation, resulting in a cooler urban environment. These results underline the importance of integrating green areas and urban farming into city planning to effectively manage UHI and enhance urban resilience.

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As the global population urbanizes, urban farming will continue to play avital role in creating sustainable, resilient cities. Thus, it is important to recognize the potentials of urban farming and indeed urban green infrastructure in general, as they go a long way in trying to mitigate the numerous challenges faced by urban inhabitants and the environment. However, it's also crucial to stress that the focus of this study is on the environmental benefits of urban greenery provided by the different forms of urban farming practice, which can help reduce the rising temperature in our cities and towns and make them liveable for the long-term sustainability of the environment and humanity.

2.17 The Imperative of Urban Farming in Maiduguri

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Urban farming, a method gaining popularity in the twenty-first century, is consistent with modern urban planning ideas, sustainable development goals, and technological advancements. However, its origins trace back thousands of years, with archaeological evidence attributing agricultural skills to Asia and Africa circa 10-5 thousand years BC. As populations swelled and groups gathered in urban centres, agriculture became critical to the survival of these early cities, which were frequently built on cultivated agricultural lands. The history of urban agriculture demonstrates its continued importance in supporting the urban populace and promoting community sustainability (Dobele & Zvirbule, 2020). Furthermore, early civilizations such as the Iranians and Babylonians pioneered novel kinds of urban farming, such as rooftop gardens and hanging gardens, emphasizing the

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practice's historical roots (Albadal & Ali, 2022; Jamal & Mortez, 2014; Y. Liu, 2019; Martin-Moreau & Ménascé (dir.), 2019; Solankey, 2020; Sullivan et al., 2019).

Urban farming has grown in popularity in the twenty-first century because it is consistent with current urban planning ideas, sustainable development goals, and technological developments. However, the link between urban and agricultural traditions dates back thousands of years. The evidence from archaeology reveals that agricultural techniques began in Asia and Africa as early as 10-5 thousand years BC before reaching Europe via the Arabian Peninsula. As populations surged and groups gathered in social hubs, the first cities arose, frequently built on cultivated agricultural grounds. Access to food was critical in the establishment and expansion of these cities, leading citizens to practice agriculture in urban areas to support themselves and for the sustainability of their communities (Dobele & Zvirbule, 2020).

The urgency and necessity of urban farming in response to the challenges the city's residents face amidst conflict, displacement, and environmental challenges cannot be overemphasized. In Maiduguri, the imperatives of urban farming are starkly evident amidst the ongoing insurgency and its resultant displacement of populations (Awodola & Oboshi, 2015). With people forced to seek safety in the city, leaving behind their rural livelihoods, urban farming emerges as a choice and a necessity for survival. Bisoka et al., (2021) over the past two decades, Maiduguri "has faced increasing security, capacity, and legitimacy gaps, evidenced in the deteriorating capacity of its government to deliver public services, including security, transportation, pipe borne water, health services, electricity, and

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education". Since 2009, 2.1 million people have been relocated to Borno State owing to Boko Haram threats, with hundreds of thousands seeking safety in Maiduguri and its neighbouring camps. Maiduguri has borne the brunt of the conflict's humanitarian burden, hosting over 800,000 internally displaced persons (IDPs) at its peak, with more than 88% living outside of camps. Furthermore, Mohammed and Babagana, (2019) reiterates that the Boko Haram insurgency has brought about considerable damage, with the loss of over 20,000 lives, the displacement of over 1 million people, and the destruction of property valued at $5.9 billion.

Local and international non-governmental organizations (NGOs) have played an important role in supporting IDPs in Nigeria's northeast. The United Nations World Food Programme (WFP) offered improved seeds and farming supplies to help one million returning IDPs rebuild their settlements throughout the cropping season. In addition, the Food and Agricultural Organisation (FAO), International Fund for Agricultural Development (IFAD), and OXFAM, with assistance from the Japanese government, committed $1.5 million to boost food distribution and agricultural inputs for IDPs. While this initiative primarily supports traditional agriculture practices to rebuild communities and improve food security, it indirectly promotes urban farming because much of the support is directed towards the state capital, where urban farming initiatives may benefit from increased agricultural productivity (Modu et al., 2023).

As agriculture forms the backbone of the state's economy and the primary occupation of many residents, the inability to venture beyond the city limits due to security

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concerns amplifies the importance of urban farming (Mohammed & Babagana, 2019). In the face of relentless violence and displacement, urban farming offers a lifeline for the urban populace and internally displaced people (IDPs), enabling them to secure sustenance and contribute to microclimate regulation. Maiduguri's reputation for persistent high temperatures underscores the significance of initiatives that can alleviate urban heat and enhance environmental resilience. For the impoverished urban dwellers grappling with the harsh realities of life, the paramount concern is putting food on the table. In this context, urban farming emerges as not just a viable venture but a critical imperative for ensuring the sustenance of the urban populace and the preservation of the environment. In summary, urban farming in Maiduguri is not merely a response to crisis but a fundamental strategy for resilience, sustainability, and the preservation of livelihoods amidst adversity. Similarly, the study was undertaken by Mustapha and Undiandeye, (2012) on the assessment of the perception of benefits of organic gardening in Maiduguri Metropolis emphasizes the importance of urban farming practices. Their study emphasizes the ecological benefits of organic agriculture in urban areas such as Maiduguri. Organic gardening promotes biodiversity, soil health, and ecosystem balance, which helps to ensure environmental sustainability and resilience in urban areas. This emphasizes the critical role of urban farming in solving food security issues while also promoting environmental well-being.

Urban farming has great potential for minimizing the environmental challenges in cities, notably the urban heat island effect. Urban farming contributes significantly to the creation of more sustainable urban settings by lowering air pollution, increasing biodiversity, and encouraging the conservation of natural resources. Furthermore, farming

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in urban areas is a sustainable land-use paradigm that strengthens urban food systems while providing critical benefits to city ecosystems. According to research, urban gardens, agricultural areas, and green spaces may efficiently reduce solar radiation, enhance evaporation, and lower temperatures through mechanisms such as evapotranspiration and shade (Turker et al., 2022). As a result, embracing urban farming techniques is critical for reducing the urban heat island effect and fostering stronger, more sustainable communities and towns.

Growing crops in cities is critical to reducing the urban heat island, which is worsened by climate change and urbanization. The UHI phenomenon, which is characterized by greater temperatures in urban regions than in surrounding areas, has an impact on cities' energy balance and thermal climate. Understanding this challenge, farming in urban areas emerged as an alternative, providing ecosystem-supporting services, including Urban Heat Island mitigation. Furthermore, Ebissa et al., (2023) studies have shown that urban farming has significantly contributed to urban environmental sustainability by reducing greenhouse gas emissions, regulating floods, increasing biodiversity, boosting agrotourism, and developing technology to address urban land allocation difficulties. Therefore, urban agriculture is an effective method for creating cooler and more sustainable urban settings in the face of climate change and rising urbanization, as well as solving critical urban environmental sustainability challenges.

According to Califano et al., (2024), urban farming promotes organic waste materials and composted food waste, which influences environmental quality due to

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changed urban-vegetation-atmosphere interactions. In the words of Grebitus et al., (2020), this technique has various benefits, including improved sustainability and local ecosystems, increased food security, and the promotion of better diets. However, it encounters difficulties such as land dependence, weather sensitivity, and possible inefficiency when compared to more technologically sophisticated approaches. Poulsen et al., (2017) Furthermore, emphasize that urban agriculture can produce revenue since it operates on a communal and commercial scale.

Vertical farming a smart form of Urban agriculture effectively manages societal, environmental, and economic concerns related to food security by maintaining regulated and ideal growth conditions such as temperature, humidity, CO^2, and lighting. This technique promotes green spaces and vegetation within urban areas, resulting in shorter growth cycles, more plant density, and higher harvest yields, all of which help to mitigate the urban heat island impact. Furthermore, urban agriculture decreases the need to transport, distribute, and store food crops, saving energy costs and decreasing the carbon footprint associated with food production.

As a result, urban agriculture makes considerable contributions to UHI mitigation efforts (Oh & Lu, 2023). Similarly, According to Mohajerani et al. (2017), green roofs and green walls, both forms of urban agriculture, are effective techniques for minimizing the urban heat island impact. As opposed to reflecting surplus energy from pavements into buildings, these green infrastructure features absorb it, which helps decrease the heat island effect in cities.

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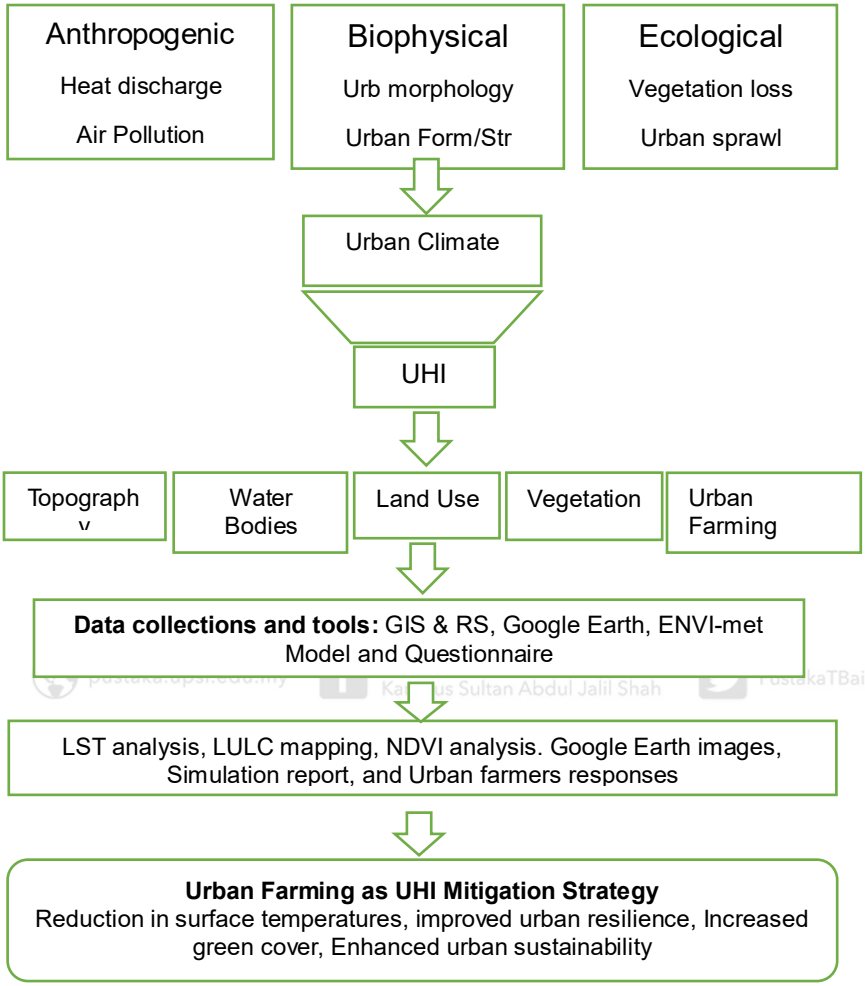
Urban farming in Maiduguri appears as an imperative response to the city's multifaceted challenges, which include violence, displacement, and environmental concerns. It emerges as a vital approach for resilience and sustainability in the face of adversity, particularly given the continuous insurgency and humanitarian crises. Furthermore, the potential of urban farming to ameliorate environmental concerns like as the urban heat island effect demonstrates how crucial it is in meeting Maiduguri's multifaceted demands.

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Figure 2. 3

Conceptual Framework for UHI Mitigation Using Urban Farming Potentials



The conceptual framework presented in figure 2.3 explains the concepts that underlay the study and set the bases for exploring the study. Rapid urbanization in Maiduguri has led to the replacement of natural landscapes with impervious surfaces such as asphalt and concrete. This transformation contributes to the Urban Heat Island phenomenon, where urban areas exhibit higher temperatures than their rural surroundings. Factors such as

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vegetation loss, increased anthropogenic heat emissions, and the use of low-reflectivity building materials exacerbate this effect, impacting urban dwellers' health and comfort.

Urban farming presents a viable strategy to mitigate UHI effects by enhancing green cover through practices like home gardens, vacant lot cultivation, community gardens, and riverbank farming. These activities promote natural cooling processes such as evapotranspiration and shading, thereby reducing land surface temperatures. Additionally, urban farming offers co-benefits including food security, improved air quality, and enhanced urban aesthetics.

This study employs a quantitative approach, utilizing structured questionnaires to gather data on urban farming practices and residents' perceptions. To assess spatial and temporal variations in land surface temperatures, Landsat 4, 7, and 8 satellite imagery from 1992 to 2022 will be analyzed. Key indices such as Land Surface Temperature (LST), Land Use/Land Cover (LULC), and Normalized Difference Vegetation Index (NDVI) will be derived to examine the relationship between urban farming and UHI mitigation. Geographic Information Systems (GIS) will facilitate the visualization and analysis of spatial data, enabling the identification of UHI hotspots and evaluation of urban farming's effectiveness in mitigating heat accumulation. This approach sets a solid foundation for exploring urban farming as a mitigation strategy, aiming to enhance vegetation cover and reduce urban temperatures through natural cooling mechanisms.

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2.18 Summary

In this Chapter, relevant literature is thoroughly examined to provide a thorough understanding of the gaps, methods, and current state of knowledge in the field of UHI research. To develop effective urban heat mitigation strategies, it is important to consider the unique characteristics of semi-arid regions when analyzing previous studies, methodologies, and findings regarding UHI phenomena. This critical review does just that. This review looks at how urban farming and UHI mitigation strategies interact to shed light on novel approaches that take advantage of the synergies between sustainable land use and green infrastructure. Building on this strong basis, the following chapters will make use of advanced techniques such as the ENVI-met simulation tool to carefully examine microclimates, evaluate the success of urban farming projects, and provide informed suggestions for promoting sustainable urban development in Maiduguri. Through the integration of theoretical insights obtained from the literature review, empirical data, and advanced modelling techniques, this study aims to provide policymakers, urban planners, and community stakeholders with relevant and useful information. The primary goal of this research initiative is to go beyond academic discourse and offer useful interventions and policies meant to support the development of a resilient and climate-aware urban environment in Maiduguri. By means of interdisciplinary cooperation and thorough investigation, this study aims to address the complex issues raised by urban heat islands and promote sustainable development strategies that improve the living conditions of urban inhabitants while strengthening the resilience of the surrounding ecosystem.

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CHAPTER 3

METHODOLOGY

3.1 Introduction

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This chapter explains generally the study area where the research is to be undertaken, it discusses all the approaches, procedures, and methods or strategies used in gathering and analyzing the data for the study. study area location, size, and population. Furthermore, all the methods to be used for this research are explicitly discussed. Research design strategy, sample size for finite population, sample frame and size, sample settlement and sample size, sampling, instrument for the collection of data, also the methods and procedure for the analysis of data are equally discussed in this part.

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3.2 Historical Background of the Study Area

The birth of Kanem-Borno as a territory with growing state-like structures is still debated among historians due to the difficulty of deciphering king lists, which are regarded as a key source for the state's early decades. The date and circumstances of the first kings coming to the throne are yet unknown. Some academics believe that the original kings of Kanem-Borno rose to power during the late sixth and early seventh centuries. This chronology is based on an examination that considers a variety of written sources as well as king lists, illustrating the difficulties in precisely defining the region's early history (Magnavita et al., 2019).

The history of Borno is deeply rooted in sixth-century Kanem, demonstrating a continuous progression of government and territorial organization under the Sayfawa dynasty. This dynasty established a territorial framework known as *chima chidibe*, which paved the way for the administrative organization (Hiribarren, 2017). The history of Islamic Borno began in the 14th century when the Sefuwa dynasty established itself on the banks of Lake Chad in modern-day Nigeria. By the 1470s, the Sefuwa sultans had constructed their capital in Birni N'gazargamu. For the next two centuries, the Borno Sultanate ruled the Sahel, influencing Kanem, Bagirmi, and the Hausa States. Borno, positioned at a strategic turning point, thrived economically as a major salt producer in the trans-Saharan slave trade. Following the Fulani jihad, El-Kanemi rose to power without dramatically modifying the geographical organization established by the Sayfawa dynasty. Instead, he deliberately merged his loyalists into existing geographical fiefs, maintaining

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stability and coherence within the kingdom while strengthening his power (Dewière, 2021; Hiribarren, 2017).

Kanem-Borno was a major and long-lasting pre-colonial empire in Sub-Saharan Africa, with a history spanning from the 8th to the 19th century AD. Located around Lake Chad, its strategic position at the southern end of the principal trans-Saharan route allowed it to engage in Arab-driven trade between Islamic North Africa and the Bilad al-Sudan, emphasizing its importance in international trade and cultural interchange (Dewière, 2021).

During the reign of Mai Ali Ghaji from 1473 to 1501, a significant migration took place with the creation of the new capital of N'gazargamu. This migration was important in Kanem-Borno history as it marked a shift in the empire's centre of political and administrative authority (Akah, 2021). Kanem-Borno's impact extended to the growth of urbanization in the northeast. The empire's capital towns, including Njimi, N'gazargamu, Kukawa, Dikwa, and Maiduguri, represent the historical evolution of early urban centers. These towns mark major milestones in the region's history, demonstrating how Kanem-Borno's mighty empires fuelled the establishment of large communities and urban development (Akah, 2021).

Borno's presence has been perceived and documented throughout European history. According to Hiribarren (2012), Borno first appeared on European maps in the 16th century. These maps were developed in Europe, demonstrating how European cartographers recognized and documented the empire. Kukawa and Maiduguri are two

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municipalities in Nigeria's northeast with a history connected to the Kanem-Borno Empire. Sheikh Muhammed El-Amin El-Kanemi established Kukawa in 1814, and it served as Kanem-Borno's capital until 1893. Kukawa thrived due to the wealth of pre-colonial Borno's broader economy and its feudal society. Maiduguri emerged as the political and administrative capital of the 20th century after British colonization in 1902 (Ladan, 2018).

In 1893, Rabiḥ b. Faḍl Allah, a Sudanese adventurer, invaded Borno and proclaimed Dikwa his capital. Rabiḥ was slain by the French seven years later, leading to the division of Borno between the British and German empires until 1914 (Dewière, 2021). This division was part of a larger European colonization attempt that resulted in considerable changes to the Kanem-Borno Empire. The British seized control of much of Borno west of Lake Chad, the French took over the territory north of the river Yobe, and the Germans controlled areas around the river Yedzaram. Following Germany's defeat in World War I (1914-1918), the German-held sector of Borno was transferred to British trusteeship. These reforms were an important turning point in the region's political history, having far-reaching implications for the empire's future (Waziri, 2009).

Under British indirect authority, Maiduguri evolved slowly and remained primarily traditional. However, substantial changes happened with the formation of states under the Federal in 1968, with Maiduguri designated as the state capital. This transition resulted in significant expansion and development in the town (Jimme et al., 2019) Concurrently, the area saw significant changes as a result of European expansionism in the first decades of the twentieth century. During colonial administration, Ancient Borno was partitioned

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among Nigeria, Niger, Chad, and the Republic of Cameroon. In 1907, Maiduguri served as the capital of the British-established province in northern Nigeria. Borno gradually got absorbed into the North Eastern state after its creation in 1967. However, a section was eventually cut off in 1991 to establish the current Yobe state. (Waziri, 2009).

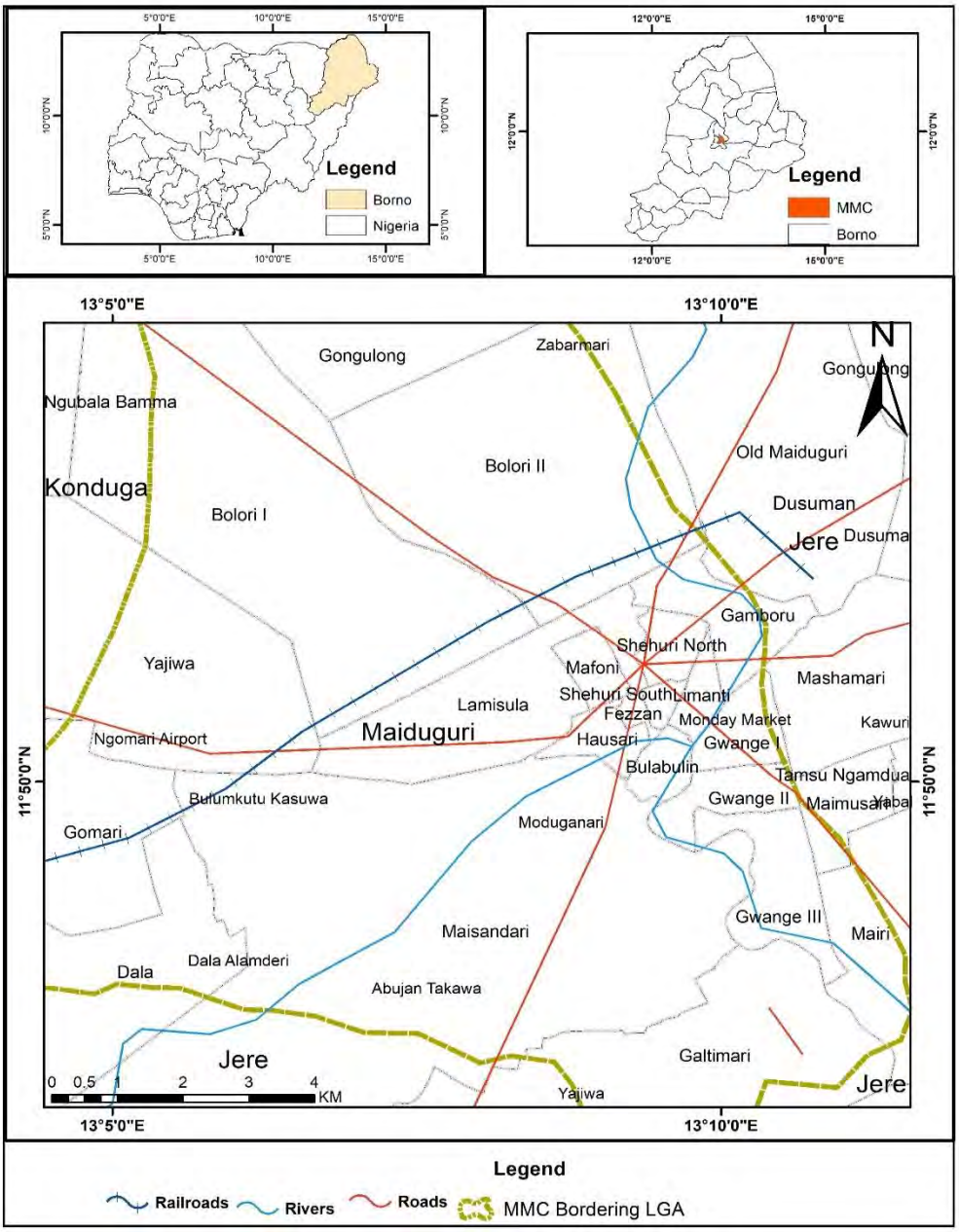
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3.2.1 Study Area Location

Figure 3.1

Map of Borno State showing Maiduguri and its environs.



Source – GEONET Cast Unit, Department of Geography, University of Maiduguri, 2021

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Borno State is located in the extreme northeastern corner of Nigeria, sharing internal boundaries with three Nigerian states Adamawa to the south, Gombe to the southwest, and Yobe to the west. It also shares international borders with three countries: the Republic of Niger to the north, Chad to the northeast, and Cameroon to the east, as clearly illustrated in Figure 3.1 (Friday Nkwocha et al., 2020). Highlighting key features such as rivers, roads, and railways, along with administrative boundaries of the Maiduguri Metropolitan Council (MMC) and Jere LGA. The rivers, shown in blue, indicate natural drainage paths that influence local microclimates and support agricultural activities. The road network (in red) connects major urban and peri-urban communities, while the existing railway line offers potential for regional connectivity. The map also identifies key settlements, including densely populated urban areas like Shehuri, Gwange, and Fezzan, as well as peri-urban farming areas like Gongulong and Dusuman, which are relevant to urban heat and land use studies.

As an ancient city-state, it existed for more than a century in the name of the Kanem-Borno Empire and was recognized as one of the largest surviving kingdoms in recorded history, (Waziri, 2009, 2012). Maiduguri, the area under investigation is the Borno state capital, located in the semi-arid North-eastern region of Nigeria. It falls within latitudes 11˚04'N and 11˚44'N, and between longitudes 13˚04'E and 13˚44'E covering an area of 543km^2. This urban centre is shared by four local government areas: Maiduguri Metropolitan Council, Jere, Konduga, and to a smaller extent Mafa Local Government Area, (Abubakar Biu et al., 2020; Waziri, 2009).

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The Borno State Urban Planning and Development law (2001) defines Maiduguri as the state capital including the Maiduguri Metropolitan Council (MMC) and parts of Jere Local Government. It also includes parts of the Konduga, Magumeri, and parts of Mafa Local Government Areas (Kaka et al., 2019; Waziri, 2012). The jurisdiction is defined as areas encompassing a 25-kilometer radius of the Shehu's Palace. This legal framework defines the precise boundaries along with the administrative scope for Maiduguri's urban planning and development (Waziri, 2012).

Maiduguri City was founded during the reign of the former Kanem Borno Empire. According to Sambo & Ikusemoran, (2022), British colonialists orchestrated the city's establishment, designating it as the newly established capital of the old Kanem Borno Empire. The birth of Maiduguri began on January 7, 1907, during the era of the then-Shehu Abubakar Garbai El-Kanemi received advice from British colonial government officials to relocate to a new location, Marking off the city's formation. Similarly, Mukhtar et al., (2015) attribute the birth of Maiduguri to Rabeh's demise. According to their findings, following the ousting of the tyrant ruler Rabeh, the British Colonialist Lord Lugard planned and executed the relocation of Kanem Borno's capital from Dikwa to the present-day capital Maiduguri, establishing it as the new administrative centre.

According to a report by Olanrewaju et al., (2019), Nigeria is the most populous country in Africa, with a population of over two hundred million. The study's focal point, Maiduguri, is one of Nigeria's most populous urban centres, and it shares this demographic prominence. As a result of its location in a hot, semi-arid area, Maiduguri perfectly captures

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the dynamics and challenges that come with a dense population under such circumstances under these harsh climatic realities. Additionally, Maiduguri's geographical setting is characterised by a generally level terrain with a gentle slope towards Lake Chad and an average relief feature that is between 300 and 600 metres above sea level. Seasonal rivers primarily form Maiduguri's drainage system; significant peak flows are recorded in the rainy season, which usually falls in July and August. This topographical overview broadens our understanding of Maiduguri's landscape by providing information on the area's elevation, drainage patterns, and seasonal dynamics that affect water flow (Jimme et al., 2016).

According to the Nigerian Meteorological Agency, NiMet, (2022), the study area is known for its extreme temperatures, which can reach as high as 45°C in the summer. For city dwellers exposed to such conditions, this elevated temperature presents a serious health risk. A thorough assessment of the complex interactions between the region's urban microclimates, terrain, and land surface temperature is necessary in order to address this challenge. The study intends to shed light on the significant effects of rising temperatures on the urban environment by comprehending these dynamics. The ultimate objective is to determine, recommend, and put into action efficient mitigating strategies that will protect urban residents' health and build their capacities to withstand rising urban temperatures.

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3.2.2 Growth and Development of Borno State North-East Nigeria

Maiduguri, the capital of Borno State in Nigeria, was established in 1907 on the recommendation of British colonialists to function as a new administrative centre for the ruins of the Kanem-Borno Empire (Mukhtar et al., 2015). The town's foundation, led by Shehu Abubakar Garbai El Kanemi, represented a crucial turning point in the region's history, representing both continuity with the empire's legacy and the start of a new era under colonial administration. Maiduguri has grown and transformed rapidly over the years, becoming a bustling metropolitan centre with expanding physical limits, a growing population, and shifting land use patterns that reflect the city's role as a regional hub in northeast Nigeria (Mukhtar et al., 2015; Waziri, 2012).

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Maiduguri, Borno State's capital, has a long history of significant developments. Originally divided into two different sections, Yerwa and Old Maiduguri, the city's growth was impacted by both colonial and traditional causes. During the British colonial period, Old Maiduguri functioned as the military headquarters, demonstrating the city's strategic significance (Waziri, 2012). Concurrently, under the rule of Borno's Shehu Abubakar Garbai, Yerwa emerged as the Kanuri people's new traditional capital, displacing Kukawa. This dual designation emphasizes Maiduguri's significance as an administrative and cultural powerhouse. Over time, the confluence of official activities and traditional practices aided the city's expansion and development (Abubakar, 2017). Today, Maiduguri is a thriving metropolitan centre that combines contemporary infrastructure with rich cultural traditions, demonstrating its dynamic past and ongoing progress. Furthermore,

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Waziri reiterates that the Shehu named his new domain "Herwa (Yerwa)," aiming to stress its importance as the "centre of prosperity" in Kanuri, expressing his vision for its future expansion and development. This choice was taken although other smaller communities were nearby, notably Maiduguri, which dates back to the early seventeenth century. Colonial authorities picked Maiduguri as Borno's new capital despite its historical significance. The former Maiduguri and Yerwa have practically combined to become one city (Waziri, 2012).

Maiduguri, the capital of Borno State in Nigeria, has seen tremendous urban expansion and transformation in recent years. Observers have seen quick changes in various areas, including their physical size, human population, land use patterns, and governmental organization. These modifications point to a changed spatial topography inside the metropolis (Ceesay, 2019; Hiribarren, 2017; Waziri, 2012). Over time, the metropolis has experienced tremendous development, as shown by landmarks such as the laying down of its first asphalt road in 1947. This growth has driven the city to its current impressive size, indicating its progress toward modernity (Waziri, 2009, 2012).

The state now has 27 local government units plus the state capital, for a total of 28, as well as eight emirates, each ruled over by a traditional monarch known as the Amir, highlighting its varied makeup. Maiduguri, the state capital, and Jere, Mafa, Konduga, and Magumeri, constitute the study area. Furthermore, the state is divided into three senatorial districts: Borno Central, South, and Northern, each represented by a senator in the upper chamber of the federal National Assembly or legislature (Waziri 2009). Moreover, the state

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has a diverse ethnic population, with Nilo-Chadic languages such as Kanuri, Shuwa, Babur Bura, Marghi, and Mandara being the most common, as well as many others such as Afkabe, Azahvana, Bade, Buduma, Chibok (Kibaku), Dera, Fulfulde, Glafda, Guduf, Hausa, Jara, Kanuri, Kare-Kare, Kotoko, Mafa, Marghi, Ngizim, Pithimdi, Waha, and Waja, as well as notable tongues such as Hausa. This variety encompasses a broad cultural spectrum, highlighting distinct customs, viewpoints, and histories within its borders. Such richness supports a vibrant and diversified society, providing numerous possibilities for research and appreciation of its diverse past. Despite many state creations in Nigeria that resulted in adjustments to the boundaries and sizes of many states, Maiduguri kept its status as Borno State's capital. These states were established in 1967, 1976, and 1987, resulting in the formation of 19, 21, and 36 states, respectively (Ehinomen, 2019; Eze et al., 2015).

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3.2.3 Size and population

Maiduguri, Nigeria's capital, holds special significance for being the largest city in the northern part of the country and the region's oldest settlement (Abba & Abbas, 2009; Bisoka et al., 2021; Jimme et al., 2016). Despite the absence of precise population data, the city's population is believed to be between 1 and 5 million, representing significant growth caused by both natural rise and the influx of displaced people across the state as a result of the ongoing conflict (Bisoka et al., 2021). This demographic increase has surpassed the city's development strategy, posing significant issues for urban planning and the development of infrastructure.

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3.2.4 Weather and Climate

The average monthly temperature in the area is constantly above 20°C, indicating consistently warm weather. On the other hand, the range of the daily temperature extremes is quite wide and varies significantly. April, for example, can see highs of up to 47°C, illustrating the wide range of daily temperature variations in the region (Friday Nkwocha et al., 2020; Jimme et al., 2016). This region tends to have high nighttime temperatures, which results in warm nighttime conditions. But these temperatures drop in the early hours of the morning, suggesting a cooling pattern as night draws in towards daybreak. This pattern indicates a change in temperature through the night, with a significant decrease in temperature in the early hours of the day, which influences the local temperature dynamics (Jimme et al., 2016). Similarly, this is affirmed by Wakil et al., (2020) reiterating that, for the most part of the year, the area's climate is dry and hot. This implies that the region endures extended spells of low precipitation and high temperatures, resulting in an arid and warm climate for a significant portion of the year.

Locally, the region's indigenous people historically distinguish four seasons: *Binim*, the cool dry season that lasts from December to February; Harmattan, characterised by dry, dusty winds originating in the Sahara from December to February; (Mala, 2023; Waziri, 2009) However some scholars like Bakari, (2014b) argued that the Harmattan extends up to march. *Bey*, is defined by the hot dry season that lasts from March to late May; *Neng3ri*, the rainy season that lasts from June up to September; and *Beila*, is dominated by a humid dry transition period that lasts from September to November. However, due to recent

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modifications in the climate, the timing of each of these seasons is not fixed, demonstrating the resilience of the indigenous cultural traditions to changing conditions in the environment. Seasonal fluidity reflects a consciousness of climate variations and emphasises the adaptability inherent in the region's traditional season classification (Waziri, 2009).

Two major atmospheric systems influence the climate in the region, the North East trade winds originating in the Sahara Desert and the South West monsoons originating from the Atlantic Ocean, respectively. These atmospheric systems are both playing important roles in shaping the region's climate dynamics. They influence the overall meteorological conditions in the area, which include rainfall, temperature, and wind patterns (Jimme et al., 2016).

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Long-term patterns of temperature are vital for understanding the dynamics of urban heat and the increased intensity of the Urban Heat Island (UHI) effect in rapidly rising cities like Maiduguri. Rising land surface temperatures have emerged as a crucial indication of urban environmental change during the last three decades (1992-2022), owing to rapid urbanization, land cover shifts, and population expansion. Temperature data from the Nigerian Meteorological Agency (NiMet) provide a solid foundation for analyzing the spatial and temporal development of heat intensity across diverse wards. The table 3.1 shows average temperatures in Maiduguri over three decades, with fluctuations that help contextualize the amount and spread of UHI impacts inside the municipality.

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The temperature data for Maiduguri from 1992 to 2022 demonstrates a steady rising trend, consistent with the features of Urban Heat Island development. The citywide average temperature grew from 30.68°C in 1992-2002 to 31.01°C in 2002-2012, and then to 31.69°C in 2012-2022, for an overall average of 31.13°C over three decades, presented in the table below. This consistent rise highlights the long-term impact of urbanization, land cover change, and population growth, all of which are known drivers to rising land surface temperatures in rapidly emerging urban areas such as Maiduguri.

Looking at wards-level data, large spatial variances in temperature patterns are visible. Tamsu Ngamdua had the greatest total average temperature (32.03°C), with a significant increase in the recent decade (from 32.00°C to 32.90°C), followed by Gwange I and Mairi, both of which exceeded 31.6°C on average. These high-temperature areas may reflect places with greater urban density, decreasing plant cover, or more impermeable surfaces. In contrast, Galtimari, Gamboru, and Shehuri South had considerably lower average temperatures, ranging around or below 30.4°C, likely due to lower construction densities or the preservation of open spaces. However, even these places showed gradual warming, indicating a citywide susceptibility to rising temperatures.

The data available show a clear pattern, Maiduguri's heat intensity is growing, both temporally and spatially. The highest temperature increases between 2002 and 2022 were observed in wards such as Gwange I, Limanti, and Bolori II, indicating exacerbated UHI effects caused by land-use changes and urban sprawl. These data are critical for guiding climate-responsive planning.

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Table 3.1

Spatial and Temporal Distribution of Average Temperatures in Maiduguri (1992–2022)

Location	1992–2002	2002–2012	2012–2022	Average (1992–2022)
Bolori I	30.92	31.84	31.32	31.36
Bolori II	30.32	31.39	33.20	31.64
Bulabulin	30.34	31.23	31.34	30.97
Dusuman	29.80	31.20	31.50	30.83
Fezzan	30.93	31.03	31.65	31.20
Galtimari	29.93	30.20	31.00	30.38
Gamboru	29.88	30.23	30.23	30.11
Gomari	31.20	32.10	31.90	31.73
Gongulong	30.10	30.30	32.30	30.90
Gwange I	30.87	31.43	33.40	31.90
Gwange II	30.94	29.43	31.23	30.54
Gwange III	29.95	30.23	31.50	30.56
Hausari	31.54	31.45	31.65	31.55
Lamisula	31.20	30.30	32.10	31.20
Limanti	31.40	31.32	32.34	31.69
Mafoni	30.74	31.45	31.65	31.28
Maisandari	30.75	31.39	31.31	31.15
Mairi	31.20	31.80	32.00	31.67
Old Maiduguri	30.40	31.20	31.80	31.13
Shehuri North	31.43	30.34	30.43	30.73
Shehuri South	29.87	30.34	30.54	30.25
Tamsu Ngamdua	31.20	32.00	32.90	32.03
City Average	30.68	31.01	31.69	31.13

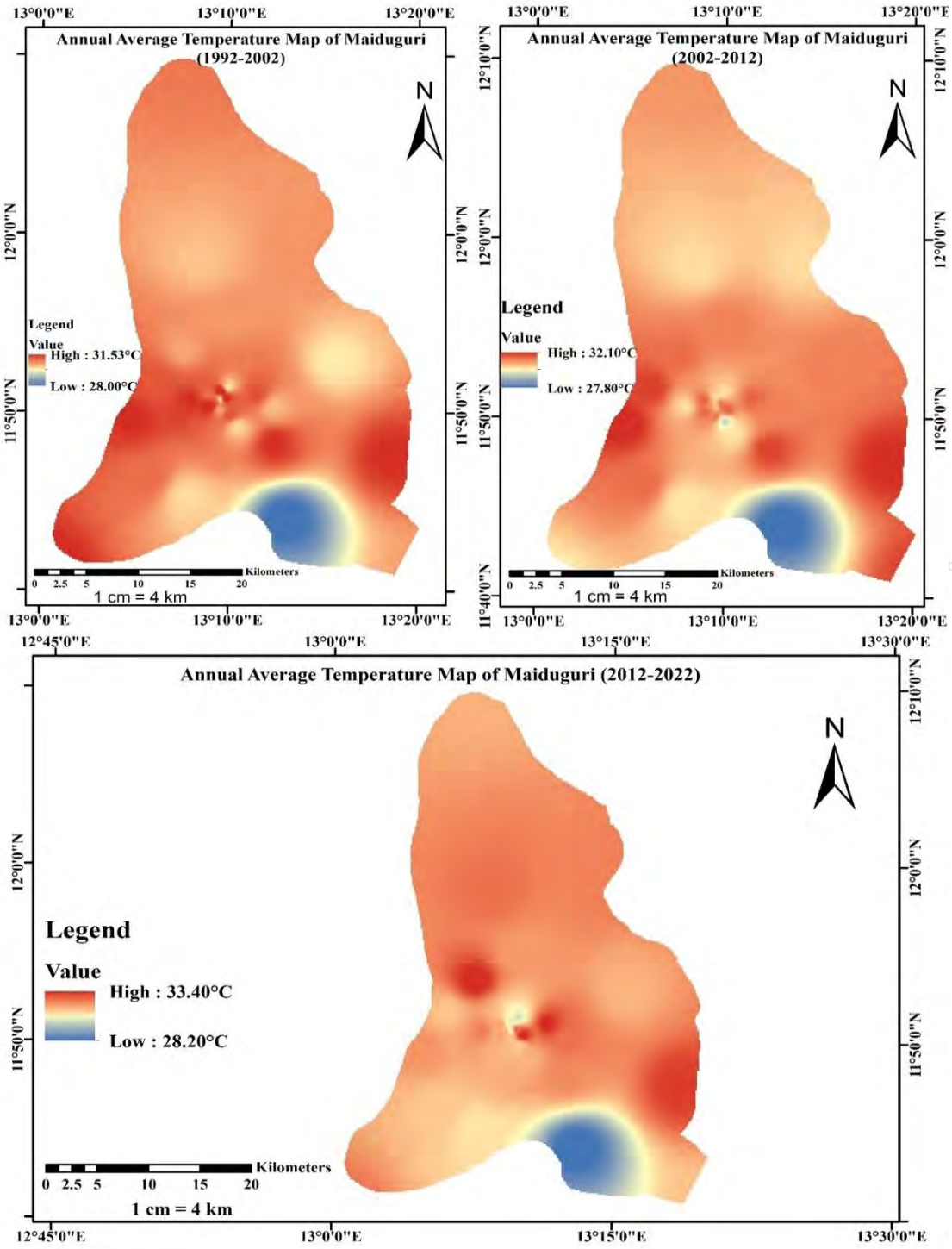
Source: The Nigerian Meteorological Agency (NiMet), Maiduguri Office, 2023.

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Figure 3.2

Annual Average Temperature Map of Maiduguri



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These maps were classed to indicate regional changes in yearly average temperatures, which can help identify emerging UHI zones. The generated temperature maps (shown in Figure 3.2) provide a visual representation of Maiduguri's progressive warming. These spatial trends are consistent with the expansion of impervious surfaces and urban development, and they serve as an important layer of analysis alongside LULC and NDVI data. This procedure ensured that ground-based and remote sensing data were combined to capture long-term climate patterns and their urban heat implications.

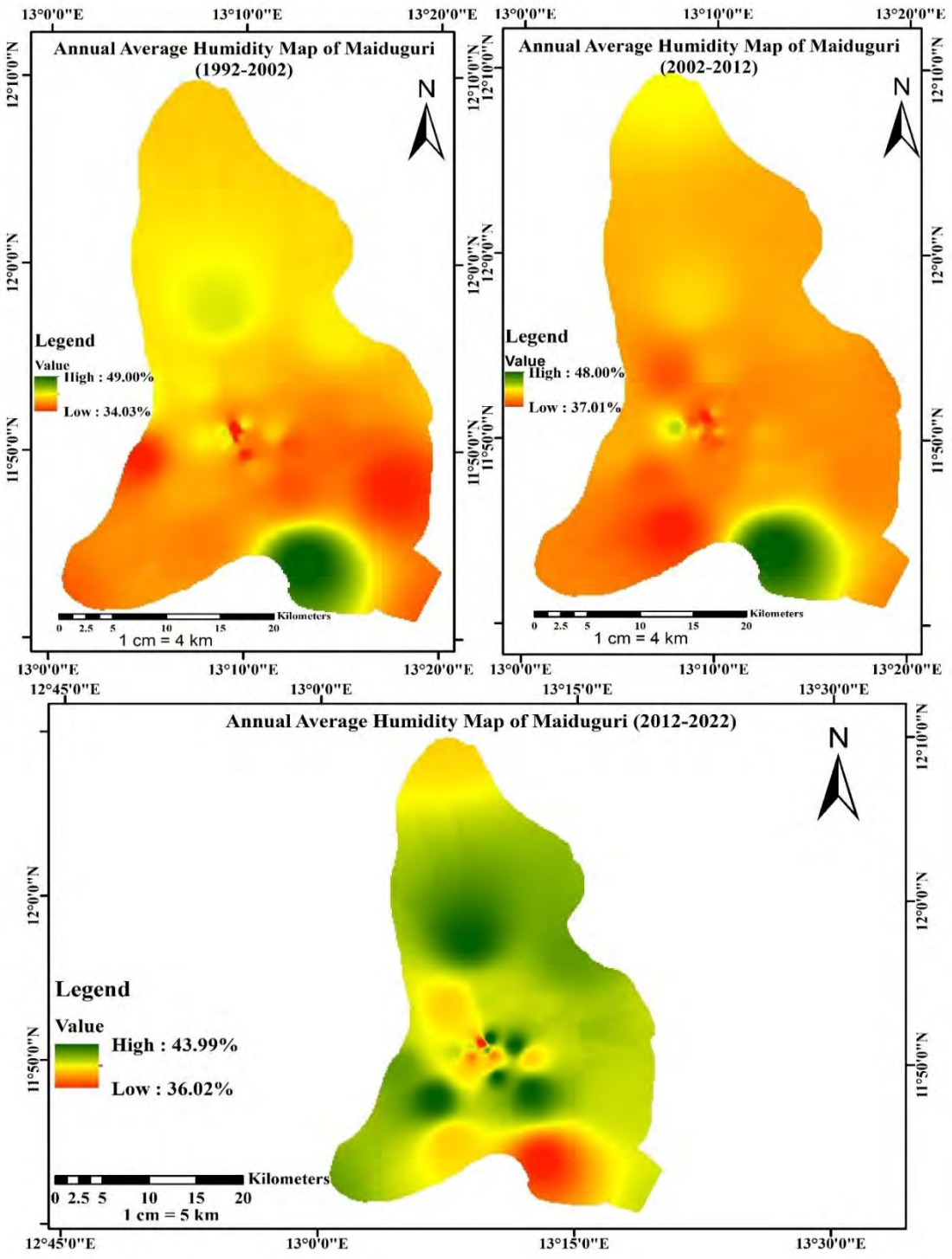
Similarly, understanding long-term humidity patterns is crucial for interpreting urban climate conditions and determining possible heat stress in urban areas. In this perspective, 30 years of relative humidity data for Maiduguri (1992-2022) acquired from the Nigerian Meteorological Agency (NiMet) provide useful information about atmospheric moisture levels. These data are critical for understanding how changing humidity levels affect the intensity and manifestation of Urban Heat Island impacts in the metropolis. Table 3.2 below shows the relative humidity trends throughout the study period, illustrating tendencies that may be related to urbanization and climate change, both of which contribute to Maiduguri's changing urban heat dynamics.

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Figure 3.3

Annual Average Relative Humidity (%) of Maiduguri (1992–2022)



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Table 3.2

Distribution of Average Relative Humidity (%) in Maiduguri (1992–2022)

Location	1992–2002	2002–2012	2012–2024	Average (1992–2022)
Bolori I	44%	41%	41%	42%
Bolori II	43%	39%	40%	41%
Bulabulin	41%	39%	40%	40%
Dusuman	42%	40%	41%	41%
Fezzan	44%	41%	40%	42%
Galtimari	40%	38%	40%	39%
Gamboru	43%	41%	44%	43%
Gomari	38%	41%	42%	40%
Gongulong	44%	42%	43%	43%
Gwange I	40%	41%	39%	40%
Gwange II	38%	39%	40%	39%
Gwange III	41%	40%	43%	41%
Hausari	43%	42%	39%	41%
Lamisula	43%	44%	41%	43%
Limanti	41%	39%	42%	41%
Maisandari	41%	39%	43%	41%
Mafoni	44%	39%	41%	41%
Mairi	39%	41%	43%	41%
Old Maiduguri	42%	41%	41%	41%
Shehuri North	34%	37%	36%	36%
Shehuri South	36%	39%	40%	38%
Tamsu Ngamdua	38%	40%	41%	40%
City Average	41%	40%	41%	41%

Source: The Nigerian Meteorological Agency (NiMet), Maiduguri Office, 2023.

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The 30 years of relative humidity data for Maiduguri (1992-2022) show a general stability in atmospheric moisture levels around the city shown in table 3.2. The city's average humidity remained consistent at about 41 percent across the decades, with just minor variations found between 1992-2002 (41%), 2002-2012 (40%), and 2012-2022 (41%). This shows that, despite urbanization and other environmental changes, humidity levels have remained steady, allowing for the analysis of other meteorological elements such as Urban Heat Island effects.

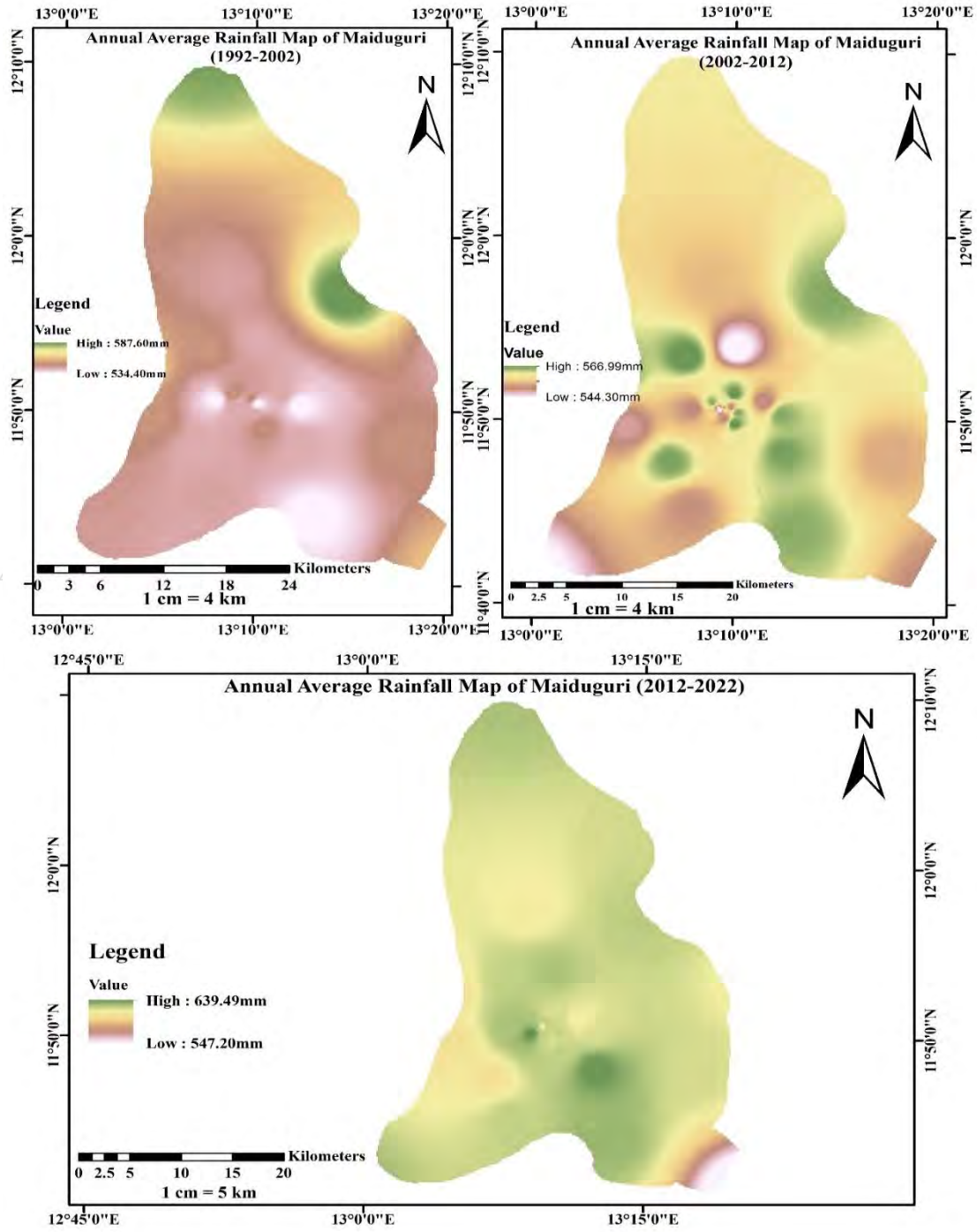
Significant changes in humidity have been discovered across different wards. Areas like Bolori I and II, Fezzan, and Gongulong showed slightly higher average humidity levels (42–43%), which could indicate localized impacts such as vegetation, water bodies, or special urban features that retain moisture. On the other hand, Shehuri North had the lowest average humidity (36%), indicating drier conditions, which could be attributable to geography or land use issues. Gamboru's humidity level has gradually increased over time, rising from 41% in 2002-2012 to 44% in 2012-2022, indicating that environmental or developmental changes may be influencing moisture levels in that ward. In general, while citywide humidity levels stay consistent, localized differences show that urbanization affects moisture retention differently across the wards. The growing temperature trends in Maiduguri, combined with generally consistent humidity levels, indicate an increased risk of heat-related stress, particularly in the city's hotter areas. These patterns highlight the crucial need for customized UHI mitigation strategies such as urban greening, smarter land use planning, and climate-responsive infrastructure that are tailored to the city's most heat-sensitive locations.

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Figure 3.4

Annual Average Rainfall Map of Maiduguri (1992–2022)



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This study examined long-term rainfall patterns in Maiduguri over a 30-year period (1992–2022) using data from 22 metropolitan locations, primarily sourced from the Nigerian Meteorological Agency (NiMet). The dataset was segmented into three decadal intervals 1992–2002, 2002–2012, and 2012–2022 to identify temporal trends in precipitation. Average annual rainfall values were computed for each location and presented in a tabular summary (Figure 3.4), which revealed a consistent upward trend in rainfall over time. City-wide average rainfall increased from 545.8 mm in the first decade to 557.9 mm in the second, and rose sharply to 618.7 mm in the final decade representing an overall increase of approximately 13.4%. This provides a quantitative foundation for understanding evolving climatic conditions that affect vegetation growth, moisture availability, and the viability of urban farming as a sustainable climate response.

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In addition to the temporal analysis, spatial rainfall distribution across Maiduguri was visualized using ArcGIS 10.8. Rainfall data points were converted into spatial point features using geographic coordinates and interpolated using the Inverse Distance Weighted (IDW) method to generate a continuous rainfall surface map (Figure 3.4). This map illustrates spatial variations in rainfall intensity, with areas like Mairi, Hausari, and Bolori II exceeding 630 mm annually, while Lamisula, Old Maiduguri, and Limanti remained below 570 mm. These spatial disparities are likely influenced by urban expansion, land cover changes, and microclimatic variations. The combined use of tabular data and GIS-based visualization enables a comprehensive assessment of both temporal and spatial rainfall dynamics, which is critical for informing water-sensitive urban design, optimizing urban farming, and implementing effective UHI mitigation strategies.

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Table 3.3

Annual Rainfall (mm) in Maiduguri Wards (1992–2022)

Location	1992–2002	2002–2012	2012–2022	Average
Bolori I	560.5	564.5	601.3	575.4
Bolori II	550.4	566.5	620.4	579.1
Bulabulin	543.4	550.4	620.2	571.3
Dusuman	543.4	560.5	612.4	572.1
Fezzan	542.3	544.5	624.3	570.4
Galtimari	544.5	551.3	620.4	572.1
Gamboru	545.5	567.0	616.5	576.3
Gomari	550.3	549.5	605.5	568.4
Gongulong	544.5	554.5	612.0	570.3
Gwange I	543.4	564.4	619.3	575.7
Gwange II	544.0	566.5	617.5	576.0
Gwange III	549.4	559.6	620.3	576.4
Hausari	543.4	556.7	639.5	579.9
Lamisula	534.5	550.4	623.4	569.4
Limanti	548.5	550.2	620.5	573.1
Mafoni	550.5	564.3	623.5	579.4
Maisandari	543.4	565.0	605.4	571.3
Mairi	543.4	565.0	634.2	580.9
Old Maiduguri	543.4	544.3	623.4	570.4
Shehu North.	545.5	561.4	621.3	576.1
Shehuri South	544.6	563.4	612.3	573.4
Tamsu Ngamdua	549.4	553.4	618.4	573.7
Average	545.8	557.9	618.7	574.1

Source: The Nigerian Meteorological Agency (NiMet), Maiduguri Office, 2023.

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Similarly, in a study conducted by Jimme et al., (2016), the analysis of three decades' worth of rainfall data spanning (1981–2010) shows a distinctive trend in the mean deviation curve, with phases that alternate between being wet (above averages) and dry (below averages). Interestingly, the dry phases persisted until the middle of the 1990s, with occasional positive changes in 1988, 1989, and 1992. For example, rainfall in 1982 varied from 234 mm to 787 mm, resulting in a yearly mean of 577 mm (Jimme et al., 2016). This analysis shows that the average amount of precipitation in Maiduguri between 1980 and 2009 was 558.9 mm. On the other hand, a significant rise of +108.4 mm, or 667.3 mm, has been observed in 2010. With a reduction of up to 3.733 when compared to the standard range, the rainfall data collected during this period shows a slight general decrease in the rain within the study area. The data presented clearly demonstrates how the climate and precipitation patterns in the area have evolved over the recorded three decades.

3.2.5 Soil

Aeolian processes are the source of Maiduguri's soils, which come in a variety of forms such as vertisol, fluvisol, brown and reddish-brown regosols, hydromorphic soils, and alluvial soils. Jimme et al. identified these soil classifications in 2019. Significant shrink-swell characteristics and a high clay content are characteristics of vertisol. Sediments carried by rivers deposit to form fluvisol, which are frequently fertile soils. Brown and reddish-brown regosols are indicative of soils that contain a combination of weathered and transported particles. Water has an impact on hydromorphic soils, while flowing water

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deposits sediment on alluvial soils. The region's geology and environment are reflected in the varied soil composition (Jimme et al., 2016, 2019).

Clay, loam, and sand are the three main textural groups in the soils in Maiduguri, as reported by Medugu et al., (2017). The most common soil texture among these is sand. This suggests that sand particles make up a significant portion of the soil in the area. High permeability and low moisture retention are linked to this textural composition. The area's drainage and water flow may be affected by the predominance of sand. Maiduguri's soil profile is generally complex and variable due to the variety of soil textures and their unique qualities.

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3.2.6 Landform Topography

The state's unique landforms define its topography. The Biu plateau as well as the Mandara mountain range rise to a height of about 650 meters above sea level in the southern highlands. On the other hand, the vast Lake Chad plains, which rise an average of 300 meters above sea level, are what define the state's northern region. Particularly, the Mandara Mountain located to the southeast, which forms part of the nation's border alongside the Republic of Cameroon, is a continuation of the Adamawa/Bamenda highlands. The diverse and striking scenery found throughout the state is enhanced by this varied landscape (Waziri, 2009).

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Maiduguri, the capital city of Borno State is an important centre in the larger geographical context highlighted. Located in the northern section of the state on the plains surrounding Lake Chad, Maiduguri has a distinct topography with comparatively flat or gently rolling terrain. Located at the base of the Bama Ridge, this urban centre is a major hub for the region's agricultural and economic activities. Furthermore, Maiduguri, the research area, offers insightful information about how the state's topography affects a variety of factors, including agriculture, climate, and demographic patterns (Waziri, 2009) The city's geographical setting on the plains around Lake Chad, inside the more expansive context of Borno State's varied terrain, adds to its importance in comprehending the general dynamics of the area.

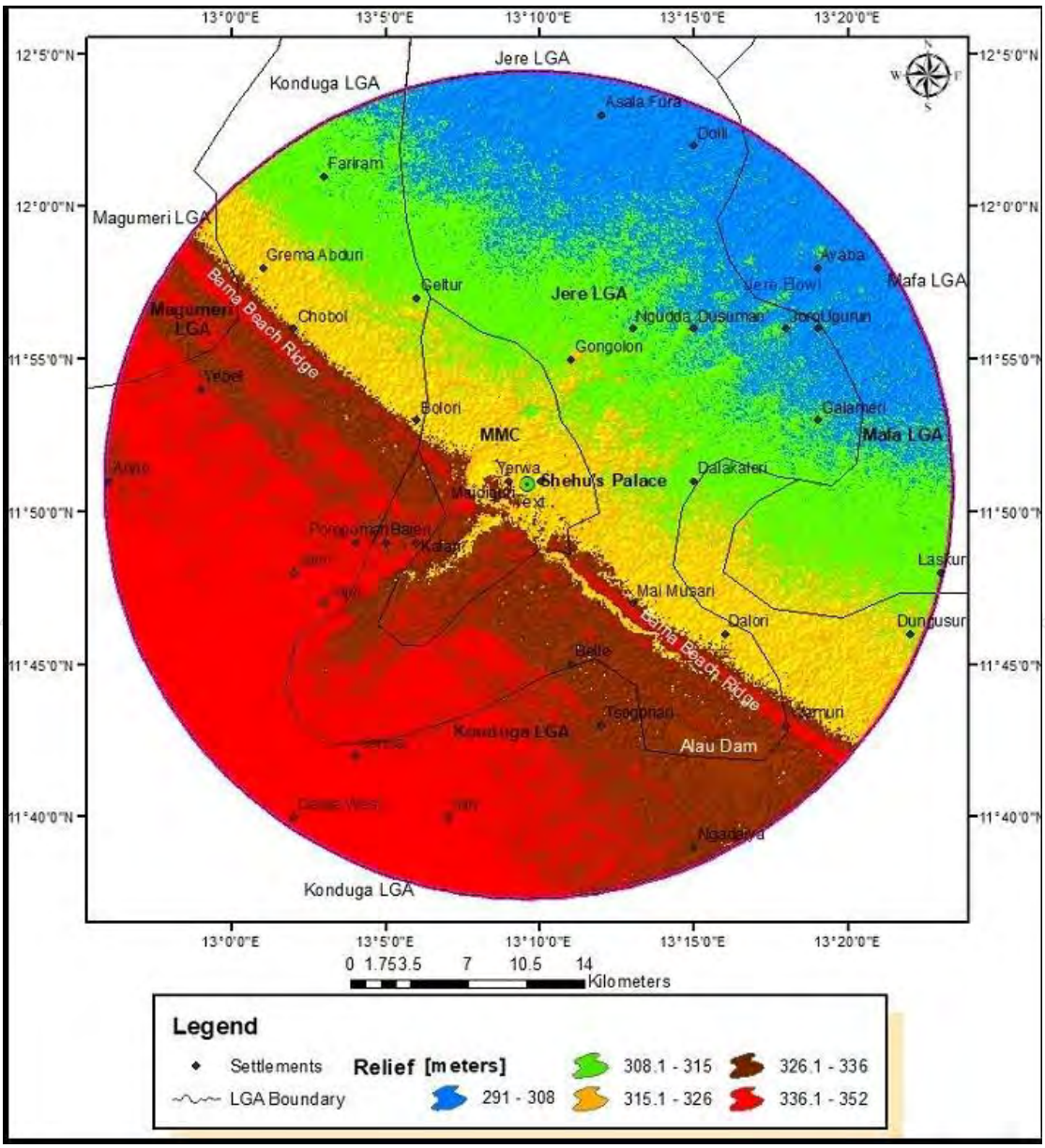
Situated on young sedimentary deposits of the Chad formation, the area is a vast open plain with flat or gently undulating terrain (Bakari, 2014). With an average elevation of between 300 and 600 metres above sea level, this generally-level terrain slopes gently toward Lake Chad. With the Cameroun Mountain ranges in the southeast and the Nigeria-Niger border in the northwest, the Bama Ridge, on which Maiduguri is situated, stretches from northwest to southeast. The topography of Maiduguri's northeast and southwest is remarkably uniform and flat, with little to no variation in elevation. The general landscape attributes and physical features of the area are influenced by this geographical setting (Jimme et al., 2016).

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Figure 3.5

Relief of Maiduguri Metropolitan Area.



Adapted from Sambo and Ikusemoran, 2022

The topography and landform of the Maiduguri Metropolitan Area have a significant impact on the spatial distribution of surface temperatures, vegetation cover, drainage

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capacity, and soil properties all of which are important to urban heat island dynamics and the potential of urban agriculture as a mitigation strategy. Maiduguri is situated in a gently undulating landscape with heights ranging from 291 to 352 meters above sea level as highlighted in figure 3.5. This relief variance is visualized through colour-coded elevation bands that offer insights into the geomorphological structure of the city and its environs. The topography progressively rises from the northeastern lowlands to the southwestern highlands, resulting in a subtle but significant gradient in microclimatic conditions and land use adaptability.

The lowest elevation zones, which range from 291 to 308 meters, are primarily found in the northeastern parts of Maiduguri, including sections of the Jere and Mafa Local Government zones. These low-lying areas are more vulnerable to seasonal flooding, water accumulation, and poor drainage conditions. These lower locations retain more heat and moisture, exacerbating localized UHI effects. However, if managed properly with enhanced drainage and moisture-tolerant farming practices, these zones provide possibilities to employ wetland-compatible urban agricultural methods that can help regulate surface temperatures and improve climate resilience clearly presented in the figure above.

The central urban core of Maiduguri is made up of moderately elevated areas ranging in altitude from 308.1 to 326 meters, which include major places such as the Maiduguri Municipal Council (MMC), Yerwa, and the surrounding area of Shehu's Palace (Sambo & Ikusemoran, 2022). These places have relatively level and stable terrain,

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allowing for considerable infrastructure and urban developments. The elevation creates good conditions for natural drainage and urban growth, making them ideal for a variety of urban farming methods such as household gardens, institutional green spaces, and rooftop agriculture. Given their high population density and built-up nature, these central locations have significant potential to mitigate UHI impacts through vegetation-induced cooling and evapotranspiration.

The higher elevation locations, which range from 326.1 to 352 meters, are predominantly found in the southern and western areas of the metropolitan region, including portions of Konduga and Magumeri LGA. These locations have more severe terrain and noteworthy formations like the Bama Beach Ridge, which runs diagonally over the countryside. While less developed due to slope and accessibility limits, these elevated areas benefit from increased airflow, decreased humidity, and cooler nighttime temperatures (Sambo & Ikusemoran, 2022). As a result, they are ideal for farming initiatives, green buffer zones, and peri-urban agriculture, which can help regulate urban microclimates and maintain the balance of nature. Understanding Maiduguri's topography and landform is necessary for identifying suitable areas for urban farming as a UHI mitigation strategy. Elevation influences heat stress, drainage, and soil conditions, all of which affect land use potential. Integrating this data into GIS analysis allows for targeted, climate-resilient planning that is in line with the natural terrain.

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3.2.7 Geology

Maiduguri has a long geological history that is inextricably linked to the presence of Cretaceous-Tertiary rift basins. These rift basins, which date from the Lower Cretaceous to the Neogene, are an important part of the region's geology. These basins are covered with sedimentary rocks with thicknesses ranging from 3,000 to 12,000 metres (m). These sediments, which were deposited in a variety of environments, including fluvial, lacustrine, and marine, tell an amazing story of Maiduguri's geological evolution (Adegoke et al., 2015; Bakari, 2014). A substantial sedimentary sequence that spans the Cretaceous to Tertiary periods, or the Albian to Pliocene epochs, characterises the Chad Basin, also called the Bornu Basin. This series, which Adegoke thoroughly documented in 2015, serves as an example of the transgressive and regressive cycles that have repeatedly occurred throughout its history. The earliest sediments in the basin date from the Albian to the Cenomanian periods and are characterised by continental deposits that are mainly made up of feldspathic sandstones with thick bedded surfaces (Adegoke et al., 2015; Adelana et al., 2008; Goni et al., 2021).

Notably, fluvial and lacustrine rocks were deposited in the rift basins of the Chad Basin, which encompasses the Maiduguri region, during the Early Cretaceous. The insights these rock formations provide into the past landscapes, climate variations, and ecosystems that were once abundant in this area are priceless. In addition to providing insight into Maiduguri's geological past, the study of these ancient sedimentary rocks may also provide hints about the region's greater geological and ecological importance (Bakari, 2014; Goni

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et al., 2021). Similarly, another study by Kaka et al., (2019) affirms that the area is part of a broad open plain that is characterized by flat or moderately undulating and is made up of young Chad formation sedimentary rocks. Diverse alluvial sand deposits dominate the surface, with intermittent alluvial sand deposits of eroded and remnant dunes.

Furthermore, an important sedimentary sequence that spans the Cretaceous to Tertiary period, covering a wide age range that spans the Albian to Pliocene epochs, is what sets the Borno Basin apart (Adegoke et al., 2015; Goni et al., 2021). A large-scale marine transgression resulting from a regional subsidence event in the Late Cretaceous shaped a broad basin that was deposited with sedimentary rocks from a range of marine and coastal environments, from the Cenomanian through the Maastrichtian epochs. Then, the Chad Basin (Borno) experienced its last stage of rifting from the Late Cretaceous to the Oligocene, which led to the build-up of massive fluvial as well as lacustrine sediments (Adelana et al., 2008; Bakari, 2014). It is primarily composed of lacustrine materials, which are characterised by sporadic deposits of silt, sand, and sandy clay between thick layers of clay, in addition, the region has a belt of alluvial deposits.

3.2.8 Hydrogeology

The region's Plio-Pleistocene Chad Formation displays a varied hydrogeological terrain, which reflects the complex interaction of aquifer conditions. There are various conditions under which groundwater occurs in this formation, such as water table situations, perched

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conditions, semi-confined conditions, and confined conditions. This region's geological diversity is demonstrated by the hydrogeological complexity, which also emphasises how important it is to comprehend the aquifers that make up the area.

Numerous studies conducted on the Chad Formation have revealed the existence of three separate water-bearing zones: these include the upper, the middle, and the lower aquifers. These studies highlight the stratification of water resources within the geological formations and offer insightful information about the hydrogeological features of Maiduguri and its environs. These aquifers greatly enhance the region's water resources and are essential to its hydrogeological dynamics (Bakari, 2014; Goni et al., 2021). Additionally, according to Adelana et al., (2008) the Upper Aquifer in Maiduguri is categorised into Units A, B, and C, each of which has distinct hydrogeological characteristics. Unit B has artesian to leaky artesian conditions, Unit C is an artesian aquifer that exhibits little leakage, and Unit A is an unconfined aquifer primarily located in superficial deposits. The importance of the aquifers in the community's water supply and the surrounding environment is highlighted by these hydrogeological features.

The upper aquifer's hydrogeological properties in Maiduguri are important. This aquifer has a complex structure and is mainly made up of Quaternary alluvial fans along with deltaic sediments from Lake Margin. It is made up of intermittent sandy clay lenses, interbedded sands, clays, and silts. As a result, it can be classified as an aquifer of three different types: confined, semi-confined, and unconfined. The aquifer can be found locally down to a depth of up to 180 metres, but it extends from surface level to an average depth

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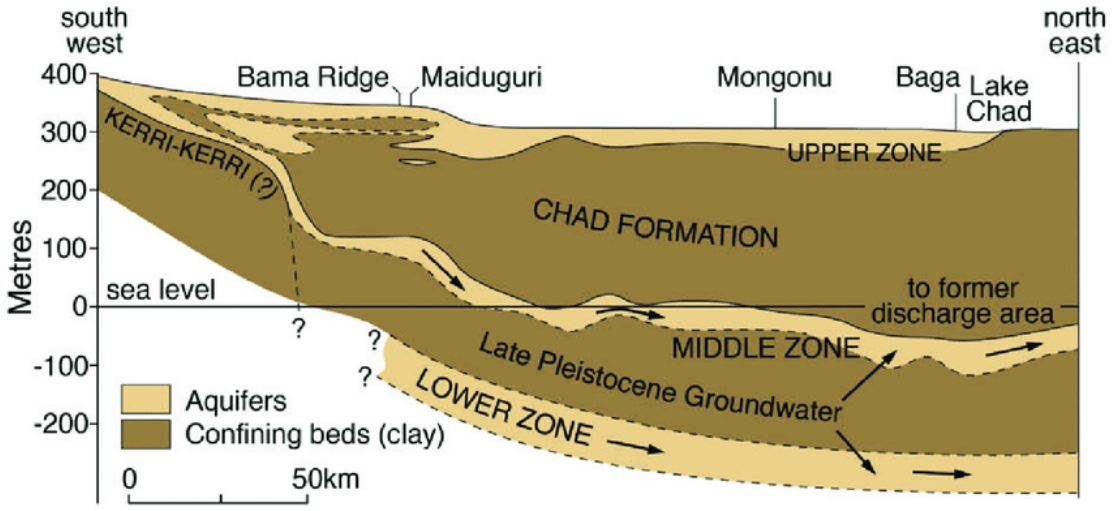
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of 60 metres. The groundwater yield in Maiduguri can differ from 2.5 to 30 litres per second, and its transmissivity fluctuates from 0.6 to 8.3 square metres per day (Bakari, 2014). This aquifer is of critical importance because it provides the majority of the water used for domestic use, both through shallow and hand-dug wells. It also makes an extensive array of urban farming activities practicable, such as the production of different home garden products and vegetables, in addition to supporting livestock watering. Furthermore, groundwater occurs in Maiduguri from these geological structures, which include three distinct arenaceous horizons among the argillaceous (Bakari 2014). These boundaries represent distinct layers that are composed of clay (argillaceous) within a broader deposit dominated by sand (arenaceous).

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Figure 3.6

Cross section of the multi-layered aquifer system (Chad Formation) in Maiduguri



Adapted from Goni et al., 2021

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3.2.9 Drainage System

The Ngadda River dominates the watercourse system in Maiduguri Metropolis and the surrounding region illustrated in (figure 3.7). According to Jimme et al., (2016), the Ngadda River serves as the primary drainage channel and is fed by its key tributary, the Ngaddabul. The Ngadda River runs into Alau Dam, expands across Maiduguri Metropolis, and ultimately discharges into Lake Chad, as established by (Sambo. G & Obroh, 2022), it originates at the confluence between the Yedzaram and Gambole Rivers in Sambisa, Nigeria. This intricate web of rivers emphasises the Ngadda River's importance in shaping the area's environmental landscape.

Similarly, a study by Mala, (2023) buttress the earlier assertions, reiterating that the Ngaddabul River, which flows through the city from its source within the southern peaks of Damboa, has a notable tendency for overbanking, resulting in erosion threats for the city on occasionally. The river's intermittent rises pose potential hazards to the surrounding regions as it flows northward. Notably, the river's waters eventually disappear into Lake Chad's Jere Main Bowl, around 70 miles (118 km) northeast, emphasizing the river's significant impact on the lake's hydrodynamics and the potential implications for the city during periods of increased water flow.

The Ngadda, formed by the Ngaddabul's confluence and Ngadda rivers, is notable for its distinctive circular flow. Aside from its geographical relevance, the river is an essential water resource for a variety of uses. The Ngadda River's water is used for

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irrigation, sustaining farming operations along its banks. It also plays an important role in addressing domestic needs as well as supplying water for livestock. Furthermore, the river promotes industrial activity in the area. Notably, the Ngadda River receives runoff from irrigated farmlands along its banks, emphasizing its importance in the local hydrological and agricultural systems (Bwala, 2023).

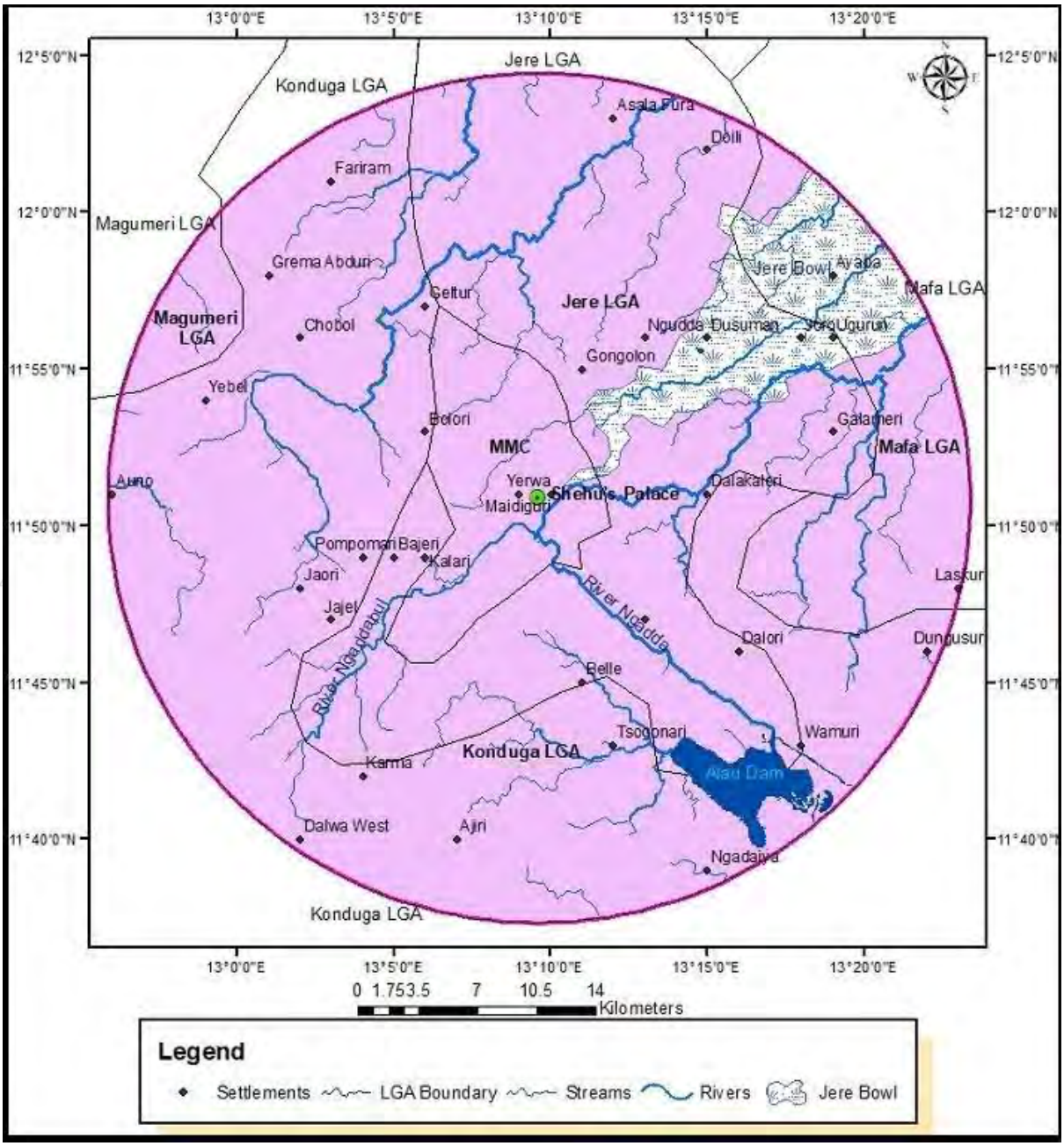
Owing to the peculiarities of the river Ngadda, which meanders through the heavily populated area of Maiduguri, it is imperative that the indigenous populace use caution when using its water for household purposes. Because of the river's vulnerability to flooding and the possible decline in water quality, users should exercise caution. Flooding events can introduce harmful substances and pose risks to water quality. They may be caused by a circular pattern of flow and runoff coming from irrigated farmlands. Therefore, to guarantee the safe use of river water for household tasks like drinking, cooking, and washing, cautious measures as well as education are crucial. In order to reduce any possible threats to health and safety related to using the river Ngadda as source of water, it would be helpful to educate the community on appropriate water treatment techniques and water quality monitoring.

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Figure 3.7

Drainage system in Maiduguri Metropolitan



Adapted from Sambo and Ikusemoran, 2022

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3.2.10 Vegetation

Maiduguri is surrounded by a landscape of shrubby vegetation entwined with tall tree woodland, situated in the heart of a hot, semi-arid region. Grass makes up the majority of Maiduguri's annual vegetation cover; this characteristic is especially noticeable during the rainy season. Interestingly, these grasses, which are found in most places, are thorny (Alkali & Uba, 2014). This distinctive composition of flora provides a clear picture of the natural environment of the area by demonstrating the local flora's adaptability and resilience to Maiduguri's harsh climate. A study by (Ngulde & Mustapha, 2018) further sheds more lights on the vegetation that characterised this environment, highlighting that the vegetation of Maiduguri bears a striking resemblance to the savannah of Sudan. With important species like *Azadirachta indica,* (Neem tree) *Balanites aegyptiaca,* (Desert date plant) *Adansonia digitata* (Baobab), and several Acacia species, the region has a notable diversity of plants. The variety of functions these plants perform highlights their significance in the regional ecology.

3.2.11 Transport System

Transportation is an essential component of the advancement of society because it allows individuals, merchandise, and ideas to flourish. A well-developed transport infrastructure promotes economic development, social connectivity, and a higher standard of living. It is critical in promoting trade, reducing disparities, and expanding opportunities for learning,

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healthcare, and employment. Efficient transport systems are critical for urban mobility and are critical to a region's overall progress and well-being (Abdullah et al., 2013; Rodrigue et al., 2020). Throughout history, this has been extremely important for human societies. Maiduguri today has a diverse range of infrastructural development, commerce, healthcare facilities, and industrial activities largely contributed by the existing transport system in the Metropolis.

The city's transport is facilitated by a well-developed road network, an international airport, and railway connections, all of which provide critical opportunities for mobility within and beyond Maiduguri (Mayomi & Mohammed, 2014). Given that the state borders three different nations, Maiduguri's strategic location emphasizes the importance of its transportation infrastructure even more. The development of modern transport systems, most notably the 1964 construction of the Maiduguri railway line, was a momentous occasion. This contemporary transport enabled effective mobility and connectivity throughout the area. (Garba, 2019).

The city's regional importance is enhanced by the city's road network, the international airport, and rail connections, which not only contribute to local accessibility and mobility but also play a critical role in facilitating cross-border movement and trade. In particular, Maiduguri's road transport system has a noteworthy historical background. The first car arrived in Maiduguri in 1904, indicating the early existence of motorized transport in the city, this was well documented by Waziri (1995, cited in Mukhtar et al., 2015). Over the years, Maiduguri's traffic has steadily increased as a result.

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3.2.12 Land use

The increasing urbanization witnessed in locations like Maiduguri raises serious ecological issues, with land use change being a major issue (Bello, 2021). This alteration undermines biodiversity, disrupts the balance of the environment, and leads to soil degradation, water and air pollution, and biodiversity loss. Such changes, caused by human activities such as urbanization, deforestation, and industrialization, can result in habitat loss and breakdown, affecting ecosystem health and functionality (Bello, 2021). Furthermore, these changes might have an impact on local microclimates, worsening the Urban Heat Island (UHI) effect and adding to environmental stress. Sustainable urban planning and green infrastructure are critical for mitigating these effects and preserving ecosystem health in the long run, necessitating a thorough understanding of and control of LULC change utilizing effective conservation strategies and policy interventions.

Maiduguri's rapid growth and development have a direct influence on land use dynamics both inside and beyond the city. As cities expand, there is a high demand for land for housing, business, and industrial needs (Mayomi & Mohammed, 2014). This growth includes not just the construction of new structures in Maiduguri, but also the formation of new villages in the surrounding region. As a result, land is being transformed to accommodate infrastructure and facilities that will sustain the growing population. Therefore, the process of urban expansion is intimately associated with land use patterns and management, influencing the spatial layout and development trend of Maiduguri and its surroundings (Jimme et al., 2019; Mayomi & Mohammed, 2014).

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The initial master plan, of Maiduguri, put forth in 1976, designated particular regions for various land uses such as public spaces, urban farming, and housing, business, and industrial zones. However, land use has changed throughout time, with public places being invaded by private companies or converted into government facilities. Moreover, the usage of public places by IDPs for informal accommodation has changed their intended purpose. The state board's planning method, which aims to extend the city outward while reducing density in the centre, has a considerable impact on land use patterns by allocating land for diverse uses. likewise, the choice of sites for urban farming highlights the necessity of strategic land use planning in addressing food security, microclimate resilience, and promoting sustainable development initiatives (Bisoka et al., 2021).

The state's economic activities, which rely mostly on natural resources like clay, salt, limestone, and kaolin, have a significant impact on land use patterns. The extraction and processing of these minerals necessitates the use of land for mining activities and accompanying infrastructure. Furthermore, active exploration for minerals like as iron ore, uranium, and petroleum along Lake Chad's shoreline influences land usage in the region. Industries such as grain mills, shoe manufacturers, and ginneries also require specific property for operation and amenities. These economic activities have an important role in defining land use patterns, emphasizing the link between economic growth and land management practices (Waziri, 2009).

Jimme et al., (2019) caution that Maiduguri's recent growth in urbanization has resulted in the conversion of areas designated for forest, farmland, and animal parks into

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fully built residential zones, indicating a troubling trend. The city has seen extraordinary expansion in physical structures, with enormous tracts of open ground converted into residential and commercial sectors. However, this fast development has occurred without adequate attention to the installation of drainage systems, posing environmental difficulties. Uncontrolled spatial growth has contributed to difficulties such as floods and insufficient water management, emphasizing the critical need for comprehensive urban planning methods to address these environmental concerns while still promoting the city's sustainable development.

Maiduguri's land use patterns and economy are heavily influenced by its agriculture sector. Farmers account for around 60% of the city's population (Mailafiya et al., 2014). These farmers grow a diverse range of crops, including rain-fed staples like millet, maize, beans, and groundnuts, as well as cash commodities like sesame seeds and dry-season sorghum (Masakwa). Onions, carrots, peppers, tomatoes, mangoes, guavas, lemons, and cashews are also grown. This enormous agricultural activity demonstrates the many uses of land for farming reasons. Furthermore, while agriculture remains the principal profession for a substantial fraction of the population, the remaining proportion comprises traders, businesspeople, and public workers, demonstrating the diversified character of economic activity supported by land usage in Maiduguri (Gana et al., 2009; Mailafiya et al., 2014).

The river channels and their surrounds, especially the Ngadda River channel, which originates in the Sambisa marsh and is fed by the flood discharge of Gombole and the river

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Yedzaram, play an important role in influencing land use in this region. According to J. Abdullahi et al., (2015), these areas in Maiduguri are experiencing significant growth in activities such as rain-fed and dry-season agriculture, animal husbandry, mining, excavation, sand quarrying, and human settlement development, demonstrating a dynamic relationship between human activities and the natural environment. Understanding the implications of these activities is critical for successful land use planning and sustainable development in Maiduguri and nearby areas, as it provides significant insight into the complex dynamics of land use, particularly in riparian zones along the Ngadda River channel.

An examination of land use patterns in Maiduguri indicates an intricate relationship between human activity and the natural environment. Rapid urbanization, commercial activity, agricultural methods, and the effect of river systems all help to shape the region's land use patterns. Understanding these processes is critical for successful land use planning, environmentally friendly development, and addressing environmental issues such as the Urban Heat Island effect. Maiduguri might strike a balance between urban expansion and environmental preservation by implementing strategic land-use planning methods and regulations that prioritize conservation and resilience, resulting in a sustainable future for its citizens.

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3.3 Research Design

This study employs quantitative methods to provide a comprehensive understanding of the research problem, as highlighted by Strijker et al., (2020). Geographers have recognized the robustness of this approach for over two decades (Finney, 2020). By adopting this method, added rigor is achieved, leading to a deeper understanding of the phenomena under study (Hawthorne, 2017). According to Creamer, (2018), quantitative research is transparent and precise in its reporting. Leavy, (2017) further supports this approach, noting that it is characterized by deductive methods aimed at supporting or refuting established theories. This type of research involves measuring variables and examining their relationships to identify patterns, correlations, or causal links.

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3.4.1 Sources of Data

Both primary and secondary data will be used. GIS and remote sensing data were explored, and Landsat data was downloaded from USGS Earth Explorer from an open-source Landsat archive (http://eathexplorer.usgs.gov). ArcGIS 10.8 Imaging software version was utilized for processing the imageries into different land cover classes; The same software was maintained in Geo modelling. The ENVI-met model was employed to assess the effectiveness of urban farming in mitigating the urban heat island. A field survey was conducted to supplement the satellite data to explore the socio-economic background of the urban populace and ascertain the benefits and challenges of the urban farmers. Using a

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hand-held Global Positioning System (GPS), several places across the study region were identified, (Stewart & Mills, 2016).

3.3.2 Data Assembly and Management

In assembling the data for the study, a multidimensional method was employed for minimizing the effects of urban heat islands through urban farming techniques, which included Geographic Information System (GIS) and remote sensing data, urban farmers' reaction data, and urban farming microclimate data. Using Landsat imagery from 1992 to 2022 obtained from the USGS Earth Explorer, we methodically choose photos based on clear-sky conditions to assure the veracity of land cover change analysis. Concurrently, comments from urban farmers collected via standardized surveys provide qualitative insights into socioeconomic dynamics and attitudes of urban farming. Furthermore, a synthesis of models, books, journals, and research articles helps to compile microclimate data, which aids in understanding the effects of urban farming on local environmental conditions. The study intends to shed light on the potential of urban farming as an ongoing strategy for mitigating UHI impacts and improving urban sustainability initiatives by integrating and analysing these various statistics.

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3.4.3 Image Pre-processing

The study utilized satellite imagery from three Landsat sensors: Landsat 4 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager (OLI) combined with the Thermal Infrared Sensor (TIRS). These sensors were selected to cover the entire study period from 1992 to 2022, consistent with previous studies that have demonstrated their effectiveness in land use and land cover (LULC) and environmental change analyses (Day et al., 2008; Senaratne et al., 2017; Shi et al., 2021).

Given the inherent variability introduced by factors such as illumination geometry, atmospheric absorption, dispersion, and sensor calibration differences, comprehensive image pre-processing was undertaken to enhance data quality and ensure temporal comparability. This involved correcting for surface reflectance variations caused by different acquisition systems through a sequence of geometric and radiometric corrections.

Atmospheric effects, including absorption and scattering, were specifically addressed to improve the fidelity of sensor data. Pre-processing steps included atmospheric correction, sensor sensitivity adjustments, and compensation for topographic variations, alongside normalization for sun angle and scene illumination differences. These corrections were applied to both visible and near-infrared spectral bands to standardize reflectance values (Koko et al., 2021). This rigorous pre-processing protocol minimized

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confounding variables and enhanced the overall accuracy and consistency of the multi-temporal satellite dataset.

A total of four Landsat scenes corresponding to path/row 185/052 were selected, with strict criteria limiting cloud coverage to below 20% to ensure data reliability (Choate et al., 2022). The imagery was resampled to a uniform spatial resolution of 30 meters by 30 meters across all spectral bands to facilitate consistent spatial analysis. Using the pre-processed imagery, LULC maps, Normalized Difference Vegetation Index (NDVI) images, and Land Surface Temperature (LST) maps were generated. LULC and NDVI products were derived directly from surface reflectance data, while LST estimation incorporated additional preprocessing steps, including surface emissivity calculation and correction, to improve temperature retrieval accuracy.

Field-collected spatial coordinates were integrated into the Geographic Information System (GIS) platform, specifically ArcGIS, to support spatial analysis and validation of the remote sensing data products. This multi-source data integration provided a robust basis for analyzing the spatiotemporal dynamics of urban land cover and evaluating the role of urban farming in mitigating the Urban Heat Island effect.

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3.4.4 Image Classification

Tewabe & Fentahun, (2020), stated that choosing the right remote sensing methods for image classification requires an understanding of both the advantages and the disadvantages of different types of sensor data. They stressed that choosing appropriate sensor data was the first step towards a successful classification. A popular method used in later classifications was the maximum likelihood classification (Azari et al., 2022; Ishola et al., 2016). Field observations and contextual knowledge of the study area were incorporated into the classification process to improve the accuracy of land cover identification. This experience expertise aided in the selection of reliable training samples and improved the interpretation of spectral data during supervised classification, in line with similar methodologies adopted by (Koko et al., 2021; Weng et al., 2019). To analyse changes in LST, NDVI, and LULC in the study area, all Landsat images and data were projected using the Universal Transverse Mercator (UTM/WGS84) 33N coordinate system. All Landsat images underwent geometric rectification following a common map reference system (UTM map projection, WGS84 geodetic datum), and data organization and analysis were conducted using ArcGIS.

As noted by Stewart & Mills, (2016), the decision to use of these satellite data was based on their consistent collection over several years and conformity to well-established high-quality standards, which allowed for the assessment of LSTs through time and across changing seasons.

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3.4.5 Accuracy Assessment

An accuracy assessment was conducted to evaluate the reliability of the supervised classified land use/land cover (LULC) maps. This involved comparing the classified results with reference data obtained through field observations and high-resolution imagery from Google Earth. Ground control points were collected using a hand-held GPS device portable Garmin eTrex 10 were used to validate the land cover classes. Additionally, digitized topographic maps were consulted to further support spatial accuracy. The evaluation metrics applied included overall accuracy, user's accuracy, producer's accuracy, and the Kappa coefficient. These measures provided a comprehensive validation of classification performance, as supported by methodologies in (Koko et al., 2021; Stehman et al., 2018; Weng, 2018), who emphasized that rigorous accuracy assessment significantly enhances the credibility and scientific value of remote sensing-based studies, the details is presented in Table 4.4.

3.4.5.1 Accuracy Assessment of Landsat-Derived LULC Maps Through GPS-Based Field Validation

To validate the LULC classification obtained from Landsat imagery, intensive field visits were conducted in ten selected wards in Maiduguri. A Garmin eTrex 10 portable GPS device was utilized to collect ground truth points to confirm the dominant land use/land cover (LULC) classifications (Adhikari et al., 2022; Dakwa, 2018). In each ward, five GPS points were collected for each dominant LULC type. To ensure consistency and ease

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accurate geographic comparisons, the coordinates were first captured in Decimal Degrees (DD) and then averaged before converted to Degrees, Minutes, and Seconds (DMS). The spatial differences between the typical GPS positions and the associated satellite-referenced coordinates ranged from 45 to 245 meters. This level of variation is regarded acceptable for validating medium-resolution satellite imagery, as supported by recent studies (Z. Abbas & Jaber, 2020). A detailed table is presented in the appendix E.2.

3.4.6 Derivation of LST from Landsat and retrieval of brightness temperature

To accurately estimate Land Surface Temperature (LST), this study employed thermal infrared data from various Landsat missions across four timeframes: 1992, 2002, 2012, and 2022. The procedure involved a multi-step process including the conversion of digital numbers (DN) from thermal bands into top-of-atmosphere (TOA) spectral radiance, brightness temperature, and finally surface temperature, incorporating surface emissivity adjustments based on vegetation indices.

For the years 1992, 2002, and 2012, Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) were utilized, both of which include Thermal Band 6 (with a wavelength range of 10.4–12.5 μm) suitable for thermal studies. In the 2022 analysis, Landsat 8's Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS) was applied, shown in table 3.1. Specifically, Thermal Band 10 (wavelength range: 10.60–

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11.19 µm) was selected for LST retrieval due to its higher calibration reliability over Band 11, which is often affected by stray light and calibration inconsistencies.

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3.4.6.1 Conversion of DN to TOA Spectral Radiance

For Landsat 5 and 7:

The initial step involved converting the raw DN values from the thermal bands to Top-Of-Atmosphere (TOA) spectral radiance using radiometric rescaling factors provided in the metadata file (MTL) of each Landsat image. This transformation employs the formula:

$$L\gamma = \left(\frac{LMAX\gamma - LMIN\gamma}{QCALMAX - QCALMIN}\right) \times (QCAL - QCALMIN) + LMIN\gamma \qquad (3.1)$$

For Landsat 8

$$L_\lambda = M_L \times Q_{CAL} + A_L \qquad (3.2)$$

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Lγ is the spectral radiance, calculated using QCAL (the digital number or DN), where QCALMIN = 1 and QCALMAX = 255, and LMAX and LMIN are the spectral radiance values corresponding to QCALMAX and QCALMIN respectively; the spectral radiances for band 6 at digital numbers 1 and 255 (i.e., QCALMIN and QCALMAX) are also provided in the header file of the images.

3.4.6.2 Conversion to Brightness Temperature (BT)

$$T_B = \frac{K_2}{In\left(\frac{K_1}{\lambda_2} + 1\right)} \qquad (3.3)$$

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Where brightness temperature (TB) is measured in Kelvin and computed using the band-specific calibration constants K_1 and K_2. For Landsat 5 TM, K_1 is 1260.56 and K_2 is 1260.56; for Landsat 7 ETM+, K_1 is 666.09 and K_2 is 1282.71; and for Landsat 8 Band 10, K_1 is 774.8853 and K_2 is 1321.07. These constants are critical for converting thermal band radiance readings to brightness temperature.

3.4.6.3 Surface Emissivity and Final LST Estimation

$$NDVI = \frac{\text{NIR} - \text{RED}}{NIR + RED} \qquad (3.4)$$

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Where Landsat 5 and 7, NIR is band 4 and Red is band 3; for Landsat 8, NIR is band 5 and Red is band 4.

Proportion of Vegetation (PV):

$$PV = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} + NDVI_{min}}\right)^2 \qquad (3.5)$$

$$LSE = 0.004 \times PV + 0.986 \qquad (3.6)$$

LST Formula:

$$LST = \frac{T_B}{1 + \left(\frac{\lambda \times T_B}{\rho}\right) In(\varepsilon)} - 273.15 \qquad (3.7)$$

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The wavelength of emitted radiance λ is a key parameter in thermal remote sensing, with values of 11.45 μm for Landsat 5 and 7, and 10.8 μm for Landsat 8 TIRS Band 10. Brightness temperature TB is derived from this radiance. The constant ρ, equal to 438×10^{-2} m, is related to physical constants including Planck's constant $h = 6.624 \times 10^{-34}$ J·s, the speed of light $C = 2.998 \times 10^{8}$ m/s, and the Boltzmann constant $k = 1.38 \times 10^{-23}$ J/K. Surface emissivity ε, which affects the radiance emitted by the surface, is typically estimated using NDVI-derived values to account for land cover characteristics.

Table 3. 4

Spectral Bands Used in the Study

Application	Landsat 5 TM & 7 ETM+	Landsat 8 OLI/TIRS	Purpose
LULC	Band 1 (Blue), Band 2 (Green), Band 3 (Red), Band 4 (NIR), Band 5 (SWIR1), Band 7 (SWIR2)	Band 2 (Blue), Band 3 (Green), Band 4 (Red), Band 5 (NIR), Band 6 (SWIR1), Band 7 (SWIR2)	Differentiation of land cover types
NDVI	Band 4 (NIR) and Band 3 (Red)	Band 5 (NIR) and Band 4 (Red)	Vegetation index and emissivity input
LST	Band 6 (Thermal)	Band 10 (Thermal)	Land surface temperature analysis

For thermal analysis, Band 6 of the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+), as well as Band 10 of the Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS) on Landsat 8, were specifically employed due to their

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high sensitivity to longwave thermal infrared radiation. These bands are crucial for deriving accurate Land Surface Temperature (LST) values.

To estimate vegetation cover and correct surface emissivity an essential input in the LST retrieval process the Normalized Difference Vegetation Index (NDVI) was calculated using the Near-Infrared (NIR) and red bands. This enabled improved classification accuracy and emissivity correction, which are vital for surface temperature analysis.

For Land Use and Land Cover (LULC) classification, a combination of visible, Near-Infrared (NIR), and Shortwave Infrared (SWIR) bands was utilized. These spectral bands were chosen due to their proven effectiveness in differentiating between various land cover types, particularly vegetation, built-up areas, bare soil, and water bodies, based on their unique spectral signatures.

3.4.7 Normalized Difference Vegetation Index (NDVI)

To quantify vegetation dynamics and identify spatial patterns of green cover in Maiduguri during the last three decades, the Normalized Difference Vegetation Index was used as the major remote sensing metric. NDVI is a common vegetation index in geospatial analysis, renowned for its ability to emphasize vegetation density by comparing near-infrared (NIR) and red (RED) reflectance values (Rahmad et al., 2019; Weng, 2018). This spectral indicator uses the high reflectance of healthy vegetation in the NIR region and the strong

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absorption in the red area of the electromagnetic spectrum to estimate photosynthetic activity.

The NDVI is calculated using the following equation:

$$NDVI = \frac{\text{NIR} - \text{RED}}{NIR + RED} \quad (3.1)$$

where NIR stands for near-infrared reflectance and RED for red reflectance.

This equation produces values ranging from -1 to +1, with higher values indicating higher vegetation density and health and lower values indicating barren landscapes, impermeable surfaces, or water bodies (Tomatis et al., (2023). NDVI values between 0.2 and 0.5 typically indicate moderate plant cover, and values above 0.5 suggest thick and robust vegetation.

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In this study, satellite data from the United States Geological Survey (USGS) Landsat series specifically Landsat 4 (Thematic Mapper), Landsat 7 (Enhanced Thematic Mapper Plus), and Landsat 8 (Operational Land Imager) were used to construct NDVI outputs for 1992, 2002, 2012, and 2022. The selection of these years was influenced by data availability, seasonal consistency, and the requirement to record decadal variations in vegetation dynamics within Maiduguri's metropolis.

Prior to NDVI calculation, all satellite images were subjected to rigorous pre-processing, including radiometric correction to standardize reflectance values and atmospheric correction to remove noise from particles and water vapour. These

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modifications are required to assure temporal consistency of NDVI readings over many years and sensors (Chander et al., 2009; Fytsilis et al., 2016). The NDVI transformation was performed in the ArcGIS 10.8, where the RED and NIR bands of each image were used to construct the index raster. The generated NDVI maps were divided into five vegetation types, ranging from extremely low (NDVI < 0.1) to very high (NDVI > 0.5), in keeping with Carlson and Ripley, (1997) standards and supported by recent research like as Rahman et al. (2019).

NDVI was chosen not only for its computational simplicity, but also for its demonstrated efficacy in reducing spectral variation from non-vegetative surfaces, making it ideal for mixed urban environments (Van De Voorde et al., 2008; Wei et al., 2023). NDVI is a vital tool for monitoring ecological integrity and the distribution of urban green infrastructure because of its extremely sensitive nature to chlorophyll content, which allows for the reliable detection of vegetation even in semi-arid or sparsely vegetated regions like Maiduguri (Chen et al., 2019; Rahmad et al., 2019).

Tomatis et al., (2023) emphasize NDVI's ability to estimate vegetation presence and density easily, which is very useful in urban heat island investigations. Given vegetation's thermal regulatory role, NDVI data enable spatial correlation to Land Surface Temperature maps, providing insights into how green spaces mitigate urban heat effects. Although this study did not include a statistical association between NDVI and Land Use/Land Cover (LULC) or Land Surface Temperature (LST) datasets, the NDVI maps provide significant visual evidence of vegetation changes. They illustrate geographical

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shifts in green cover, which could be due to urban expansion, infrastructural development, or environmental interventions Tomatis et al., (2023) note that NDVI is especially useful for urban heat island inquiries because vegetation plays a temperature regulation role. As a result, these maps serve as the foundation for future research into the relationship between vegetation patterns and urban microclimate trends.

The NDVI approach used in this study is critical for understanding vegetation dynamics and informing policy decisions on urban greening, climate adaptability, and land use sustainability. Its integration with other remote sensing measures, such as LULC and LST, increases its relevance for monitoring urban environmental condition and designing urban heat island mitigation techniques.

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3.5 ENVI-met Simulation

The well-established ENVI-met model was used to evaluate urban farming's efficiency in minimizing UHI impacts. ENVI-met is a three-dimensional, non-hydrostatic microclimatic tool that allows advanced modelling and analysis of urban environments (Piroozfar & Farr, 2022). Furthermore, as Dialesandro et al., (2019) note, the model has evolved to provide a wide range of microclimate data. ENVI-met simulates interactions between the atmosphere, vegetation, and built environment, offering valuable insights into how urban farming can reduce urban heat islands and enhance microclimate resilience.

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The ENVI-met simulation aimed to understand the impact of urban farming on urban microclimates, focusing on temperature reduction and humidity increase. The methodology involved data preparation, simulation, and analysis. Simulated data for meteorological conditions, land use distribution, vegetation characteristics, and urban farming scenarios were used for Maiduguri. The simulation was guided by prior land use/land cover mapping and NDVI analysis for Maiduguri. The collected data was structured into appropriate formats for input into the ENVI-met model. Scenarios were designed to evaluate the impact of different levels of urban farming coverage, converting 10%, 20%, and 30% of bare land and built-up areas into urban farming areas.

The justification for this approach is reinforced by recent studies suggesting that small increases in green covering and Leaf Area Index (LAI) can lead to significant improvements in UHI mitigation. For instance, this strategy is consistent with Iaria & Susca, (2022) study, which similarly used 10%, 20%, and 30% green space increases to determine their effects on urban cooling capacity and thermal comfort. By evaluating various incremental scenarios, this study hopes to provide practical insights into the minimal and optimal scales of urban agricultural interventions required to achieve considerable reductions in surface temperature and UHI intensity in Maiduguri.

In contrast to alternatives such as RayMan, Ladybug, or ANSYS Fluent, ENVI-met was chosen for this study because of its superior ability to simulate essential urban microclimate processes, such as air and heat exchange, radiation, evapotranspiration, and acoustics, at high spatial and temporal resolution. This comparative advantage was

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established by Abdulateef and Al-alwan, (2021), who found ENVI-met to be the most appropriate tool for assessing the microclimatic performance of urban development. Furthermore, ENVI-met is a high CFD-based model for assessing the thermal effects of urban greenery, as reported by Liu et al. (2023), who also stress the significance of precise vegetation modeling to improve the caliber and dependability of simulation results.

3.5.1 ENVI-met Simulation Procedure

A three-dimensional, high-resolution microclimate simulation model the ENVI-met designed to examine the relationships between vegetation, soil, and built surfaces. A 3D core model that replicates localized environmental dynamics inside a user-defined grid and a 1D boundary model that estimates vertical meteorological profiles up to 2,500 meters, including air temperature, wind vectors, and humidity, make up the model. The fine-scale evaluation of land-use changes and their thermal effects at the urban block level is made possible by this hybrid structure.

The model domain in this study was set up as a 60 × 60 × 30 grid, with each cell measuring 2 × 2 × 2 meters. This resulted in a total modeled surface area of 14,400 m² and a simulated volume of 120 m × 120 m × 60 m. In order to enhance the accuracy of near-ground processes including evapotranspiration, soil heat flux, and thermal conduction, the vertical layering employed equidistant intervals, with the exception of the lowest atmospheric layer, which was separated into five finer sub-layers (dzs = 0.4 m) which is

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the initial vertical grid cell height. This setup guaranteed that the simulation effectively reflected microscale differences in transfer of heat and moisture dynamics at the vegetation–soil–atmosphere interface.

A high-density residential area in Maiduguri was chosen as the study site because of its characteristic urban shape, high Land Surface Temperatures, and limited vegetation cover. Baseline environmental parameters, such as surface material properties (albedo, thermal conductivity, emissivity), weather conditions (air temperature, wind speed and direction, relative humidity), and structural layout, were maintained constant throughout all simulation scenarios in order to isolate the effects of urban farming interventions. The land cover type, which reflected three intervention scenarios 10%, 20%, and 30% conversion of bare soil surfaces and built-up areas into urban farming zones was the only variable that was changed. 2,100 ground-level cells (8,400 m^2) were set aside for vegetation conversion in the most intense scenario (Scenario 3).

The varieties of vegetation chosen for the simulation were derived from species that are frequently grown in the urban farming practices of Maiduguri. To enable realistic simulation of biophysical processes as shading and evapotranspiration, they were extracted from ENVI-met's vegetation database and parameterized using values for Leaf Area Index (LAI), root depth, stomatal resistance, and transpiration rate. The understanding of urban farming as an active, moisture-regulating system that can modify microclimatic conditions, rather than merely as a change in land cover, is supported by this biologically guided approach.

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For the simulations, a normal hot-season day that coincided with Maiduguri's peak Urban Heat Island conditions was considered. Key output variables such as Land Surface Temperature, relative humidity, and Normalized Difference Vegetation Index were retrieved and examined in order to assess how much each urban farming scenario reduced localized UHI effects. This robust modeling methodology offers a reliable, empirically based approach to assessing the cooling potential of urban farming in semi-arid urban environments. It highlights the importance of urban farming as a practical natural option for reducing urban heat, enhancing atmospheric moisture balance, and supporting sustainable climate adaption programs in vulnerable places like Maiduguri. Further details are presented in the appendix

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3.6. Population and Sampling

3.6.1 Sample

A sample is needed to draw conclusions about the entire population because studying the entire population is impractical, if not impossible, due to factors such as time, cost, resource constraints, and the sheer size of the whole population. Hence, a sample will be drawn from it. A Probability sampling technique is adopted in the selection of the participants during the instrument administration by the researcher. Yamane's (1967) formula was used to determine the sample frame and size for this study at a confidence level of 95% (Ajay & Micah, 2014; Alhaji Mukhtar et al., 2022). To obtain a representative of a good sample, a

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stratified random sample was implored. Based on a shared characteristic or attribute, the study population is divided into two or more groups, known as strata. Each stratum reflects a subgroup of the population, and a sample is drawn from each stratum independently (Leavy, 2017). The study involves adult inhabitants, especially household heads, who are expected to provide valuable research insights. In each ward, the primary sampling frame consists of adult residents, with a focus on household heads due to their potential for in-depth knowledge of local conditions.

3.6.2 Sample Frame

The study targets adult residents, who are thought to be better positioned to provide valuable insights into the research's various constructs. The primary sampling frame within each ward is made up of adult residents, with a preference for household heads due to their potential in-depth knowledge of local conditions ethical compliance.

To make sure the sample is representative and diverse, stratified random sampling will be used. The strata will be the wards that make up the study area. With an understanding of the distinctive qualities and challenges each ward presents, each ward will be treated as a separate stratum. Random sampling, respondents will be chosen at random within each stratum (ward). This will be accomplished through the use of computer-generated random numbers. A potential respondent will be identified as the adult resident or head of household whose designated number matches the generated number.

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Data Collection Process:

A trained research assistant will reach out to the selected respondents once they have been identified. The research assistant will explain the study's purpose and objectives to the respondent and obtain informed consent to participate. If a randomly selected respondent is unavailable or unable to participate at that time, the research assistant will make a note of it and move on to the next randomly selected individual.

Flexibility in Respondent Participation

Respondents will have the option of completing the questionnaire at their leisure. This approach recognizes urban residents' busy schedules and commitments, allowing them to complete the questionnaire when it is most convenient for them.

Permission and Ethical Considerations

Before beginning data collection, the researcher will follow a strict set of guidelines to ensure that the study is carried out ethically and with the necessary permissions.

Formal Permit: To conduct this study within their respective jurisdictions, formal permission from relevant authorities such as ward heads, district heads, leaders in the community, and Metropolitan officials will be sought.

Ethical Compliance: The whole study will be carried out strictly with ethical considerations. This includes acquiring informed consent from each of the participants,

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whose participation will be completely voluntary. The study is committed to protecting the rights and privacy of everyone involved.

Anonymity and Confidentiality:

Upholding the respondents' anonymity and confidentiality is a top priority when gathering the data.

The Yamane formula for sample determination will be used to select sampled respondents within each chosen ward. It is written as follows:

$$n = \frac{N}{1+N(e)^2} \qquad (3.1)$$

Where:

n = Desired sample size

N = Total population

e = Accepted error limit (0.05 based on 95% degree of confidence)

Therefore:

$$n = \frac{N}{1+N(e)^2}$$

$$n = \frac{421{,}832}{1+421{,}832(0.05)^2}$$

= 399.62106140699893

≈ 400

The study involves adult inhabitants, especially household heads, who are expected to provide valuable research insights. In each ward, the primary sampling frame consists of adult residents, with a focus on household heads due to their potential for in-depth knowledge of

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local conditions. Stratified random sampling is used to guarantee a representative and diverse sample. The procedure is well-established by (Ajay & Micah, 2014; Awang, 2012; Leavy, 2017), and defines strata according to the number of wards in the study area, each of which is treated as a separate stratum. Within the 22 wards in the study area, an aggregate sample size of 400 was used as determined by Yamane's formula.

Formal approvals were requested from relevant authorities, such as ward heads, district leaders, and community leaders, following ethical standards. The participation of respondents was entirely voluntary, with informed consent. Respondents were chosen at random from each stratum (ward) through computer-generated numbers, identifying the head of the household whose assigned number matches the automatically generated number. A trained research assistant approaches the selected respondents once they have been identified. The research assistant explained the purpose and objectives of the study and sought informed consent for participation. If a randomly chosen respondent is unavailable or unable to participate at that time, the research assistant documents the situation and moves on to the next randomly chosen person.

Respondents were given armful time to complete the questionnaire at their leisure. This approach recognizes urban residents' busy schedules and commitments, allowing them to respond at their preferred times, this procedure is well recognized by (Awang, 2012). To ensure respondent confidentiality and anonymity, each questionnaire will be included with a cover letter. The cover letter explains the purpose of the study and reassures respondents that their identities will be kept confidential. Respondents were chosen at

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random from each stratum (ward) through computer-generated random numbers. The head of the household whose assigned number corresponds to the generated number was recognized as a potential respondent. All information gathered will be handled in the strictest of confidence and kept in a secure location. To protect participant privacy, data access will only be permitted for authorized research staff.

The questionnaire was given out to a total of 400 respondents who represent the wards comprised of all income classes. The table below shows the distribution of the sampled population for each ward. This study strictly adhered to ethical guidelines as mandated by The Sultan Idris Education University Malaysia Research Ethics Committee (RMIC). After a thorough review, ethical clearance was granted (No: 2023-0210-01), ensuring that all research activities complied with established ethical standards and protected the rights and welfare of all participants. The ethical committee's approval is presented in appendix C.1.

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3.6.3 Sample wards and sample size

Table 3. 5

Sample wards and sample size

Wards	Population	Percentage	Sample size
Bolori – 1	53,325	12.6	50
Bolori – 2	63,654	15.0	60
Bulabulin	10,647	2.5	10
Fezzan	10,859	2.6	10
Gamboru	12,926	3.0	12
Gwange - 1	14,987	3.5	14
Gwange - 2	14,878	3.5	14
Gwange - 3	10,352	2.4	10
Hausari	11,828	2.8	11
Lamisula	10,053	2.4	10
Limanti	9,055	2.1	8
Mafoni	9,292	2.2	9
Maisandari	108,672	25.6	102
Shehuri North	9,345	2.2	9
Shehuri South	8,421	2.0	8
Bale Galtimari	10,321	2.4	10
Dusuman	7,675	1.8	7
Gongulong	7,109	1.7	7
Old Maiduguri	12,458	2.9	12
Mairi	12,319	2.9	12
Gomari	10,647	2.5	10
Tamsu Ngamdua	3,009	0.7	3
Total	421,832	100	400

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3.6.4 Pilot study

A pilot study is a preliminary, small-scale research undertaking designed to assess the viability and practicality of the techniques planned for application in a later, more comprehensive inquiry. It functions as an initial stage to optimize research procedures, recognize possible challenges, and guarantee the efficiency and dependability of the techniques utilized in the more extensive investigation (In, 2017; Viechtbauer et al., 2015). A pilot study is a crucial initial phase in the research procedure, providing critical insights and benefits. It enables researchers to assess the possible viability of their main study by evaluating study methods and procedures, identifying and addressing potential issues or challenges, refining research methods for accuracy, determining appropriate sample size, managing resources efficiently, gathering preliminary data, and addressing ethical concerns (In, 2017). Researchers can significantly improve the quality and efficiency of the main study by conducting a pilot study, to ensure it is well-planned and positioned to produce reliable and valuable results (In, 2017; Memon et al., 2020).

Therefore, a sample size of 150 was chosen for the pilot study in this study based on the specific analytical method of exploratory factor analysis to assess its practicability and feasibility. This choice is consistent with (Memon et al., 2020; Viechtbauer et al., 2015) recommendations for a minimum of 50 observations for such analysis. This sample size is deemed appropriate for the pilot study by adhering to these established recommendations, allowing for effective data collection and analysis while ensuring that the study's objectives can be met. (Memon et al., 2020). This sample size is justified by Memon et al., (2020).

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who emphasises the importance of the data collection procedure. A sample's strength and reliability are more dependent on the participants' careful and deliberate selection than on their sheer number. In research, the representativeness of the selected respondents and the quality of the data are essentially more important factors than the assumption that a larger sample size is always more appropriate. However, Knekta et al., (2019), argues that larger sample sizes are generally beneficial because they boost the precision of estimates and increase the statistical accuracy of a study. A larger sample size increases the likelihood that the results will be representative of the population, lowering the margin of error as well as increasing the potential to detect real effects or variances. This is a widely accepted research principle because it contributes to accurate and robust findings, but concluded that, the sample size required for a pilot survey varies depending on elements like the number of factors being analysed and the amount of items per factor (Knekta et al., 2019).

3.6.5 Exploratory Factor Analysis

Table 3.6

Kaiser-Meyer-Olkin Measure of Sampling Adequacy and Bartlett's Test of Sphericity

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**.648**
Bartlett's Test of Sphericity	Approx. Chi-Square	3257.037
	df	1326
	Sig.	.000

Note. KMO = .0648 (exceeded the accepted 0.6 thresholds indicating a high level of common variance)

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As a statistical technique, an exploratory factor analysis (EFA) was used to uncover underlying structures in the survey data. The primary goal was to identify patterns of correlation between survey items in order to produce valid and reliable scales. This method enabled the investigation of latent factors that led to the observed variations in the dataset, resulting in the development of valuable scales for further investigation and interpretation. To assess the data's suitability for factor analysis, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was calculated. The computed KMO value was 0.648, which exceeded the commonly accepted 0.6 threshold illustrated in table 3.5. This indicates that the variables have a high level of common variance, indicating that the set of variables is well-suited for the use of factor analysis. According to Almquist et al., (2019), a KMO value higher than 0.6 is appropriate for any study, supporting the feasibility of performing factor analysis on the given set of data.

To determine whether or not the correlation matrix is an identity matrix, a condition that indicates that variables are uncorrelated and not appropriate for factor analysis, Bartlett's Test of Sphericity was used. The test yielded a highly significant outcome with a p-value of 0.000, resulting in strong evidence. This result suggests that there are significant correlations between the variables, which supports the conclusion that the set of variables is appropriate for factor analysis. Almquist et al., (2019) argue for the importance of such findings, adding to the conclusion that the set of data is appropriate for factor analysis.

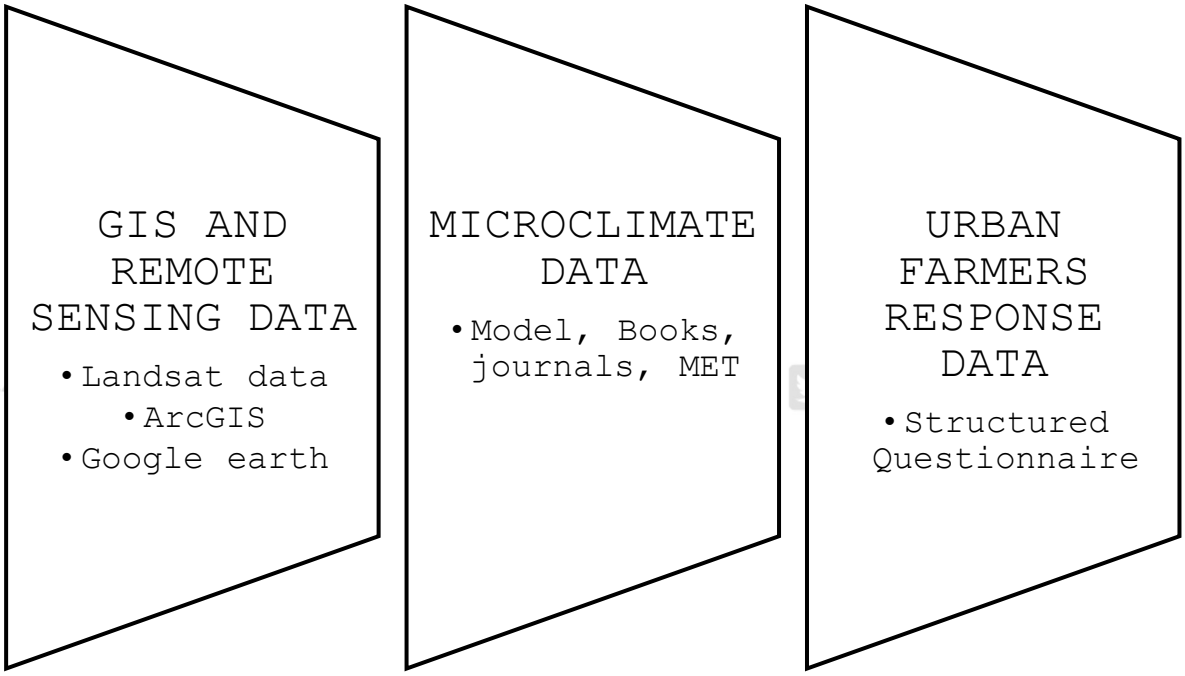
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3.6.6 Data Source from

Figure 3. 8

Types of Data Collected



The data gathering methods employed for this study is comprehensive, involving primary and secondary data sources as well as advanced geospatial and environmental modeling techniques, aimed at assessing the potential of urban farming as an approach for mitigating the Urban Heat Island (UHI) effects in Maiduguri, Nigeria, over a 30-year period (1992-2022).

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Primary data were obtained through structured questionnaires aimed at capturing socioeconomic factors such as gender, age, education level, employment status, income, and duration of residence. The surveys gathered residents' perceptions of the UHI phenomena, as well as their awareness of and participation in urban farming activities. These data offered critical context for understanding local adaptation responses and the city's socio-environmental dynamics. The structured questionnaire was distributed to 400 urban dwellers across the 22 wards in Maiduguri. This survey explored participants' understanding of urban heat island (UHI) impacts, perceptions of local climate change, and attitudes toward urban farming as a viable mitigation technique. To achieve representativeness across demographic groupings and geographic areas, a stratified random sample procedure was used. Perception-related questions were measured using a five-point Likert scale, and the responses were quantified and interpreted using the weighted average approach. The data was then evaluated using descriptive statistics to discover patterns in awareness and community attitudes.

Secondary data sources were crucial to the spatial analysis. Multitemporal satellite imagery from the Landsat archive (years 1992, 2002, 2012, and 2022) was obtained using the USGS Earth Explorer, which ensured cloud-free conditions for optimal quality. The images were processed with ArcGIS to extract Land Use and Land Cover (LULC) categories, calculate the Normalized Difference Vegetation Index (NDVI), and determine Land Surface Temperature (LST). The NDVI was a critical indication for measuring vegetation cover, allowing for the detection of spatial and temporal changes in green infrastructure. LST analysis provided quantitative insights into surface temperature

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changes among land cover types, supporting the NDVI-LST inverse relationship that is essential for UHI studies. Together, these layers provide an extensive spatial understanding of vegetation distribution and heat dynamics in the urban environment.

The addition of geo-modeling capabilities via the ENVI-met model improved the study's ability to simulate and predict the microclimatic effects of urban farming interventions. ENVI-met, a 3D environmental model, was used to simulate several vegetation expansion scenarios (10%, 20%, and 30%) and evaluate their effects on localized urban temperature, humidity, radiation balance, and air flow. The model's geographical accuracy permitted comprehensive forecasts of how increased urban farming coverage could mitigate UHI impacts and improve thermal comfort at a community level. Historical satellite imagery from Google Earth was also used to identify, outline, and validate the spatial extent of existing urban farming areas in Maiduguri. This spatial mapping contributed to a baseline assessment of present green infrastructure and agricultural activity in the urban environment.

Data from the Nigerian Meteorological Agency (NiMET) in Maiduguri provided a 30-year dataset (1992-2022) of climatic variables such as temperature, rainfall, and humidity. This climate data was analyzed using GIS methods to identify trends and determine how long-term climatic variability relates to the city's UHI challenge. Maps of average temperature provided further context for the developing urban heat threat and informed the environmental modeling technique. To assess the effectiveness of urban farming as a local climate adaptation measure, three vegetation conversion scenarios 10%,

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20%, and 30% were developed and tested using spatial and environmental simulations based on established protocol (Iaria & Susca, 2022), which used similar thresholds to assess the heat mitigation potential of urban greening.

Furthermore, the method used was strengthened by a comprehensive literature review encompassing academic publications, technical reports, and field-based investigations. This theoretical underpinning led the analytical process and verified urban agriculture as a strategic instrument for UHI mitigation, sustainable land use planning, and climate resilience in fast urbanizing locations.

3.7 Data Analysis

3.7.1 Materials and Method for the Analysis of Objectives

All of the images and data from the Landsat as earlier stated, were projected in the (UTM/WGS84) UTM coordinate system, to analyze the changes on LULC, LST, and NDVI in the study area remote sensing and geographic information system was employed. All Landsat images were geometrically rectified to a common map reference system (UTM map projection, WGS84 geodetic datum). ArcGIS 10.8 was used for further organization and analysis of the data acquired, relying on established protocols (Folorunsho et al., 2017). Urban farm sites were identified and mapped leveraging Google Earth Image. The survey data collected were organized and then analyzed using a descriptive statistical technique of

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simple percentage and bar chart and then inferential statistics of time series trend analysis and chi-square test of association, using the SPSS statistical package. To analyze the impact of urban farming on UHI, ENVI-met was utilized.

Specifically, the objectives identified were analyzed as follows: -

i. To determine the UHI phenomenon, the difference in mean LST between the standard deviation was computed using a raster calculator (Rahaman et al., 2022). The LST was extracted and mapped using (TIR) bands. This procedure employs a radiometric calibration by converting the digital number (DN) from spectral radiance to brightness temperature and the resulting temperature was converted to ^{0}C. Based on high-resolution satellite imagery, the city limit is used to define urban areas, and the shape file of the city is created in ArcGIS (Darshana & Yuji, 2021; Koko et al., 2021; Rasul et al., 2016).

$$UHI = \frac{T - Tm}{Tsd} \qquad (3.2)$$

ii. The study examined the spatiotemporal dynamics of land surface temperature and land use/land cover using Landsat images and data from the United States Geological Survey archive. The study focused on LST, LULC, and NDVI, utilizing datasets from Landsat 4 TM, Landsat 7 ETM+, and Landsat 8 OLI, and TIRS. The study applied pre-processing steps, including atmospheric and radiometric corrections, to these datasets. For the retrieval of LULC data, a ten-year interval was chosen (1992–2002, 2002–2012, and 2012–2022) and supervised classification based on the maximum likelihood technique was employed to define distinct land

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use classes and for rectification. The raw LST data was converted into spectral radiance values and then to calibrated pixel values (digital number, DN). Additionally, all LST, LULC, and NDVI pixel values were converted to data points for analyzing variations in LULC, LST, and NDVI. This procedure has been utilized in previous studies by (Darshana & Yuji, 2021; Koko et al., 2021; Naserikia et al., 2019).

iii. To examine urban residents' knowledge, awareness, and perceptions of urban heat islands, as well as the significance of urban farming as a mitigation technique, 400 structured questionnaires were distributed among residents of Maiduguri. A stratified random sample technique was used to choose respondents, ensuring fair representation throughout the city's many demographic and geographic strata. This method enabled the incorporation of varied opinions based on characteristics such as residential areas, age groups, education levels, and socioeconomic origins. The acquired data was coded and processed using the SPSS statistical tool to ensure proper organization and analysis. The analysis used descriptive statistical techniques to synthesize and present the data in a way that is easy to comprehend. Responses were analyzed using simple percentages and frequency distributions, while bar and pie charts were used to visually display patterns of respondents' awareness, knowledge, and perceptions. Furthermore, a weighted average method was used to analyze responses gathered using Likert-scale items, allowing for a more accurate evaluation of attitudes and the level of agreement or disagreement across important metrics.

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iv. The significance of urban farming in ameliorating the effect of the urban heat island phenomenon is highlighted, leveraging the ENVI-met simulation, the data collected from the Google Earth Image was also fully utilized.

3.8 Summary

Chapter Four features an integrated analysis that uses remote sensing, simulation modeling, and survey-based research to examine the effectiveness of urban farming as an approach for reducing Urban Heat Island in Maiduguri, Nigeria. It looked at both the physical dynamics of land surface modification and the socio-environmental implications of urban farming adoption.

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Satellite imagery from USGS Landsat missions (Landsat 5, 7, and 8) was processed with the ArcGIS platform to derive key environmental variables such as Land Surface Temperature (LST), Land Use/Land Cover (LULC), and the Normalized Difference Vegetation Index (NDVI). These data were processed to illustrate the spatiotemporal evolution of Maiduguri's urban environment from 1992 to 2022. Remote sensing techniques enabled the extraction of vegetation indices and thermal properties critical to understanding UHI dynamics across time.

Urban farming practices were also analyzed through a geospatial audit of historical imagery from Google Earth (2002–2022), finding four important urban farming sites every

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year. Farm sizes and perimeters were measured to examine spatial changes in urban agriculture, providing insights into its geographical expansion and structural evolution. To evaluate the microclimatic impact of urban farming, the ENVI-met model was utilized. This high-resolution 3D simulation tool facilitated a thorough assessment of temperature and humidity variations in three urban farming coverage scenarios (10%, 20%, and 30%) within a typical high-density area. The model's input data came from previous LULC and NDVI evaluations. The simulation findings showed meaningful decreases in surface temperature and increases in relative humidity, confirming urban farming's cooling potential as a promising natural approach for UHI mitigation in Maiduguri's semi-arid climate.

In addition, a structured survey was given out to a representative sample of Maiduguri's urban residents to assess their knowledge, perceptions, and practices regarding UHI and urban farming. The survey examined respondents' sociodemographic factors (age, gender, education, occupation, income), how they live (energy usage, disposal of waste, transportation), and environmental habits. It also assessed awareness and comprehension of UHI causes and effects, as well as challenges to implementing urban farming as a mitigation method, such as limited land access, water scarcity, financial constraints, and regulatory concerns.

Furthermore, this survey looked at public attitudes regarding environmental sustainability and urban greening activities, such as desire to participate in community-based projects, practice urban farming, and support green infrastructure. These findings

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shed light on public readiness for urban climate adaptation and identified potential for governmental action and community participation. In general, Chapter Four presents a thorough, multidisciplinary evaluation of Urban Heat Island reduction through urban farming. It combines spatial analysis, empirical modeling, and community-level perspectives to support the Maiduguri plan for sustainable urban growth and climate resilience.

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CHAPTER 4

RESULTS AND DISCUSSION

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4.1 Introduction

This chapter presents the integrated results and interpretations of both geospatial analyses and field-based assessments, combining remote sensing outputs with simulation modeling and community perspectives for evaluating urban farming as a UHI mitigation strategy in Maiduguri. The transformation of natural landscapes into human settlements has intensified, significantly impacting both global and local climates. Cities, as primary hubs for human activities, have undergone substantial changes in land use and land cover due to population growth and economic development (Li et al., 2011). The proliferation of impervious surfaces has contributed to the creation of a warmer urban environment, leading to the Urban Heat Island (UHI) effect. The replacement of natural surfaces with pavement and other urban construction

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types has diminished the cooling effects typically provided by vegetative surfaces (Santamouris, 2013; Jamei et al., 2016).

Each piece of land has a unique cover, and land cover and land use on Earth's surface are separate but interconnected (Bello, 2021). Farming practices, urbanization, logging, mining, and grazing are all examples of how people use and manage the land's resources. Conversely, land cover analyzes the physical properties of the land surface and encompasses areas like farms, forests, wetlands, deserts, pastures, highways, water bodies, and the built environment.

A thorough data analysis using image classification techniques was performed to produce digitally GIS-based land cover and land use maps for the study area over four temporal intervals (1992, 2002, 2012, and 2022). Landsat satellite pictures from these years were analyzed to create maps that differentiate various land cover classes and colour them appropriately. These maps can be used to view and understand the spatiotemporal changes in land cover throughout the given periods, as well as to lay the groundwork for additional interpretation and analysis.

To evaluate the efficiency of urban farming in minimizing UHI effects, the ENVI-met simulation model was used. Furthermore, Google Earth was utilized to assess the evolution of urban farming techniques throughout time, offering a visual and spatial knowledge of these changes. This comprehensive approach was supplemented by a systematic survey of 400 urban residents to gather information on their socioeconomic features as well as their awareness, perceptions, and experiences with UHI and urban farming.

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The survey results are analyzed across five primary theme categories. First, respondents' demographic characteristics such as age, gender, and occupation are offered to contextualize the study's social setting. Second, the respondents' awareness and understand of the UHI phenomenon are investigated. The final section investigates attitudes and views of urban farming as a strategy for UHI mitigation, with a focus on environmental and food security concerns. Fourth, the chapter discusses potential challenges to the adoption and implementation of urban farming practices in the metropolis. Finally, IBM SPSS Statistics 23 is used to perform both descriptive and inferential statistics on the dataset, including frequencies, percentages, averages, and graphical visualizations. Together, the above approaches provide a solid platform for evaluating urban farming as a sustainable adaptation strategy for UHI mitigation in Maiduguri.

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Each portion of land has a distinctive cover, and land cover and land use on Earth's surface are distinct yet interconnected (Bello 2021). Farming practices, urbanization, logging, mining, and grazing are all examples of how people utilize and oversee the land and its resources. Conversely, land cover explores the physical features of the land surface and includes areas like farmland, forests, wetlands, deserts, pastures, roads, water bodies, and the built environment.

Utilizing image classification techniques, a thorough data analysis was conducted to produce digitally GIS-based land cover and land use maps for the study area over four temporal intervals (1992, 2002, 2012, and 2022). Landsat satellite images from these years were analysed to generate maps, with various land cover classes

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distinguished and given appropriate coloration. The spatiotemporal modifications to land cover over the designated periods can be seen and understood using these maps, which also serve as a foundation for additional interpretation and analysis.

To assess the effectiveness of urban farming in mitigating UHI effects, the ENVI-met simulation model was employed. Additionally, Google Earth Pro was used to evaluate the evolution of urban farming practices over time, providing a visual and spatial understanding of these developments. This comprehensive approach was supplemented by a survey involving 400 urban dwellers to gather data on their socio-economic characteristics and awareness of UHI.

Table 4. 1

Details of Landsat datasets of the study area, Maiduguri, of the last three decades at 10-year intervals (1992–2022).

Sensors	Acquisition Date	Scene ID	Cloud Cover (%)	Path/ Row	Resolution (m)	Bands
Landsat - 4 (TM)	1992/12/22	LC04_L1TP_185052_19921222_20200914_02_T1	>20%	185/052	30m	1,2,3,4,5, &,7
Landsat - 7 (ETM+)	2002/02/17	LC07_L1TP_185052_20020217_20200916_02_T1	>20%	185/052	30m	1,2,3,4,5, &,7
Landsat - 7 (ETM+)	2012/02/13	LC07_L1TP_185052_20120213_20200909_02_T1	>20%	185/052	30m	1,2,3,4,5, &,7
Landsat - 8 (OLT/TIR)	2022/02/16	LC08_L1TP_185052_20220216_20220223_02_T1	>20%	185/052	30m	1,2,3,4,5,7, 8, &,9

The table Landsat Datasets of the Study Area (Maiduguri) from 1992 to 2022 at 10-year intervals shown in table 4.1 provides a structured overview of the satellite imagery used to analyze Land Use Land Cover and Land Surface Temperature changes over

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three decades. The data is sourced from three Landsat missions: Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager (OLI) with Thermal Infrared Sensor (TIRS). These missions capture critical urbanization trends and their influence on the Urban Heat Island phenomenon in Maiduguri. The table includes acquisition dates to ensure temporal consistency, scene IDs for precise identification and re-access through platforms like USGS Earth Explorer, and cloud cover percentages to assess the quality and reliability of the imagery. Cloud cover is particularly significant because excessive cloudiness can obscure land features, impacting the accuracy of LULC classification and LST calculations. The datasets include multispectral and thermal bands with a spatial resolution of 30 meters for multispectral data and 60 to 100 meters for thermal data (resampled to 30 meters).

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Analyzing the datasets at 10-year intervals. specifically for the years 1992, 2002, 2012, and 2022 enables a systematic evaluation of Maiduguri's urban growth, changes in vegetation cover, and temperature variations. The application of indices like the Normalized Difference Vegetation Index (NDVI) for assessing vegetation health and LST calculations for understanding surface temperature dynamics offers in-depth insights into the city's transformation. This approach supports evaluating the effectiveness of urban farming as a mitigation strategy for UHI effects, exploring the relationship between urbanization and rising temperatures, and identifying the potential of green infrastructure to enhance urban sustainability. The findings can inform sustainable urban planning practices, helping develop strategies to promote climate resilience and effective UHI mitigation in Maiduguri.

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4.2 Data acquisition

To ensure the veracity of the land cover change analysis, the Landsat images have been carefully chosen. The selected epochs (1992, 2002, 2012, and 2022) span the years 1992 to 2022 and were chosen based on their quality, with a focus on clear-sky conditions to reduce the impact of seasonal variations. To assess long-term land cover changes accurately and consistently, this selection strategy is necessary. To improve the findings' robustness, image quality is prioritized, and temporal factors are taken into account.

Previous research in Nigeria has supported the decision to focus on February as the temporal focus (Koko et al., 2021). The purpose of this method is to minimize the influence of seasonal factors on image classification, especially those about cloud cover and plant growth. The focus on these months is intended to provide a clearer picture of land cover patterns through more stable conditions in the environment because they are outside the study region's growing season as well as the rainy season (June to September). This intentional temporal selection enhances the veracity of the results obtained and improves the accuracy of our analysis.

Moreover, this study incorporates an understanding of the local climate. Therefore, all the images were acquired outside of the rainy season. This is important because it reduces the possibility that precipitation and vegetation growth will have an impact on how an image is interpreted. The relevance and applicability of the results were improved to the unique environmental conditions of the study area by coordinating the image acquisition with the local climate patterns.

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As previously indicated, the study made use of a dataset that included four cloud-free Landsat images that were taken on 22, December 1992, 17, February 2002, 13, February 2012, and 16, February 2022 by the TM-4, ETM+ 7, and OLI/TIR-8 sensors. For improved accuracy, these images which were acquired from the USGS Earth Explorer Landsat archive were rectified and geometrically corrected to UTM zone 33N. All four images were visually interpreted to evaluate the classification procedure. Using bands 2, 3, and 4, a standard FCC was created using the ArcGIS. A summary of the study area's satellite images is given in Table 4. 1 which also contains further details regarding the imagery that was used for the investigation.

Table 4. 2

Area (km2) and percentage of Land Cover classes during the study period 1992 – 2022

Land Cover Types	Area 1992 (km^2)	Area (%)	Area 2002 (km^2)	Area (%)	Area 2012 (km^2)	Area (%)	Area 2002 (km^2)
Built up Area	70.55	6.3	67.02	6	68.04	6.1	124.58
Water bodies	24.03	2.2	18.46	1.7	21.23	1.9	19.29
Farmland	601.14	53.8	576.57	51.6	350.44	31.3	397.53
Grass Land	52.62	4.7	33.92	3.0	99.85	9.0	93.9
Bare land	368.98	33	421.33	37.7	577.75	51.7	482.01
Total	1117.32	100	1117.28	100	1117.31	100	1117.31

The table 4.2 presents the changes in Land Use Land Cover (LULC) over four decades in Maiduguri. It categorizes the land cover into five main types: Built-up Area, Water Bodies, Agriculture/Farmland, Grassland, and Bare Land. Each category's area in square kilometres (km^2) and its percentage share of the total study area are provided for

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the years 1992, 2002, 2012, and 2022. The total area of 1,117.32 km² remains constant throughout the study period, ensuring consistency in analysing the changes.

The data reveals significant urban growth, with the Built-up Area expanding from 6.3% (70.55 km²) in 1992 to 11.2% (124.58 km²) in 2022, indicating rapid urbanization. Meanwhile, the Agriculture/Farmland category shows a declining trend from 53.8% (601.14 km²) in 1992 to 35.6% (397.53 km²) in 2022, possibly due to urban expansion and conversion to built-up areas. The Bare Land category initially increased from 33% (368.98 km²) in 1992 to 51.7% (577.75 km²) in 2012 before slightly declining to 43.1% (482.01 km²) in 2022, indicating possible attempts at land reclamation or vegetation regrowth. The area of Water Bodies and Grassland remained relatively small and fluctuating, suggesting minimal impact on these categories. These dynamics highlight the need for sustainable urban planning to balance urban growth and environmental conservation, especially given the potential for urban farming to mitigate the Urban Heat Island (UHI) effect and promote green infrastructure in Maiduguri. The table "Area (km²) and Percentage of Land Cover Classes During the Study Period 1992–2022" presents the changes in Land Use Land Cover (LULC) over four decades in Maiduguri. It categorizes the land cover into five main types: Built-up Area, Water Bodies, Agriculture/Farmland, Grassland, and Bare Land. Each category's area in square kilometres (km²) and its percentage share of the total study area are provided for the years 1992, 2002, 2012, and 2022. The total area of 1,117.32 km² remains constant throughout the study period, ensuring consistency in analysing the changes.

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The composition of LULC in different regions needs to be examined to predict future developments and guide sustainable development. Each area's distinct qualities, such as homes, businesses, factories, and natural areas shaped that region's LULC composition (Wang et al., 2020). This analysis offers useful details about the state of the environment, potential development areas, and current socioeconomic activities. It informs planners and policymakers about the need for infrastructure, business opportunities, and environmental preservation initiatives. Communities can plan for climate resilience, create liveable urban spaces, and balance economic development with environmental sustainability by identifying LULC trends. Simply put, understanding the composition of LULC is essential to developing strategies and policies that support a sustainable and equitable future.

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4.3 Image Processing LULC Classification

One of the most important parts of this study was creating maps of LULC, which was performed by using the Maximum Likelihood Supervised Image Classification Method (MLSICM). An approach that functions by using the probability that is obtained from training samples provided by the user. The principal source of data for this classification was the multispectral imagery of Landsat, which is widely recognized for its capabilities (Al et al., 2023; Rahman et al., 2022; Ullah et al., 2023). ArcGIS is a robust GIS program that was used to process and analyse the imagery. A thorough and accurate characterization of the landscape was made possible by the ArcGIS environment's integration of MLSICM via Landsat data, which also offered insightful information about the distribution and makeup of different land cover types. This method adds to a

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thorough assessment of environmental changes over time and improves our understanding of the dynamics of land use in the Maiduguri metropolis.

Based on the Bayes theorem, the MLSICM algorithm was instrumental in producing LULC maps under the assumption that the data followed a multivariate Gaussian distribution. MLCSICM operates at the pixel level, classifying each pixel according to its likelihood in order to discriminate against other pixels. Assigned training pixels linked to a particular class are used to estimate the covariance matrix and class mean vector (Al et al., 2023; Allam et al., 2019). Using four Landsat satellite images acquired in 1992, 2002, 2012, and 2022, this study examines changes in LULC over a three-decade period. The dataset ensures continuity and consistency in monitoring by combining imagery from Landsat 4-5 TM, Landsat 7 ETM+, and Landsat 8 OLI/TIR sensors. With Datum WGS-84, all analyses are carried out inside UTM Zone 33N, offering a consistent geospatial reference. Restricting the selection of images to those with less than 20% cloud cover is a crucial criterion for improving the dataset's reliability (Choate et al., 2022).

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Table 4. 3

The description and composition of the LULC types used in the study.

Land Cover Class	Description/composition
Built-up Area	This covers residential, commercial, mixed-use, and industrial areas, settlements, (transportation-related infrastructure) road networks, railways, pavements, and man-made structures, (tents, and temporary settlements) - All infrastructure.
Water bodies	This area is characterized by river, lakes, ponds, canals, drainage canals and reservoirs. This represents all bodies of open water, regardless of depth, including all kinds of moving and stagnant bodies of water in the region.
Green Land	These represent all kinds of vegetation such as Neem trees and other scattered trees, natural vegetation, gardens, parks, grassland, shrubs, and vegetated land found in the area regardless of density and height.
Agriculture/Farmland	These cover all types of cultivated land (crop field, urban agriculture), and irrigated lands.
Bare-land	This area is marked by fallow land, earth and sand land in-fillings, construction sites, excavation sites, open space, exposed soil, bare soils, and vacant land.

4.4 LULC accuracy assessment

The final and most important step in the classification of images is accuracy assessment. By measuring the degree of similarity between the generated and reference maps, it evaluates how well pixels (or segments) are assigned to the appropriate LULC classes (Amini et al., 2022; Diksha et al., 2023). Studies indicate that spectral images acquired by satellite sensors are often affected by numerous factors such as sensor calibration, atmospheric absorption, scattering, and illumination geometry. As a result, all the

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acquired images were subjected to radiometric calibration and geometric corrections to rectify the various surface reflectance variations due to the acquiring systems. This pre-processing operation improves atmospheric absorption/scattering, sensor sensitivity, topography and sun angle, scene illumination, and visible near-infrared wavelengths. necessary to ensure the exact positioning of an image (Young et al., 2017).

Compared to the Multispectral Scanner (MSS), these satellites provided higher radiometric and spatial resolution thanks to their TM or ETM+ sensors. These group's improved capabilities included increased bit depth, finer pixel size, and broader spectral coverage that included bands in the mid-infrared wavelength ranges. Interestingly, the term "shortwave infrared" (SWIR) has replaced the term "middle-infrared." Although middle-infrared and SWIR wavelengths typically span slightly distinct spectral ranges, the Landsat bands that are pertinent to this conversation are situated within the overlapped area.

One major benefit of supervised classification is its ability to identify and correct errors made during the procedure for classification. This feature improves the mapping of land cover accuracy. However, since analysts might not have selected all of the conditions present in the image, it is crucial to recognize the possibility of human error introduced during the training data selection process. Carefully selecting representative and diverse training samples is necessary to reduce this limitation. Several algorithms are frequently used in the context of supervised classification; each has advantages and disadvantages. Maximum likelihood classification (MLC), which is renowned for its adaptability and reliability (Allam et al., 2019; Ullah et al., 2023; Weng et al., 2004), was used in this investigation. With the right training data selection,

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this approach has a high classification accuracy that makes it one of the most widely utilized techniques for classifying LULC (Almalki et al., 2022). The complexities and variability observed within the research area are captured by this algorithm, which helps to create a solid and thorough classification of land cover. Furthermore, the potentials of other algorithms for classification are the artificial neural network (ANN), spectral angle mapper (SAM), random forest classifier based on tree decision (RF), and support vector machine (SVM) acknowledged.

$$Overall\ Accuracy = \frac{Total\ number\ of\ correctly\ classified\ pixels\ (diagonal)}{total\ number\ of\ reference\ pixels} \times 100\ \ category \quad (4.1)$$

$$User\ Accuracy = \frac{number\ of\ correctly\ classified\ pixels\ in\ each\ category\ (diagonal)}{total\ number\ of\ reference\ pixels\ in\ each\ category\ (row\ total)} \times 100 \quad (4.2)$$

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$$Producer\ Accuracy = \frac{number\ of\ correctly\ classified\ pixels\ in\ each\ category\ (diagonal)}{total\ number\ of\ reference\ pixels\ in\ each\ category\ (column\ total)} \times 100 \quad (4.3)$$

$$Kappa\ Coefficient = \frac{Total\ number\ of\ sample \times Total\ number\ of\ corrected\ sample - \Sigma(col.tol. \times row\ tol)}{(Total\ number\ of\ sample)^2 - \Sigma(col.tol. \times row.tol.)} \times 100 \quad (4.4)$$

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Table 4. 4

Land use land cover accuracy assessment

Year	Validation points for different LULC classes							
	LULC Class	Built-up Area	Water bodies	Grass Land	Farmland	Bare-land	Total	User Accuracy
1992	Built-up Area	36	0	1	0	3	40	0.9
	Water bodies	0	39	1	0	0	40	0.975
	Grass Land	1	1	34	2	2	40	0.85
	Farmland	1	0	0	35	4	40	0.875
	Bare-land	0	0	2	2	36	40	0.9
	Total	38	40	38	39	45	200	0
	Producer Accuracy	0.947368	0.975	0.894737	0.897436	0.8	Overall Accuracy 0.90	Kappa Coefficient 0.875
2002	Built-up Area	36	0	1	0	3	40	0.9
	Water bodies	0	40	0	0	0	40	1
	Grass Land	2	2	35	0	1	40	0.875
	Farmland	0	0	0	38	2	40	0.95
	Bare-land	0	0	0	0	39	39	0.975
	Total	38	43	36	39	43	199	0
	Producer Accuracy	0.947368	0.930233	0.972222	0.974359	0.906977	Overall Accuracy 0.94	Kappa Coefficient 0.931
2012	Built-up Area	37	2	1	0	0	40	0.925
	Water bodies	0	39	0	0	0	39	1
	Grass Land	2	1	35	2	0	40	0.875
	Farmland	0	0	0	39	1	40	0.975
	Bare-land	0	1	0	2	37	40	0.925
	Total	39	43	36	43	38	199	0
	Producer Accuracy	0.948718	0.906977	0.972222	0.906977	0.973684	Overall Accuracy 0.94	Kappa Coefficient 0.925
2022	Built-up Area	37	1	2	0	0	40	0.925
	Water bodies	0	40	0	0	0	40	1
	Green Land	2	0	36	2	0	40	0.9
	Farmland	0	0	2	33	5	40	0.825
	Bare-land	1	1	0	2	36	40	0.9
	Total	40	42	40	37	41	200	0
	Producer Accuracy	0.925	0.952381	0.9	0.891892	0.878049	Overall Accuracy 0.91	Kappa Coefficient 0.888

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Using both firsthand experience and the aid of Digital Globe imagery (Google Earth), the five distinct types of land cover in the area under study were identified and categorized. To identify land cover dynamics, the traits of each type of land cover were outlined and measured in kilometers (km^2). To accomplish this, statistics for each type of land cover were generated using ArcGIS's "Calculate Geometry" tool, guaranteeing precise and consistent area measurements. Table 4.2 provides an in-depth description of the attributes and spatial distribution of the different land cover types, along with an in-depth description of their nomenclature.

4.5 Changes in Magnitude, Trend Percentage, and Annual Change Rate

The ArcGIS "Calculate Geometry" tool is a highly effective and adaptable tool for precisely quantifying polygon areas. The tool was utilized in this study to compute and document area measurements for the polygons in the attribute table. The decision to use the measure of square kilometres as the preferred unit of measurement made it possible to generate accurate and consistent area values for every polygon feature. The results were systematically recorded as an additional entry in the attribute table, which made it easier to do further analysis and improved the dataset's overall spatial understanding. This crucial procedure is important for many uses, especially in this research where it was utilized for land cover examinations and yielded insightful spatial data via spatial analysis across the GIS framework. This is consistent with a similar methodology used by Abbas et al., 2018; Idowu, (2013), who made use of the "Calculate Area" tool in the ERDAS Imagine software.

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Sustainable management of land and environmental monitoring depend heavily on the dynamics of LULC. It is crucial to comprehend how these dynamics change over time to make wise decisions and arrange resources efficiently (Kaiser et al., 2022; Koko et al., 2021; Rousta et al., 2018). The current study emphasizes the spatiotemporal assessment of land use and land cover patterns from 1992 to 2022 to determine the rates of change, trends, and percentage changes within various land cover types. Comparing statistical data becomes critical to understanding the complex changes that take place in different landscapes.

Two fundamental approaches were employed in this thorough analysis of the spatiotemporal evolution of land use and land cover change: Both pre- and post-classification. The pre-classification technique entailed a thorough analysis of pixel differences across imagery acquired at different times. With the help of a specialized algorithm, I was able to analyse the digital numbers (DN) of cells and determine how land features changed over time. Furthermore, post-classification was applied, which entails classifying the different types of land cover independently for every image and then comparing the outcomes. By first classifying the land cover and then evaluating changes between these classifications, this method offers a distinctive perspective. By combining pre- and post-classification approaches, the study's analysis of temporal and spatial variations in land use as well as land cover was enhanced and a more thorough understanding of how this particular area evolved was provided.

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Table 4. 5

Change Magnitude of Maiduguri Metropolis from 1992 – 2022

Land Cover Types	1992 - 2002 (km^2)	2002 - 2012 (km^2)	2012 - 2022 (km^2)
Farmland	-	24.57	-26.13
Bare land	52.35	156.42	- 95.74
built-up Area	-	3.53	1.02
Grass Land	-	18.7	65.93
Water bodies	-	5.57	2.77

Table 4.5 illustrates the variations in Land Use Land Cover (LULC) across three-time intervals: 1992–2002, 2002–2012, and 2012–2022. It presents the area changes (in km²) for five land cover categories. Agriculture/Farmland, Bare Land, Built-up Area, Grassland, and Water Bodies. Positive values indicate an increase in area, while negative values indicate a decrease, providing insights into the dynamic shifts within the urban landscape over three decades.

The data indicates significant urban expansion, with the Built-up Area increasing substantially by 56.54 km² between 2012–2022, reflecting accelerated urbanization. Conversely, the Agriculture/Farmland category experienced a notable decline between 2002–2012 (-26.13 km²) but saw a partial recovery of 47.09 km² between 2012–2022, possibly due to urban farming initiatives or land reclamation. The Bare Land category expanded significantly between 2002–2012 (+156.42 km²), likely due to deforestation or land degradation, followed by a marked reduction (-95.74 km²) in the subsequent decade, indicating efforts toward reforestation or urban greening. The Grassland experienced a major increase between 2002–2012 (+65.93 km²) but remained relatively stable afterward. Meanwhile, the Water Bodies category saw a

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slight decline (-1.94 km²) between 2012–2022, indicating potential water body reduction due to urban development or climate impacts.

To successfully carry out this change analysis, a thorough examination of the percentage variations and the extent of change for each static year (1992, 2002, 2012, and 2022) was conducted. Quantifying and understanding the changes in land use and land cover types across the designated temporal intervals is the primary objective. One important metric for determining the degree of changes within each LULC class is the magnitude change, which is computed by deducting the area coverage of the following years from that of the first year (I. I. Abbas et al., 2018), as observed in equation (I). The study intends to provide a significant understanding of the spatial dynamics of the area under study area by exploring these quantitative measures, setting the basis for rational approaches to land management and well-informed decision-making.

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$$Magnitude = Magnitude\ of\ the\ new\ year - Magnitude\ of\ the\ previous\ year \quad (4.5)$$

The next stage of the analysis was to determine the percentage change (trend) for each type of land use and land cover (LULC). Equation iv outlines how this crucial metric was established by dividing the magnitude change associated with every LULC class by the area coverage of the base year and multiplying the result by 100.

$$Tend = \frac{Magnitude\ of\ chane}{Sum\ of\ change} \times 100 \quad (4.6)$$

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Table 4. 6

The Trends of the LULC from 1992-2022

Land Cover Type	1992 - 2002 (km^2)	2002 - 2012 (km^2)	2012 – 2022 (km^2)
Farmland	-	2.086	0.073
Bare land	6.623	15.656	- 9.519
built-up Area	-	2.565	0.755
Grass Land	-	21.608	49.286
Water bodies	-	13.108	6.979

Table 4.6 displays trends in Land Use Land Cover (LULC) throughout three decades: 1992-2002, 2002-2012, and 2012-2022. The data captures changes in area (km^2) for several land cover types, such as agriculture/farmland, bare land, built-up areas, grassland, and water bodies. Positive values imply an increase in area, while negative values suggest a decline, providing insight into trends in the urban landscape.

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From 2012 to 2022, the Built-up Area increased by 29.535 km^2, indicating fast urbanization. The Agriculture/Farmland category declined by 2.086 km^2 in the first decade, but had positive increase in subsequent years, probably due to urban farming activities. Between 2002 and 2012, the Bare Land category increased dramatically (15.656 km^2), but then decreased by 9.519 km^2 in the last decade, possibly due to reforestation or urban greening activities. Grassland increased significantly from 2002 to 2012 (49.286 km^2), but stabilized thereafter. Between 2012-2022, there was a steady decrease in aquatic bodies, namely by 4.787 km^2. This could be attributed to urban expansion or climate changes.

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Each land cover (LC) type's annual rate of change was calculated by dividing the trend which was expressed as a percentage change by 100. Then, as shown in equation (III), the outcome was multiplied by the total number of study years that separated the two periods, which are represented by intervals like 1992–2002 (10 years), 2002–2012 (10 years), and 2012–2022 (10 years), see Table 4. 7.

$$Annual\ rate\ of\ change\ = \frac{Trend \times number\ of\ study\ years\ in\ between}{100} \qquad (4.7)$$

Table 4. 7

The annual change rate of the LULC from 1992-2022

Land Cover Types	1992 - 2002 (10)	2002 - 2012 (10)	2012 – 2022 (10)
Farmland	- 0.208	0.007	0.063
Bare land	0.662	1.565	2.953
Built-up Area	- 0.256	0.076	2.953
Grass Land	- 2.161	4.927	0.307
Water bodies	- 1.311	0.698	- 0.479

For the three decades 1992–2002, 2002–2012, and 2012–2022, the average yearly change rate for each Land Use Land Cover (LULC) category is shown in Table 4.7. To better understand the dynamics within each land cover category, the change rate is computed as the average yearly change in area (km²) for each 10-year interval.

Significant patterns can be seen in the data, especially in the Built-up Area, which showed a remarkable 2.953 km²/year growth rate between 2012 and 2022, indicating rapid urbanization. On the other hand, Agriculture/Farmland experienced a minor decrease of -0.208 km²/year over the first ten years, but recovered with positive

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growth rates in subsequent periods, maybe as a result of growing interest in urban farming or initiatives to revitalize agriculture. Between 2002-2012, the Bare Land category saw a significant increase of 1.565 km²/year, presumably due to deforestation or land degradation. This was followed by a rapid increase of 2.953 km²/year in the last ten years, indicating ongoing land exposure. Between 2002-2012, Grassland increased by 4.927 km²/year before stabilizing, while Water Bodies decreased by 1.311 km²/year between 1992-2002, possibly due to urbanization and decreasing catchment areas.

4.6 Land Surface Temperature (LST) Dynamics

The findings show a considerable and steady increase in surface temperature during the study period. The LST maps in Figure 4.6 show a definite rising trend in surface temperatures as heat intensification spreads outward from the city centre. In 1992, LST ranged from 13.88°C to 32.48°C, with cooler areas around vegetation and water bodies. By 2002, the maximum LST had risen to 40.71°C, while the lowest temperature had risen to 17.77°C, indicating the early phases of enhanced urban heat, which was most likely caused by increased built-up areas and vegetation loss. The maximum temperature occurred in 2012, when temperatures reached 49.11°C, indicating fast urban expansion and a worsening Urban Heat Island (UHI) effect. Although the maximum LST dropped slightly to 47.80°C in 2022, the minimum temperature remained high at 21.79°C, indicating ongoing heat stress.

These findings are consistent with Bello, (2021), who documented rising temperature anomalies in Maiduguri in recent decades, confirming a local warming

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trend. Similarly, Ladan et al. (2023) discovered that inhabitants attribute greater urban heat to increased building and less vegetation, which supports the spatial trends shown here. Furthermore, Buba & Ibrahim, (2018) identified a general warming trend in northern Nigeria during the 1950s, with even the least urbanized areas enduring significant temperature rises, highlighting the region's vulnerability to climate change.

Ugonabo et al., (2023) reinforce this warming trend by reporting that Maiduguri remains hot for the majority of the year, with average yearly temperatures around 37°C and persistently low humidity, characteristics that promote heat buildup in urban areas. Likewise, Jimme et al., (2016) and Mayomi & Mohammed, (2014) reported that daily temperatures in Maiduguri routinely reach 40°C, especially during the hottest months of March and April, which is consistent with the elevated LST values recorded in 2012. The Annual Average Temperature Maps (Figure 3.2) for the last three decades show the spread of high-temperature zones, which aligns well to expanding urban footprints and decreasing green areas.

Table 3.1 provides additional numerical details by capturing the average annual temperatures across the study locations and period. The citywide average temperature increased from 30.68°C (1992-2002) to 31.69°C (2012-2022), with hotspots such as Tamsu Ngamdua (32.03°C), Gwange I (31.90°C), and Mairi (31.67°C) experiencing the most significant increases. These temperature increases match to the red and orange zones depicted in Figures 3.2 and 4.6, emphasizing the spatial expression of UHI effects.

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This is reinforced by a study on urban development in Maiduguri published in the Jalingo Journal of Social and Management Sciences by (Jimme et al., 2016), which linked urban sprawl to higher surface temperatures and worsening of the environment. Olanrewaju, (2018) Similarly observed in northern Nigerian cities, demonstrating that urbanization causes long-term increases in surface temperature due to diminished vegetation and increasing impervious surfaces.

These temperature increases are directly related to changes in LULC, specifically the alteration of natural land cover into dense urban buildings. The loss of vegetation and green spaces, which had been responsible for evapotranspiration and temperature regulation, has increased the urban environment's susceptibility to heat. This trend has been observed in other Nigerian cities; for instance, in Abuja, built-up areas rose by 19.93% while greenery declined by 35.63%, resulting in a temperature rise from 24.3°C in 1987 to 32.54°C in 2014 (Olanrewaju, 2018). Furthermore, Rehman et al. (2022) observed that higher LST classes grew by 25.18% due to urbanization, confirming that the loss of vegetative cover and increase in impervious surfaces are directly linked to rising urban temperatures. Integrating sustainable land use practices and reintroducing vegetation into the urban environment can help to minimize surface temperatures and mitigate UHI effects. This highlights the importance of urban farming, vegetation restoration, and climate-sensitive planning for Maiduguri's future development.

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Table 4. 8

Summary of LST (°C) for Maiduguri Metropolis (1992–2022)

Year	Minimum	Maximum	Mean	Standard Deviation
1992	13.88	32.48	26.84	1.46
2002	17.77	40.71	32.02	2.13
2012	20.78	49.11	36.95	2.49
2022	21.79	47.80	40.62	3.02

4.7 Derivation of NDVI, from the Landsat Imagery

Among the many indices used to identify vegetated land and its attributes is the NDVI. The NDVI is a commonly used urban climate indicator in environmental studies. For obtaining details of vegetation conditions via remotely sensed data, this index represents a reliable metric system The NDVI is a useful tool for evaluating urban climate dynamics because it analyses the spectral reflectance of various wavelengths to provide information about the density and health of vegetation (Koko et al., 2021). The NDVI, which is determined by dividing the red and infrared bands in satellite imagery, offers insightful information for any location (Allam et al., 2019). An essential metric for understanding urban climate conditions is the NDVI. The NDVI has a range of -1 to +1. Vegetation is represented by high positive values, built-up areas or bare soils by small positive values, and water bodies by negative values. It provides information on the phenology, health, and abundance of the vegetation. Equation 6 is used to calculate the NDVI using the red band and near-infrared (NIR) band (Jannat & Alam, 2022; Maskooni et al., 2021). Many distinct kinds of vegetation and non-vegetated areas can be distinguished using the NDVI method. It makes use of the spectral properties of

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these bands and is computed as the proportion of Red (R) with Near-Infrared (NIR) values (Rahman et al., 2022). Its preference for worldwide vegetation monitoring is a result of its capacity to adapt to changes in exposure, surface slope, lighting, and other environmental variables. The vegetation index, an important metric used in many research studies, was derived in this study using the NDVI.

The fundamental idea behind the NDVI is the difference in how green plants' chlorophyll reacts to light in the near-infrared (strongly reflected because of the spongy nature of the mesophyll leaf structure) and red (poorly reflected) spectrums. Because of this, NDVI provides a consistent method for mapping and contrasting the greenness of vegetation across different remotely sensed observations. On the other hand, (F. Chen et al., 2019), cautioned that even minute differences in the channel characterizations of different sensors can cause an increased bias in the NDVI.

NDVI is typically obtained from the difference between the near-infrared as well as red bands specific to the satellite sensor being used and is used to compute the NDVI from image pixels. For Landsat TM, it utilizes bands 4 and 3, while for Landsat OLI, it utilizes bands 5 and 4. Shown in the equation below, in the analysis is the specific equation that was used to obtain the NDVI results.

$$NDVI = \frac{NDVI_{(Band\ 4,5)} - NDVI_{(Band\ 3,4)}}{NDVI_{(Band\ 4,5)} + NDVI_{(Band\ 3,4)}} \qquad (4.7)$$

Where the NIR ranges from 0.76 to 0.90 µm (Band 4) for Landsat 4-5 TM and from 0.85 to 0.88 µm (Band 5) for Landsat 8 OLI. On the red band (RED), Landsat 4–5 TM

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as well as Landsat 7 ETM+ had a range of 0.63–0.69 µm (Band 3), while Landsat 8 OLI boasts a range of 0.64–0.67 µm (Band 4).

Land surface emissivity

Spectral data analysis is a common method for determining land surface emissivity, and the (NDVI) is an increasingly common instrument for this analysis. The red and near-infrared bands of a surface's spectral reflectance are used to calculate the NDVI. The amount of vegetation found within a pixel or area is represented by the Proportion of Vegetation (PV), a parameter obtained from the NDVI. The measurement of land surface emissivity is possible due to the relationship between vegetation cover and NDVI. After that, the mean emissivity value is computed using the relative amounts of the various surface elements.

4.8 Urban Heat Islands Estimation

The intensity of Urban Heat Island was quantified using a normalized statistical approach based on land surface temperature, computed as: UHI = (T - Tm) / Tsd, where T is the LST at a specific site, Tm is the mean LST of the research region, and Tsd is the standard deviation. This method standardizes temperature variances, allowing for the identification of hotspots (positive UHI values) in densely populated areas and cooler zones (negative values) in areas with vegetation or bodies of water. This approach is consistent with Rahman et al., (2022), who found that urban growth and

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vegetation loss greatly exacerbate LST and UHI impacts in quickly expanding locations. This methodology provides a dependable method for mapping and interpreting the spatial extent of UHI in Maiduguri.

This portion offers a set of geospatial maps and raster-based estimates for 2002, 2012, and 2022 to assess the geographical and temporal dynamics of the Maiduguri Urban Heat Island. Each map depicts land surface temperature distributions obtained from satellite data and normalized using raster computations to provide a standardized UHI index. These figures show a visual and quantitative representation of thermal intensity across the metropolis, emphasizing the effects of urbanization, land cover change, and vegetation loss over time. The accompanying inset graphs and raster data offer further insight into the course, concentration, and variance of UHI effects, giving a basis for analyzing environmental impacts and informing mitigation efforts.

To assess the intensity of the Urban Heat Island effect across different areas within Maiduguri, the following raster calculation formula was used, the equation below illustrates the calculation of UHI utilized in many studies (Rahaman et al., 2022; Rahman et al., 2022).

$$UHI = \frac{T - Tm}{Tsd} \qquad (4.8)$$

Where:

UHI = the Urban Heat Islands

T = the Land Surface Temperature

Tm = The mean temperature of land surface temperature in the study area

Tsd = The standard deviation of Land Surface Temperature

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This normalized index facilitates spatial comparisons of urban heat intensities by identifying hot spots and variations in the city's thermal behavior. The growing impact of the Urban Heat Island phenomenon on environmental change and urban climate has become a pressing global concern (Rahman et al., 2022). In response, various methodologies have been employed worldwide to detect UHI formation and to quantify its magnitude and spatial extent. These methods range from numerical modeling and in situ ground-based temperature measurements to remote sensing techniques using satellite-derived thermal imagery. Such approaches enable researchers to analyze temperature disparities between urban and rural areas, offering critical insights into the scale and severity of UHI effects (Rahaman et al., 2022; Rahman et al., 2022). For, urban sustainability and climate mitigation, an understanding of the dynamics of UHI is essential. Through the application of diverse methodologies in various geographical areas, researchers hope to gain a thorough grasp of how urbanization influences LULC shifts and, in turn, the emergence and effects of the UHI phenomenon on regional climates and ecosystems.

Figure 4.1 depicts Maiduguri's urban heat island pattern in 2002, providing a baseline for assessing thermal changes over time. The image displays land surface temperature variations using a green-to-red gradient, with cooler areas (as low as 2.72 °C) and hotter zones (up to 25.66 °C). Elevated temperatures are concentrated in the city's centre and densely populated sections, demonstrating a typical UHI effect induced by impermeable surfaces and sparse vegetation.

The figure below contains both a temperature profile and raster-based UHI calculations, which clearly show thermal peaks in urbanized zones and dips in greener

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or less developed areas. These data demonstrate that fast urbanization, the loss of green space, and increasing surface sealing all contribute to early-stage UHI generation.

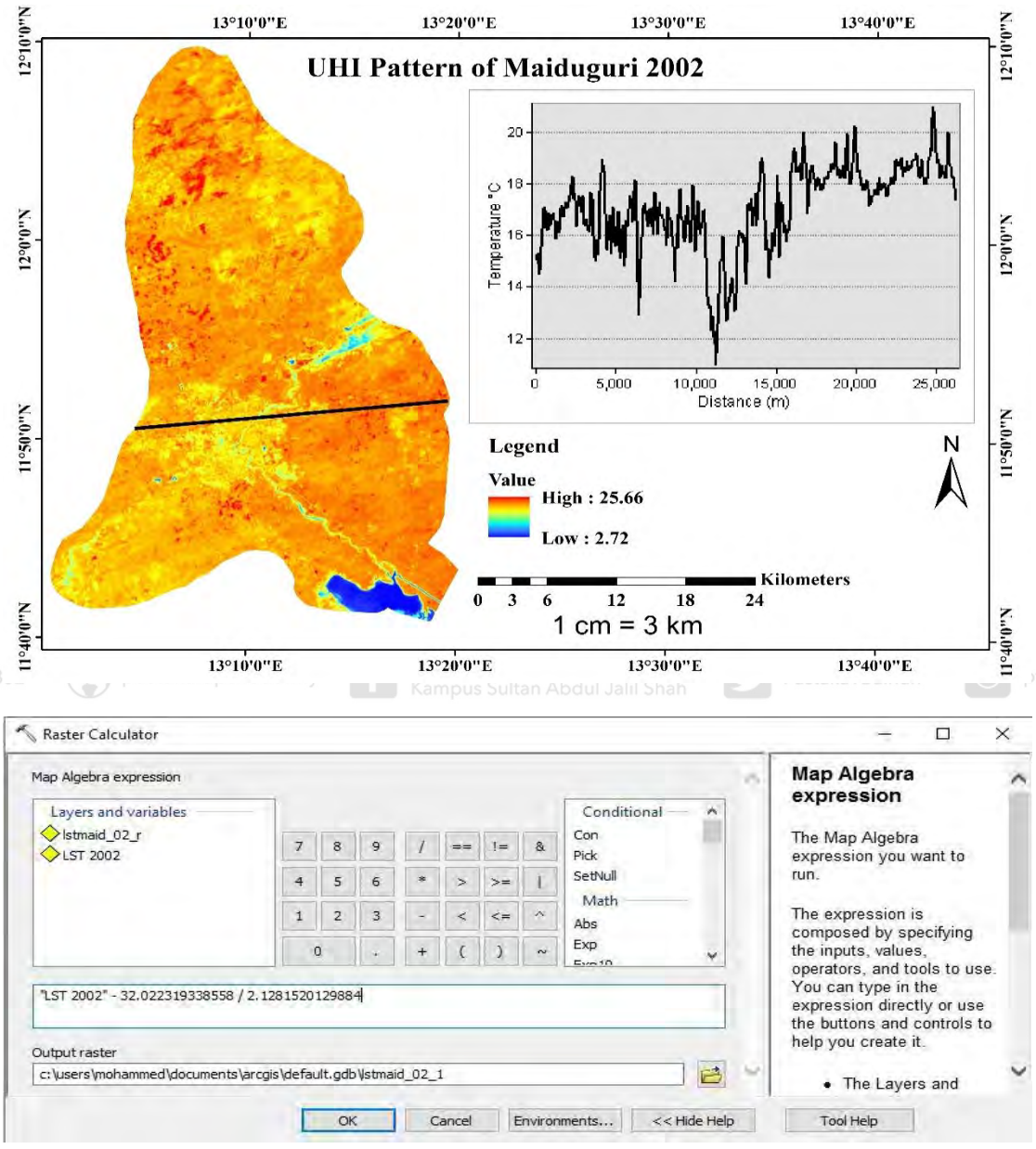
The inset graph reinforces this by showing a temperature profile across the city. Peaks in the graph indicate areas of intense urbanization with higher LST values, whilst dips show green spaces or less urbanized areas. The significant temperature changes in the profile reflect the difference between developed and undeveloped or vegetated areas. The high LST values are consistent with growing urbanization, loss of vegetative cover, and expansion of built-up areas, all of which contribute to greater heat stress.

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Figure 4. 1

UHI Pattern of Maiduguri Metropolis in 2002 with Raster-Based Temperature Index.



Furthermore, the graphs for the UHI maps of 2002, 2012, and 2022 illustrate the variation in Land Surface Temperature across Maiduguri. The X-axis represents the distance along the transect line in meters, while the Y-axis shows the LST in degrees Celsius. These graphs enable a visual comparison of UHI intensity and spatial distribution over time, showing temperature changes across different parts of the city.

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Figure 4.2

UHI Pattern of Maiduguri Metropolis in 2012 with Raster-Based Temperature Index.

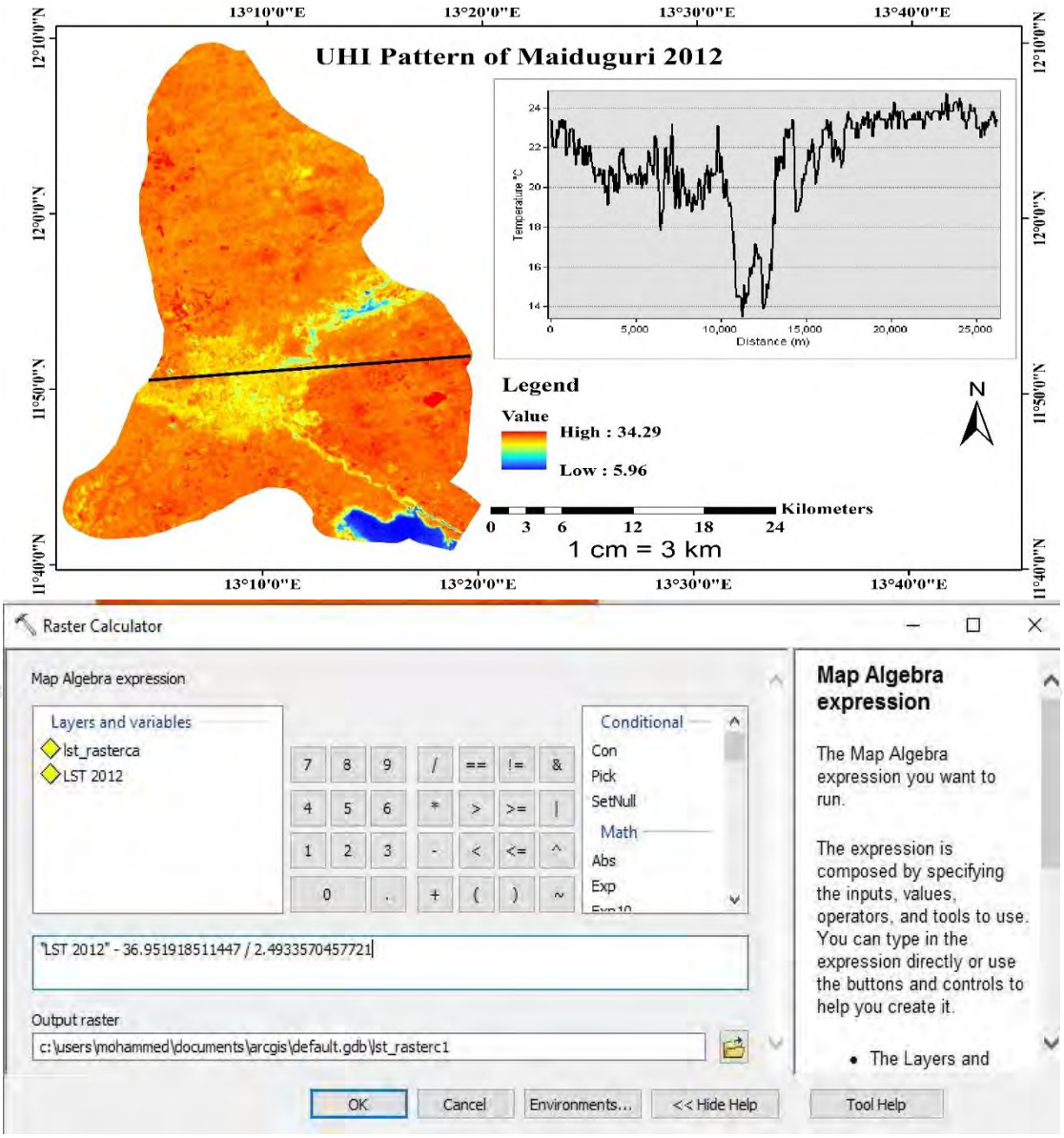


Figure 4.2 shows the Urban Heat Island pattern in Maiduguri for 2012, demonstrating a significant increase from 2002. The maximum land surface temperature reached 34.29 °C, while the minimum was 5.96 °C, indicating a wider temperature range and increased heat stress. The image shows an unprecedented rise of high-temperature

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zones, notably in the urban core, showing the effects of increased impervious surfaces and the loss of vegetated buffers.

The image contains a raster-derived UHI index and a temperature profile, both of which demonstrate consistent high-temperature peaks across larger urban regions. This geographical homogeneity indicates that urban heat intensity has become more widespread and persistent, owing to increased urban development, denser construction, and shrinking green space. These patterns confirm that the UHI phenomena has intensified during the last decade.

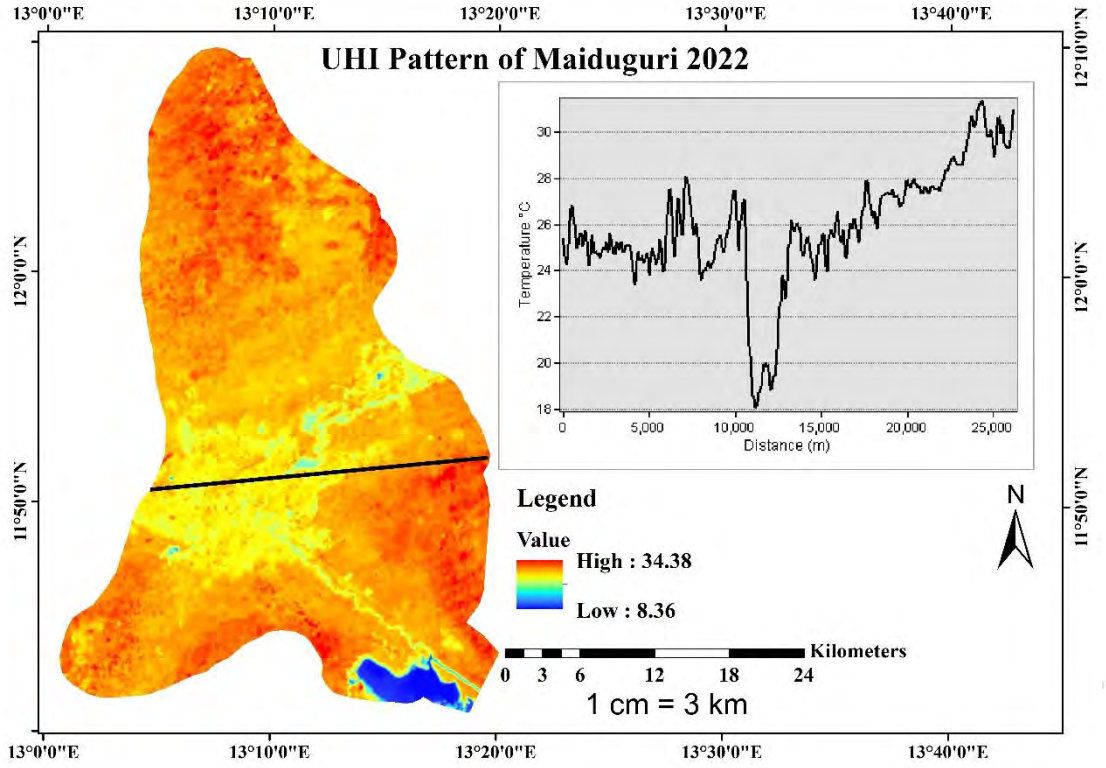
Figure 4.3 shows Maiduguri's UHI configuration in 2022, with a peak temperature of 34.38 °C and a minimum of 8.36 °C, slightly higher than 2012. Although high temperatures continue to thrive in major metropolitan areas, there is some fragmentation of high-heat zones, which could signal localized improvements due to vegetation or urban planning initiatives. The inset combines raster UHI results with a temperature profile to show more variations in heat intensity across the city. The variations in the graph represent fresh development combined with green or less urbanized patches. While such changes may indicate growing mitigation initiatives, the continuation of high LST zones suggests that the UHI threat remains serious, necessitating more integrated cooling techniques.

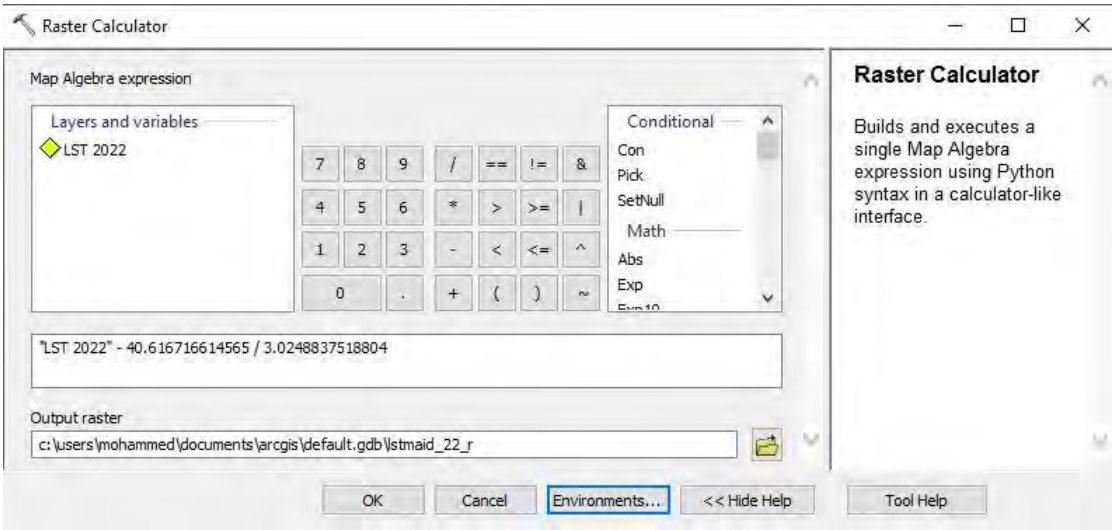
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Figure 4. 3

UHI Pattern of Maiduguri Metropolis in 2022 with Raster-Based Temperature Index.





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Despite these efforts, the overall pattern suggests that the UHI effect is still a significant challenge, requiring more effective and comprehensive mitigation strategies, such as increased urban farming and vegetation cover, to mitigate rising temperatures and promote urban sustainability.

4.9 Spatiotemporal Pattern of LU/LC Dynamics

The spatial distribution of LULC classes in the Maiduguri metropolis, which encompasses five categories under investigation, is shown in the LULC maps and tables. Multi-temporal satellite image analysis has been used to classify LULC classes; this process is summarised in Table 4.2 and shown in Fig. 4.1. In 1992, the metropolitan area's built-up area accounted for roughly 7054.89 km^2 or 6.3% of the study area. At 53.8% (60114.45 km^2), agricultural or farmlands emerged as the most common land cover, which was followed by bare lands at 33% (36897.86 km^2). Moreover, water bodies made up 2.2% (2403.07 km^2), and green land covered 4.7% (5261.83 km^2). This classification corresponds with Bello, (2021) exact identification of every class apart from water bodies in line with the goals and parameters of his research.

However, by 2002, the built-up area had decreased to 6%, attributed to population growth as the major contributing factor. Notably, grassland was reduced to 3.0%, water bodies to 1.7%, and farmland to 51.6%. In contrast, bare land increased to 37.7%, highlighting the abandonment of even agricultural lands in this agrarian community. Multiple factors may have influenced these results, potentially linked to the introduction of democracy in 1999. During this period, the state government

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initiated extensive housing estates, including the construction of many houses, leading to the migration of local politicians from city fringes to the centre. Similar developmental programs across the 27 local government areas in the state also contributed to the shift, reducing pressure on the city centre, with some senior politicians relocating to the nation's capital. According to Abdul-Azeez, (2018), the state government has been carrying out an in-fill housing development program in the last decade, which entails relocating and utilizing open spaces in existing layouts for development. About 4,000 housing units have been constructed in Maiduguri over the past 20 years at various locations under the direction of various Borno State governments. Among the noteworthy projects are the 101, 202, 303, 505, 707, and 1001 Housing Estates (1999–2009), as well as the Teacher's Village Estate and the Legacy Gardens Estate in Bulumkutu ward.

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The built-up area had risen by a meagre 6.1% by 2012. This was mostly due to the insurgency's disruptive actions, which effectively stopped every productive endeavour in the state. After remaining stable between 1992 and 2022, the study area's predominant agricultural/farmland saw a sharp decline in 2012, falling to about 31.3%. While grassland and water bodies widened to 9.0% and 1.7%, respectively, at the same time, the bare surface increased to 51.7%. This result is consistent with a study done in Maiduguri by Sambo and Ikusemoran, (2022), who found that the number of water bodies expanded by almost doubled between 1987 and 2017.

In 2022, there was a notable rise in the built-up LULC class, which constitutes the city core. The built-up LULC increased sporadically between 1992 and 2022, reaching a sharp peak of 11.3% (compared to 2012 figures), as shown in Fig. 4.1. A

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significant proportion of Maiduguri's urban growth was observed in regions that were previously thought to be peripheral. According to Jimme et al., (2019), these areas included the Brigadier Mai Malari and Giwa Barrack areas, the Bulumkutu/Ngomari area, parts of the Gamboru Ngala and Dikwa roads, Baga roads, the University of Maiduguri (Unimaid) and its surrounds, and other outlying suburbs. The University, which is situated north of Ngomari Costain, has seen some of the most notable developments aimed at providing for the increasing demand for housing, especially from university students.

The resulting land use/land cover maps were displayed in Table 4.2, and Figure 4.2 and 4.3, and the area covered by the various land use/land cover classes and their rate of change were revealed in Tables 8 and Figure 2. According to this analysis, the built-up area increased gradually between 1992 and 2012 and substantially between 2012 and 2022. This is a result of both increased anthropogenic activities and residential development due to the region's dynamic population growth. In addition, a major factor in the observed increase in built-up areas was the influx of people who had been internally displaced (IDPs) from different local government areas devastated by the ongoing insurgency.

In line with the data presented in Tables 4 and 5, the predominant land use and land cover (LULC) in Maiduguri in 1992 was agricultural/farmland and bare land. This type of land cover accounted for 86.8% of the total land cover and constituted a significant portion of the study area, measuring 97012.31 km^2. On the other hand, with 7664.9 km^2, or 6.9% of the total land cover, grasslands, as well as water bodies consisted of the least common land cover types. In contrast to built-up areas, water

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bodies, bare surface, and agriculture/farmland, bare land increased from 33% in 1992 to 37.7% by 2002. Furthermore, the coverage of agriculture and farmland fell slightly over the next period, from 53.8% in 1992 to 51.6%.

There was a slight increase in the built-up area between 2002 and 2012. In the meantime, the built-up area experienced the greatest rate of expansion, rising from 6804 km^2 (6.1%) to approximately twice that amount at 12458.25 km^2 (11.2%). From 42132.88 km^2 (37.7%) to 57775.46 km^2 (51.7%), the bare surface increased. Notably, water bodies increased from 1845.68 km^2 (1.7%) to 2122.66 km^2 (1.9%), eventually declining to 1928.98 km^2 (1.7%) in 2022. Grassland, on the other hand, significantly increased from 3398.11 km^2 (3.0%) to nearly triple its size at 9984.87 km^2 (9.0%).

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The results of (Mayomi & Mohammed, 2014; Sambo & Ikusemoran, 2022) who observed an almost twofold increase in the size of bare surfaces, are in line with this study. This pattern is consistent with both the growth of built-up areas and the ongoing population increase. As a result, factors like urbanization, farming, and the removal of trees for fuel wood have contributed to environmental degradation and vegetation depletion. Given the observed decrease in vegetation and expanding bare surface areas, it is critical to implement prompt and efficient planning procedures to preserve the natural environment and vegetation in the metropolis for sustainable growth. The findings of this study align with those of (Sambo & Ikusemoran, 2022). highlighting the importance of tackling vegetation loss as a serious environmental problem and the necessity of careful planning and conservation measures to guarantee sustainable development. Furthermore, The detrimental effects of urbanization and construction are highlighted in the analysis of Land Use and Land Cover (LULC) change in Maiduguri

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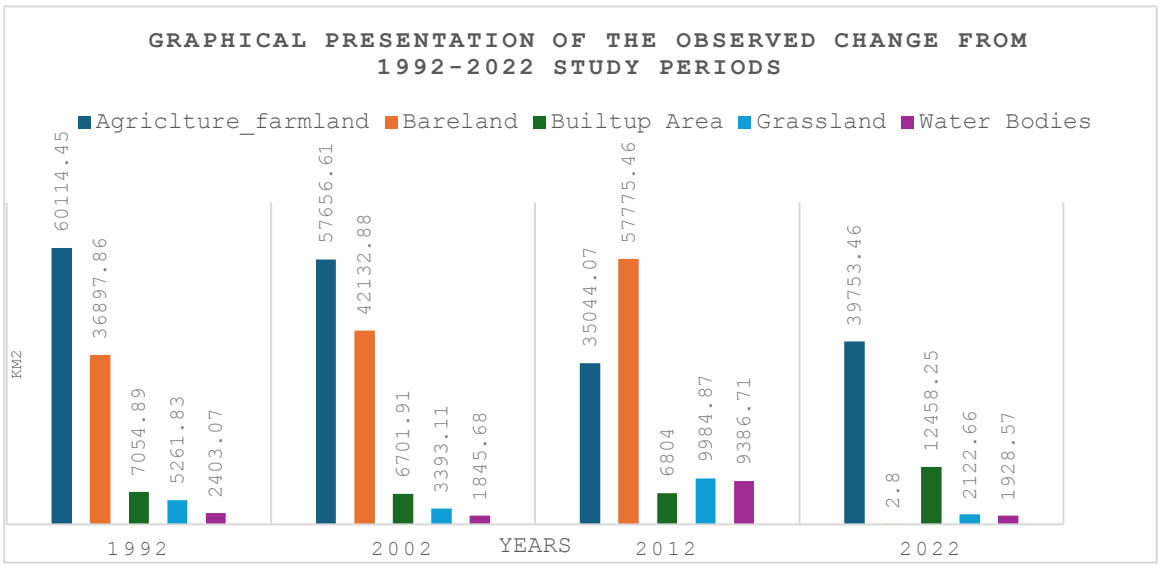
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(Bello, 2021), highlighting the risk of food insecurity due to the direct conversion of farmland to construction land. Land use changes cause biodiversity loss and aid in the extinction of some plants and animals, particularly in areas like Galtimari, Dala Alamderi, and Mairi districts on the outskirts of the city.

The figure below 4.2 shows the observed land cover changes between 1992 and 2022 demonstrate major changes in Maiduguri's metropolitan landscape, with important consequences for the metropolitan Heat Island (UHI) effect and urban sustainability. Agricultural land decreased from 60,114.45 km² in 1992 to 39,753.46 km² in 2022, whereas bare land expanded until 2012 (57,775.46 km²), then decreased to 39,753.46 km² in 2022. Urbanization has accelerated, with built-up areas more than doubling from 7,054.89 km² in 1992 to 12,458.25 km² by 2022. Grassland area decreased from 5,261.83 km² to 2,122.66 km², indicating a loss of natural vegetation. Water bodies were stable, decreasing slightly from 2,403.97 km² to 1,928.57 km².

Figure 4. 4

LULC distribution of Maiduguri from 1992 to 2022 is shown in square kilometres.



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These patterns show the increased urban footprint and the resulting decline in vegetative cover, which exacerbates UHI impacts by raising surface temperatures and diminishing natural cooling. The loss of green spaces and agricultural land emphasizes the importance of long-term urban planning measures in Maiduguri, like as urban farming and green infrastructure, to reduce rising temperatures and increase climate resilience.

Similarly, the categorized Land Use Land Cover (LULC) maps from 1992 to 2022 (figure 4.5) below show tremendous urban expansion and landscape transformation in Maiduguri over the last 30 years. The most noticeable change is the rapid expansion of built-up areas beyond the metropolitan core, replacing farms and green spaces. The built-up region was relatively confined in 1992, but it had expanded significantly by 2022, intruding on agricultural areas and lowering vegetative cover. This extension implies intense urbanization driven by population growth and development demands, which has most likely contributed to rising land surface temperatures and worsened the Urban Heat Island (UHI) effect. Additionally, bare areas have grown, indicating soil degradation and a decrease in vegetative ground cover, exacerbating the heat impact of urbanization.

Simultaneously, there has been a considerable loss in farms and green spaces, which are critical for moderating the UHI effect via evapotranspiration and shading. While water bodies appear to be rather stable, the loss of vegetation around them may impair their role in urban cooling. The decline in green spaces emphasizes the critical need for long-term urban planning efforts, particularly the incorporation of urban farming and green infrastructure as UHI mitigation techniques. Urban farming, when

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intelligently implemented, has the potential to help restore lost green spaces, improve local food security, and contribute to climate resilience. However, as the maps show, urban expansion continues to outstrip green conservation initiatives, underlining the importance of good governance, policy interventions, and community engagement in balancing development and environmental sustainability.

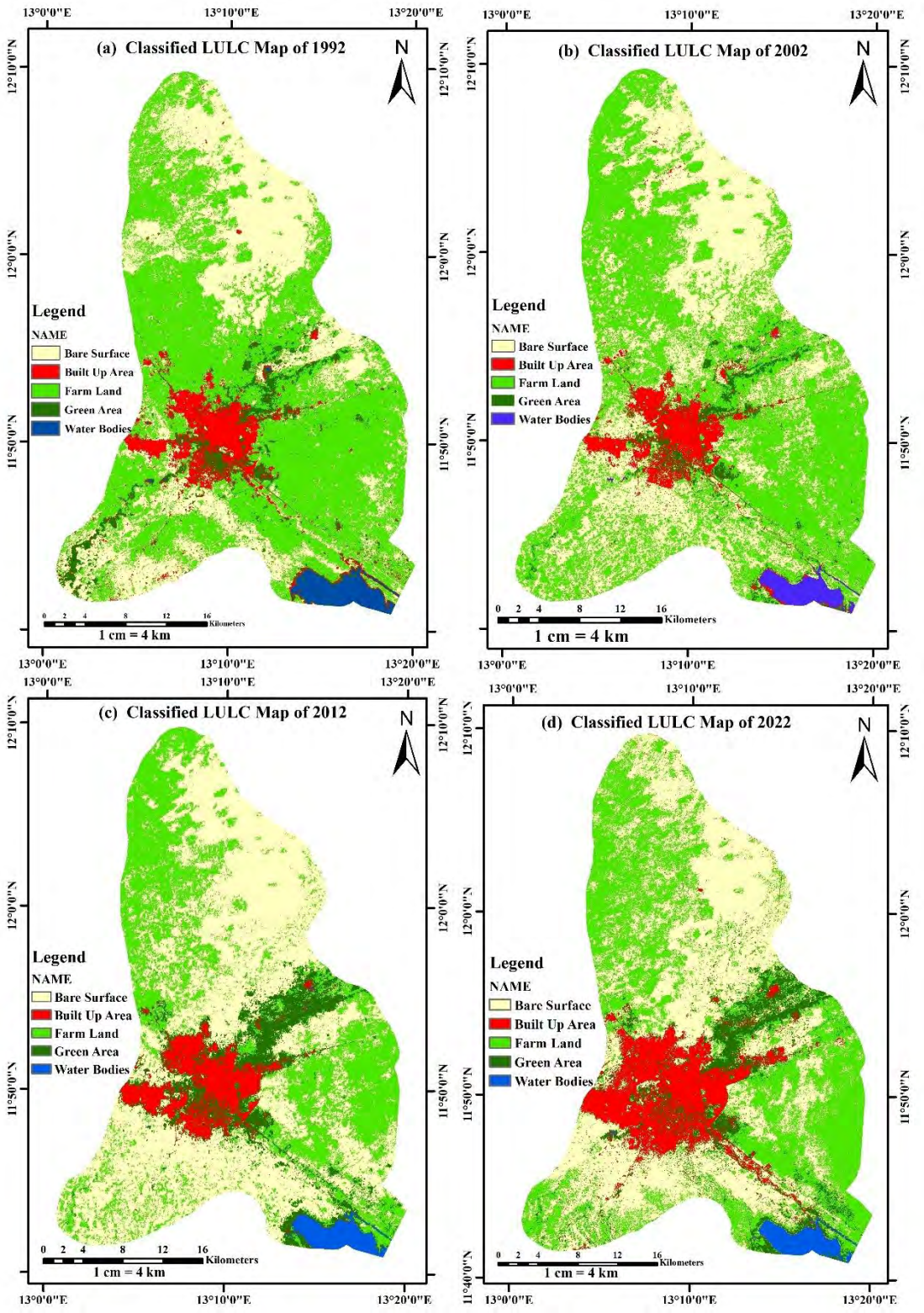
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Figure 4. 5

Classified LULC maps of Maiduguri in; 1992, 2002, 2012, and 2022



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The Land Surface Temperature (LST) maps from 1992 to 2022 shown in (figure 4.6) below illustrate a clear upward trend in surface temperatures across Maiduguri, reflecting the impact of urbanization and diminishing vegetation cover. In 1992, the city's LST ranged from 13.88°C to 32.48°C, with cooler areas predominantly concentrated near water bodies and vegetated zones. By 2002, the maximum LST had increased to 40.71°C, while the minimum rose to 17.77°C, indicating a noticeable rise in urban heat likely due to the expansion of built-up areas, reduced vegetation, and increasing human activities. The intensification of urban heat during this period suggests the early stages of the Urban Heat Island effect.

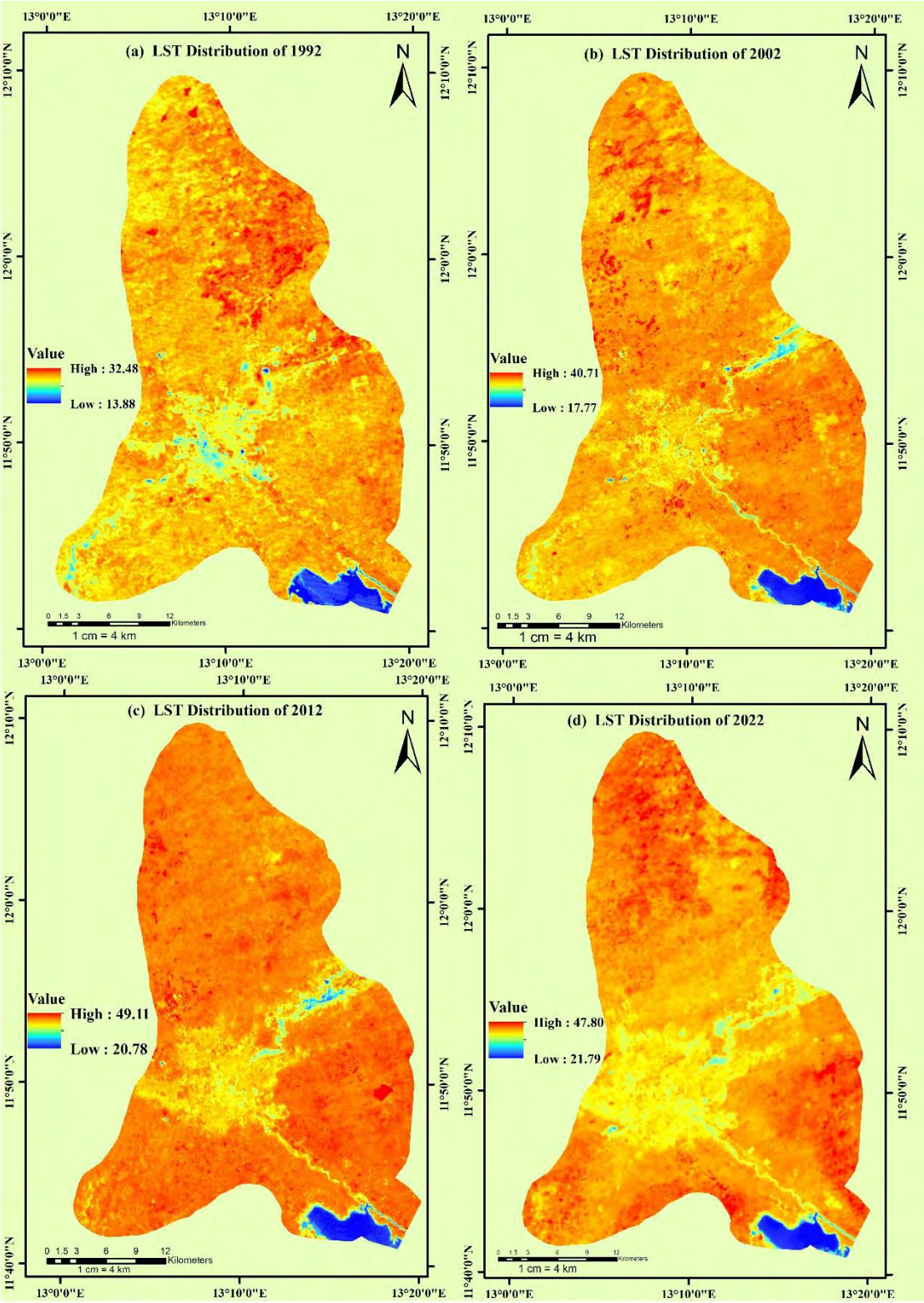
The most substantial temperature spike occurred in 2012, with LST values peaking at 49.11°C, highlighting the exacerbation of the UHI effect. The considerable increase in surface temperatures corresponds with rapid urban expansion, land use changes, and a decline in green spaces. Although the maximum LST slightly decreased to 47.80°C in 2022, the persistent high temperatures (minimum of 21.79°C) indicate that the UHI effect remains a significant concern. The limited reduction in temperature could be attributed to some greening efforts or the stabilization of urban growth. However, the extensive red zones in the 2022 map reveal that heat stress is still prevalent across the city, necessitating strategic interventions like urban farming, green infrastructure, and sustainable urban planning to mitigate UHI impacts and enhance urban resilience in Maiduguri.

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Figure 4. 6

LST Distribution of Maiduguri Metropolis in 1992, 2002, 2012, and 2022



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The NDVI maps from 1992 to 2022 shown in (figure 4.7) below reveal significant spatiotemporal changes in Maiduguri's vegetation cover, illustrating the interplay between urbanization, agricultural activities, and environmental conservation. In 1992, the city exhibited relatively high NDVI values (maximum of 0.463), indicating dense vegetation, particularly in the northern and central regions. However, by 2002, a substantial decline in NDVI values (maximum of 0.221) was observed, signifying vegetation loss likely due to urban expansion, deforestation, and agricultural encroachment. The presence of more extensive areas with low NDVI values (-0.528) in 2002 reflects increased built-up areas and possible land degradation, aligning with the rapid urbanization experienced during that period.

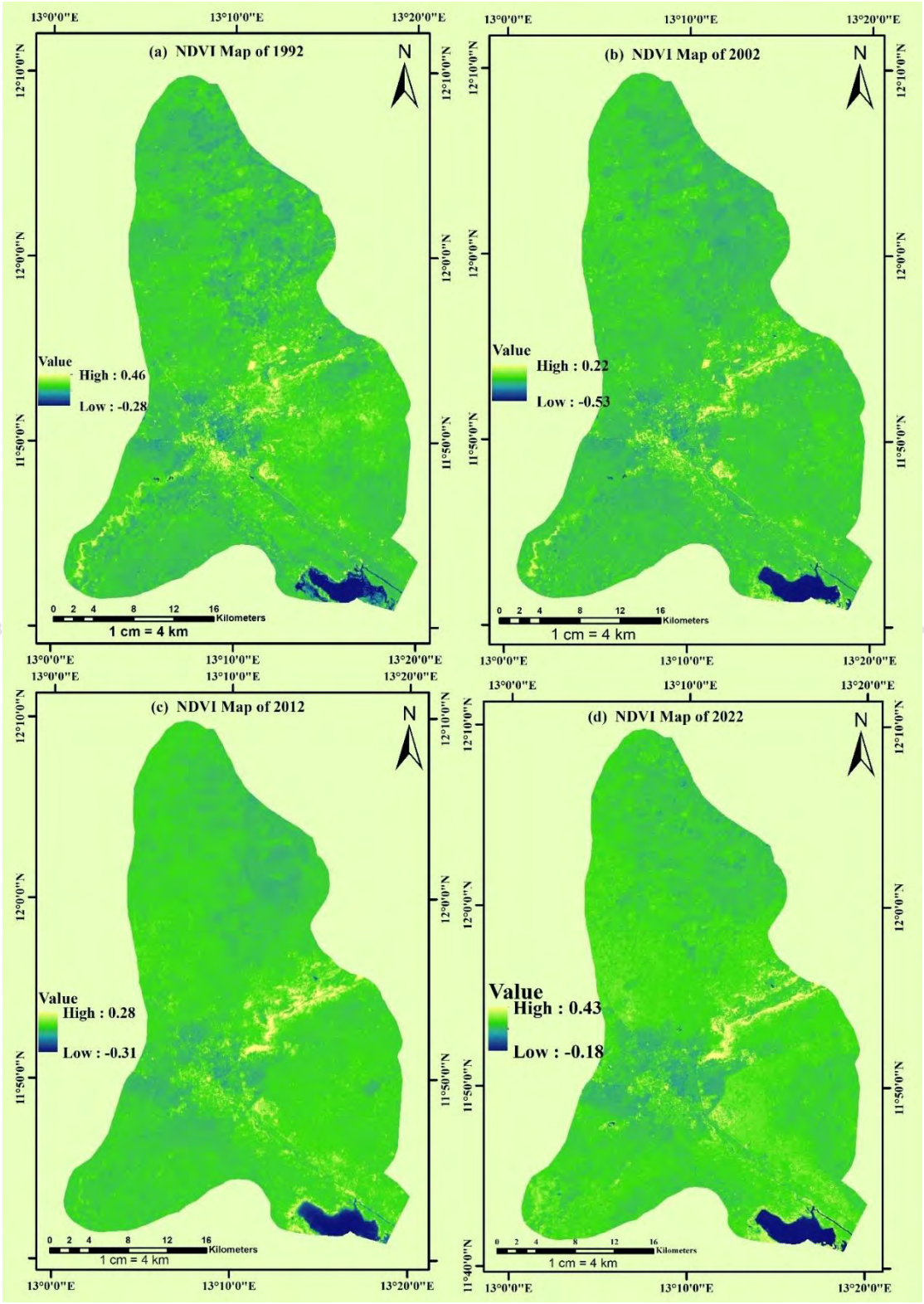
From 2012 to 2022, there is a gradual recovery in NDVI values, with the maximum NDVI increasing to 0.430 in 2022. This improvement may indicate reforestation efforts, urban greening initiatives, or a shift toward sustainable agricultural practices. However, the persistence of low NDVI areas (-0.179) suggests that urban growth and environmental pressures continue to challenge vegetation cover. The fluctuating NDVI trends highlight the need for more sustainable land use policies to balance urban development with environmental conservation. Effective integration of urban farming, green infrastructure, and afforestation programs could help mitigate the Urban Heat Island (UHI) effect while enhancing urban resilience in Maiduguri. These insights emphasize the importance of strategic urban planning to reduce the adverse effects of urbanization and foster sustainable urban ecosystems.

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Figure 4. 7

NDVI Spatial Distribution of NDVI of Maiduguri Metropolis in 1992 – 2022.



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4.10 Relationship Between Land Surface Temperature and Vegetation Cover

The NDVI in the Maiduguri Metropolis study over four distinct periods (1992, 2002, 2012, and 2022) was analyzed. A range of NDVI values was found in the results, with the highest values (roughly 0.22 to 0.46), demonstrating areas dominated by agriculture/farmlands, shrubs, and grasslands. Conversely, bare land, water bodies, and built-up areas were linked to the lowest NDVI values ranging from -0.18 to -0.53. These results point to a dynamic landscape with changing patterns of urbanization and vegetation cover throughout the study periods.

There is a significant relationship between vegetation intensity's spatial distribution and UHI and LULC. The UHI effect is exacerbated in urban areas by impervious surfaces like concrete and asphalt, which tend to take in and retain more heat. Local temperature regulation is greatly influenced by the type of land cover present, including the availability or absence of vegetation. In addition to reflecting sunlight, providing shade, and releasing moisture through transpiration, vegetation also helps to reduce the heat island effect (Rahaman et al., 2022).

Land surface temperature and vegetation cover in Maiduguri are clearly inversely related, according to the analysis of NDVI and LST maps for the years 1992, 2002, 2012, and 2022. This relationship is fundamental to research on urban climate because vegetation is essential to regulating microclimates through shading, evapotranspiration, and albedo modification (Chen et al., 2019; Rahaman et al., 2022; Rahmad et al., 2019; Ramaiah et al., 2020). NDVI values, which are derived from the red and near-infrared spectral bands of Landsat imagery, offer a reliable indicator of

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the health and density of vegetation; areas with higher NDVI values (usually above 0.2) indicate sparse vegetation, built-up land, or water bodies (Jannat & Alam, 2022; Allam et al., 2019).

In 1992, the NDVI ranged from -0.28 to 0.46, indicating a significant vegetal presence, particularly in the city's southern and southwestern areas. The corresponding LST values during the same period were modest, showing that vegetation lowered land surfaces. However, by 2002, NDVI readings had decreased significantly (varying from -0.53 to 0.22), correlating with growing urbanization and loss of green cover. This degradation of vegetation corresponded to greater LSTs throughout the study area, particularly in the central and northern zones, where land use had rapidly changed from natural to built-up areas.

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With varying but generally declining NDVI values in urban cores, the trend persisted in 2012 and 2022. The overall trend of vegetation loss was not reversed, despite a minor recovery in the peak NDVI (0.43) in 2022. NiMET meteorological data, which showed an increase in average daily and monthly maximum air temperatures throughout Borno State, is consistent with the rise in LST seen in these years. The relationship between vegetation loss and surface warming is further supported by the correlation between ground-based NiMET records and satellite-derived LST. Urban expansion lowers vegetation cover, increases impervious surfaces, and thus raises LSTs, according to numerous studies that have validated this pattern both internationally and in Nigeria (Olanrewaju, 2018; Rahaman et al., 2022).

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The spatial inverse correlation between LST and NDVI highlights the critical role of vegetation in mitigating the Urban Heat Island (UHI) effect. The statistical normalization of LST using the UHI index (UHI = (T - Tm) / Tsd) further demonstrated that zones with low NDVI values consistently corresponded to high UHI intensity values, and these "hot spots" are often associated with high-density built-up areas lacking vegetative buffers, while "cool zones" with negative UHI values frequently aligned with areas of relatively high NDVI, such as along water bodies or vegetated edges.

Thus, the results validate that the primary cause of Maiduguri's elevated surface temperatures and, consequently, urban heat stress is the removal of vegetation. This finding is in line with the findings of Rahman et al. (2022), who emphasized that in many rapidly expanding cities, rising LSTs are closely related to lowering NDVI values brought on by urbanization. Similar to this, Maskooni et al., (2021) stressed that the NDVI is a reliable indicator of the potential for surface cooling in cities. These results provide compelling evidence in for incorporating sustainable land use planning, urban greening methods including urban farming, and green infrastructure restoration into climate resilience and UHI mitigation approaches

4.11 Urban Farming Practices in Maiduguri

To map and analyse UF locations over time, the study examined historical satellite imagery from Google Earth Pro between 2002 and 2022, as data for 1992 was unavailable. Using GIS analysis and physical audits, the study located and assessed four

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active UF sites for each identified year, determining their sizes (in hectares) and perimeters (in kilometres). The study focuses on assessing the level of urban farming practices, measuring their area and perimeter, and comparing data from 2002 to 2022 to analyse changes in their geographical extent and layout, providing insights into the evolution of urban farming in Maiduguri.

Google Earth Pro, in conjunction with GIS, has been effectively utilized to map and document UA sites, as demonstrated by Newell et al., (2022). This approach has been validated by studies where gardens were identified and scanned using these tools (Langellotto et al., 2018). Additionally, historical data spanning two decades, from 2002 to 2022, has been successfully acquired and analysed using these methods (Mayomi & Mohammed, 2014). This robust combination of tools provides a comprehensive and reliable means to study the spatial dynamics of urban farming sites over time.

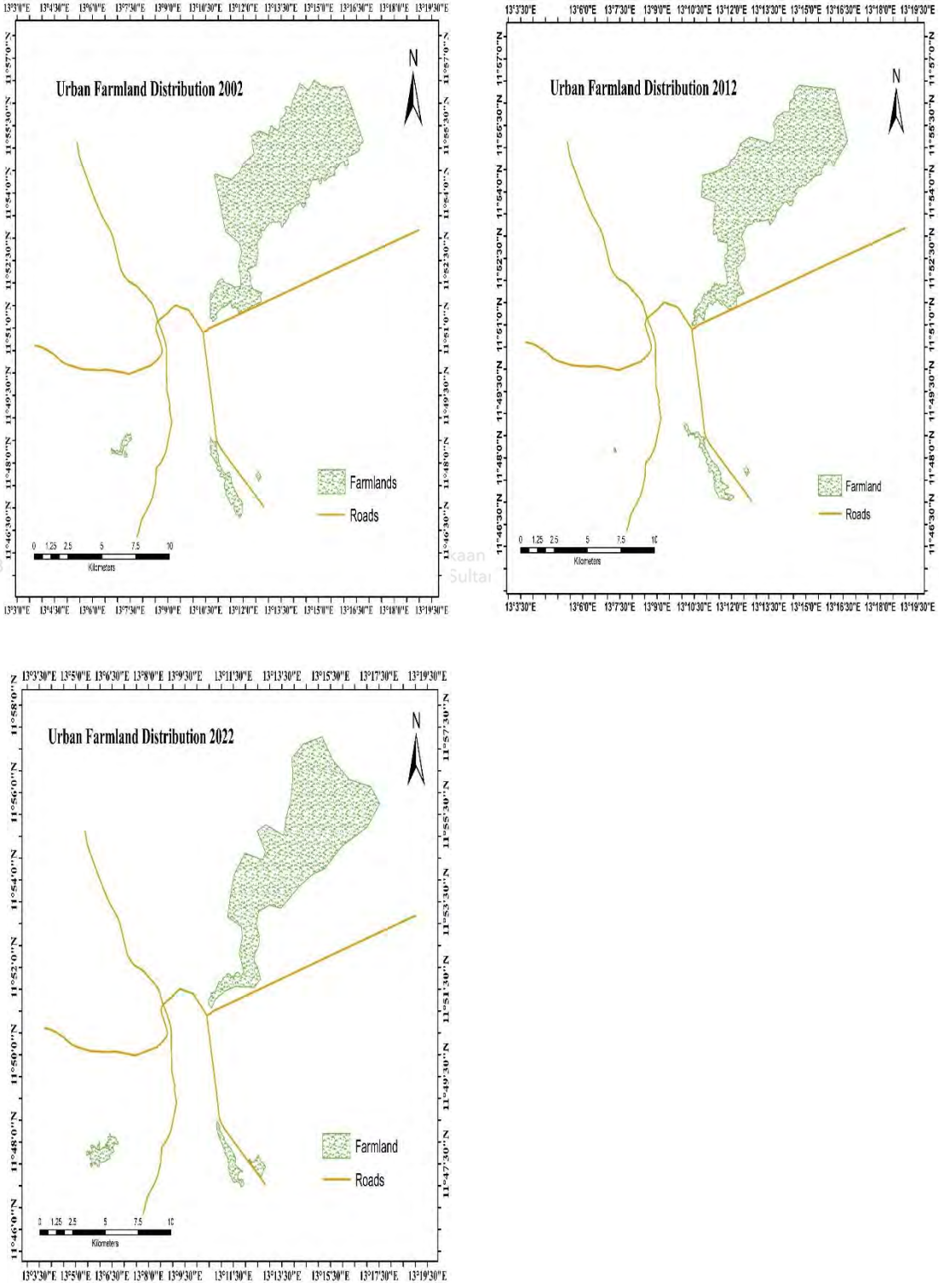
The table below presents an in-depth overview of urban farming sites in Maiduguri, highlighting variations in size and perimeter throughout three time periods: 2002, 2012, and 2022. The data includes four farming locations, with differences in geographic dimensions over the last two decades. This research seeks to depict the evolution and spatial dynamics of urban agricultural activities within the city, providing insights into how these sites have grown or shrunk over time.

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Figure 4. 8

Farm site Spatial Distribution of Maiduguri Metropolis in 2002 -2022



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The urban farmland distribution maps of Maiduguri shown in (figure 4.8) above provide a clear visual representation of the spatial dynamics and continuity of urban farming over the study period. In 2002, farmlands were prominently distributed in the northeastern part of the city, with additional fragmented patches observed around the city centre and the southern outskirts. These farmlands appeared relatively widespread, indicating the presence of active agricultural activity within the urban fabric at that time.

By 2012, a notable reduction in farmland coverage had occurred. This decline was particularly evident in the southern and central urban areas, likely due to the increasing encroachment of built-up infrastructure and the intensification of urbanization. The shrinking farmland footprint during this period reflects the growing competition for land amid expanding residential, commercial, and infrastructural developments.

Interestingly, the 2022 map shows a resurgence or persistence of urban farming, especially in the northeastern zone, where farmland coverage appears to have stabilized or even slightly increased compared to 2012. A significant observation is that most of the farming sites are located along river channels, which guarantees a continuous water supply a key factor supporting the resilience and sustainability of urban farming in the face of climate and infrastructural pressures.

This spatial pattern indicates a renewed interest in urban farming as a means of enhancing food security, improving livelihoods, and mitigating the Urban Heat Island effect. Despite increasing urban pressure, these farmlands have remained resilient, due

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to local adaptation strategies and the recognition of urban farming as a critical land use in response to environmental and economic challenges.

Table 4. 9

Urban Farming Sites: Size and Perimeter (2002-2022)

Farm Site	Location Name	Year	Size (ha)	Perimeter (km)
1	Gamboru, Old Maiduguri, Gongulong, Dusuman	2002	4100	44.8
2	Bale Galtimari, Mairi	2002	156	10.2
3	Maisandari	2002	38.9	5.60
4	Mairi	2002	6.17	1.10
1	Gamboru, Old Maiduguri, Gongulong, Dusuman	2012	3848	46.9
2	Bale Galtimari, Mairi	2012	161	13.6
3	Maisandari	2012	1.97	0.72
4	Mairi	2012	7.11	1.17
1	Gamboru, Old Maiduguri, Gongulong, Dusuman	2022	4294	44.3
2	Bale Galtimari, Mairi	2022	123	8.66
3	Maisandari	2022	45.9	3.36
4	Mairi	2022	127	10.3

This table identifies major trends in urban farming practices in Maiduguri, demonstrating the dynamic variations in the size of farms across different sites during the study period. The table shows important developments and trends in Maiduguri's urban farming practices in 2002, 2012, and 2022. Each farm site has varied patterns in size and perimeter, demonstrating the dynamic nature of urban farming in various parts of the city.

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Table 4. 10

Total Area and Perimeter of Urban Farming Sites (2002-2022)

Year	Total area (ha)	Total Perimeter (km)	Change
2002	4301.07	61.7	-
2012	4018.08	62.39	Decreased
2022	4589.90	66.62	Increased

4.11.1 Farm Site 1: Gamboru, Old Maiduguri, Gongulong, and Dusuman

The result reveals that in 2002, Farm Site 1 covered 4100 hectares and had a perimeter of 44.8 km. By 2012, the area had shrunk to 3848 hectares, although the perimeter had grown to 46.9 km. However, in 2022, the area expanded to 4294 hectares with a perimeter of 44.3 km, signalling more expansion and potentially more effective use of space. This development might be due to Maiduguri's growing urban population, which requires more urban farming to fulfil increased food demands and enhance food security. Furthermore, variations in size and perimeter over time may represent dynamic land-use policies and urban planning adaptations to meet rising urbanization demands and environmental sustainability.

4.11.2 Farm Site 2: Bale Galtimari, Mairi

Farm Site 2 had 156 hectares in size in 2002, with a 10.2 km perimeter. By 2012, the size had increased somewhat to 161 hectares, with a large rise in circumference to 13.6

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km, potentially indicating fragmented land usage. In 2022, the size was reduced to 123 hectares, with a circumference of 8.66 km, which might indicate consolidation or an alteration in land use plans. These changes indicate that urban planning measures were applied to simplify and optimize land use, presumably as a result of urban development pressures and the necessity to provide space for other activities in the city.

4.11.3 Farm Site 3: Maisandari

The results show that Farm Site 3 began in 2002 with 38.9 hectares and a perimeter of 5.60 km. By 2012, the size had shrunk dramatically to 1.97 hectares with a perimeter of 0.72 km, indicating significant land loss, probably owing to regional instability. However, by 2022, the farmland had returned to 45.9 hectares with a 3.36-kilometer perimeter, indicating recovery and maybe new urban farming operations. This recovery might be ascribed to relative calm and a growing urban population, which necessitates the resurrection and extension of urban farming to fulfil rising food demands while enhancing food security. This pattern emphasizes the adaptability of urban farming in an environment of shifting sociopolitical situations and its role in urban sustainability.

4.11.4 Farm Site 4: Mairi

The results indicated that in 2002 Farm Site 4 had the smallest in size, spanning 6.17 hectares and a perimeter of 1.10 km. By 2012, it had expanded marginally to 7.11 hectares with a 1.17-kilometer perimeter, showing little but consistent increase. By

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2022, there had been an immense increase to 127 hectares encompassing a perimeter of 10.3 km, demonstrating tremendous growth and investment in urban agriculture. This substantial development shows a greater emphasis on farming in urban areas, which might be driven by increasing investment, regulatory assistance, rising food costs, inflation, and a population shift to the city centre. These reasons have most certainly influenced the need to increase the production of local foods, making urban farming an important method for improving food security, fulfilling the demands of an expanding urban population, and boosting microclimate resilience. In general, the distinctive features of urban farming techniques in Maiduguri have numerous implications for reducing urban heat islands.

Increased Green Infrastructure Coverage: The growth of urban farming sites, such as Mairi, increases the quantity of green space in the city. This plant serves to cool the city's urban environment through evapotranspiration and shadowing, reducing the UHI impact.

Efficient Land Use: The modification and consolidation of urban farming sites, as shown in Farm Sites 1 and 2, can result in more efficient land use and the formation of green corridors. These green spaces may break up the continuous expanse of built-up regions, minimizing heat buildup and fostering cooler microclimates.

Adaptation to Socioeconomic Pressures: The response of urban farming techniques to socioeconomic pressures such as rising food costs, inflation, and population growth demonstrates their importance in urban resilience. Urban farming helps to reduce these

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stresses by supplying local food sources, but it also adds to a cooler urban atmosphere, which promotes both the sustainability of society and the environment.

Overall, the growth and effective management of urban farming techniques in Maiduguri not only boosts food security and socioeconomic resilience but also contributes significantly to minimizing the urban heat island effect, resulting in a more sustainable and liveable urban environment.

4.12. ENVI-met Simulation Report

The simulation was informed by previous land use/land cover mapping and NDVI analyses for Maiduguri. The acquired data was organized into suitable forms for entry into the ENVI-met model. Various levels of urban farming areas were examined to determine their effect on temperature decrease and humidity increase. Each scenario involved converting a specified percentage of raw land and built-up regions into urban farming categories, with conversion rates of 10%, 20%, and 30%, respectively.

The ENVI-met model was then set up with this organized data to simulate how each urban farming scenario affected temperature and humidity. The simulation results were analyzed to assess temperature and humidity changes for each scenario and their implications for urban heat island reductions and overall urban climate improvement.

The impact of urban farming on temperature and humidity was evaluated by running the model with different levels of urban farming coverage. The purpose of the

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scenarios was to determine the effects of varying urban farming coverage on temperature decrease and humidity increase. The simulation results were examined to identify temperature reductions and humidity increases and their implications for urban heat island reduction and urban climate.

Table 4. 11

Baseline data used for the simulation

Land Cover Type	Baseline Tempt (°C)	NDVI	Coverage (cells)
Green Spaces	25	0.6	3000
Bare Land	35	0.1	2000
Built-up Areas	33	0.2	5000
Marginal Areas	30	0.3	1000

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The analysis shows substantial differences in microclimatic conditions between vegetated and non-vegetated areas. Bare areas had the highest surface temperature (35°C) and the lowest NDVI (0.1), indicating low vegetative cover and significant thermal absorption. Built-up areas also had higher surface temperatures (33°C), which were caused by impermeable materials like concrete and asphalt. In contrast, green regions had much lower temperatures (25°C) and a healthy NDVI of 0.6, highlighting the cooling effects of vegetation.

Urban farming scenarios were established to assess the effect of various degrees of urban farming coverage on temperature decrease and humidity rise. Each scenario involves transforming a specific percentage of bare land and built-up regions into urban farming zones, as illustrated in Table 4.12 below. The data tables for different urban farming scenarios are presented below.

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Table 4. 12

Scenario 1: 10% Urban Farming Coverage

Land Cover Type	Original Coverage (cells)	Converted to Urban Farming (cells)	New NDVI
Bare Land	2000	200	0.3
Built-up Areas	5000	500	0.3

Bare Land: 10% of bare land was converted to urban farming, leading to a new NDVI of 0.3 and a temperature of 32°C. Built-up Areas: 10% of built-up areas were converted to urban farming, which generated a new NDVI of 0.3 and a temperature of 31.5°C.

Table 4. 13

Scenario 2: 20% Urban Farming Coverage

Land Cover Type	Original Coverage (cells)	Converted to Urban Farming (cells)	New NDVI
Bare Land	2000	400	0.4
Built-up Areas	5000	1000	0.4

Bare Land: 20% of bare land was converted to urban farming, bringing the temperature down to 30°C and changing the NDVI to 0.4. Built-up Areas: 20% of built-up areas were converted to urban farming, lowering the temperature down to 30°C and changing the NDVI to 0.4.

Table 4. 14
Scenario 3: 30% Urban Farming Coverage

Land Cover Type	Original Coverage (cells)	Converted to Urban Farming (cells)	New NDVI
Bare Land	2000	600	0.5
Built-up Areas	5000	1500	0.5

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Bare Land, 30% of bare land was converted to urban farming, lowering the temperature to 28°C and creating a new NDVI of 0.5. Built-up Areas: Urban farming was implemented in 30% of built-up areas, resulting in a new temperature of 28.5°C and an NDVI of 0.5.

4.12.1 Simulation Results

The ENVI-met simulation findings show that urban farming can substantially lower temperatures while increasing humidity in urban environments. Table 4.15 summarises the temperature decrease and humidity increase for each scenario.

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Table 4. 15

Simulated result of different urban farming Scenario and how it reduces temperature and Humidity

Scenario	Temperature Reduction (°C)	Humidity Increase (%)
Scenario 1	0.5	2.0
Scenario 2	1.0	4.0
Scenario 3	1.5	6.0

Visualization of Simulation Results

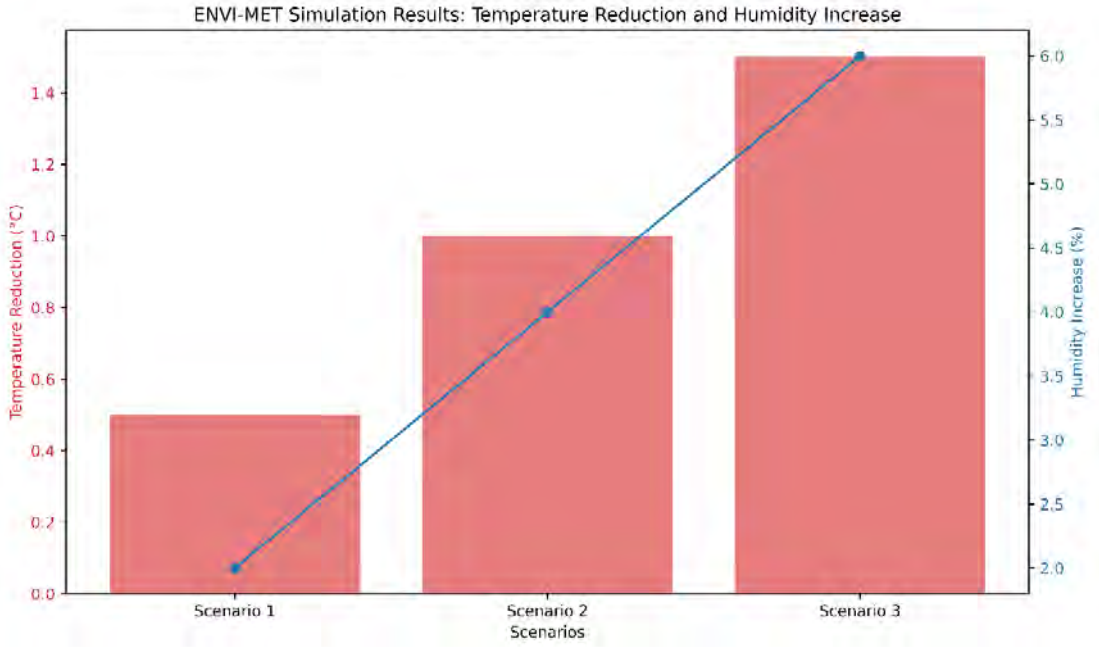
Figure 4.9 below demonstrates the temperature decrease and rise in humidity for the various urban farming conditions mentioned in Table 4.15.

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Figure 4.9

ENVI-MET Simulation Results, Temperature Reduction and Humidity Increase



The simulation results utilizing ENVI-met modeling in this study present strong empirical evidence for the potential benefits of urban farming as a microclimate-enhancing approach in Maiduguri, Nigeria. Across all modeled scenarios, the planned introduction of plants in form of farming into previously impermeable and underutilized surfaces, notably bare lands and built-up regions, resulted in noticeable cooling effects. These effects are driven by key biophysical processes such as increased surface albedo, greater evapotranspiration, and decreased thermal absorption and storage, all of which contribute to a gradual decrease in Land Surface Temperature (LST).

Specifically, the study found that increasing urban farming coverage by 10%, 20%, and 30% resulted in average LST reductions of 0.5°C, 1.0°C, and 1.5°C. This pattern is consistent with the findings Mohammed et al., (2023), who showed surface temperature decreases of 0.5°C to 1.8°C with 25% to 100% green infrastructure (GI)

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coverage in Dubai's high-density residential zones. Despite differences in geographic and climatic locations (semi-arid Maiduguri versus desert Dubai), the results show that vegetative treatments are universally effective in minimizing the effects of Urban Heat Island. Both studies demonstrate that increased vegetative coverage leads to larger temperature reductions, making urban farming a viable and climate-resilient option for thermally stressed cities.

In addition to heat regulation, the simulations showed significant increases in relative humidity for all urban farming scenarios. As vegetative coverage increased, atmospheric moisture increased by 2.0%, 4.0%, and 6.0%, which translates to 10%, 20%, and 30% vegetation, respectively. This rise is due to plant-mediated evapotranspiration, a key process that not only cools but also improves human thermal comfort especially in semi-arid places like Maiduguri, where dry air exacerbates heat stress. These findings are supported by Cortes et al., (2022), who found that green techniques, particularly at the ground level, were more effective in lowering urban temperatures (by 0.5°C to 1.1°C) than green roofs alone. Similar to the current study, they determined that vegetation enhances both heat and moisture conditions, which are critical for public health and quality of life in cities. Table 4.15 presents a comprehensive account of these findings. As simulated, the rise in humidity implies good changes in the urban microclimate, which might improve human comfort and vegetation health.

Moreover, the study discovered a consistent pattern of environmental improvement as urban farming increased. Areas with degraded surfaces (bare soil or concrete) increased their Normalized Difference Vegetation Index (NDVI) from 0.1-

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0.2 to 0.3-0.5 after vegetation was introduced. This marks a significant increase in vegetation density and ecosystem resilience. Thus, the findings are consistent with the work of Iaria and Susca, (2022), who underscored the impact of vegetal density (measured using the Leaf Area Index, LAI) on UHI reduction. Their research discovered that boosting LAI considerably increases cooling potential across various green envelope technologies, with increased LAI levels resulting in 10% to 90% improvements in temperature moderation, depending on the greening approach used. The proportional relationship between vegetative density and thermal performance reported in their study is similar to the trend identified in Maiduguri, where increased vegetation resulted in improved cooling and moisture retention. These cross-validated findings reveal a multidimensional role for urban farming.

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Thermal moderating via albedo and evapotranspiration.

Hydrological cycling improves humidity.

Ecological regeneration through vegetative recovery.

The resulting benefits transcend beyond regulating the microclimate to improved urban aesthetics, biodiversity support, and environmental justice, particularly for marginalized or underserved communities in rapidly rising cities such as Maiduguri. The integration of simulation results from four different geographical regions Nigeria (this study), the UAE (Mohammed et al., 2023), the Philippines (Cortes et al., 2022), and Europe (Iaria & Susca, 2022) confirms the broad relevance and sustainability of green-based urban initiatives. Urban farming appears not only as a UHI mitigation technique, but also as a multifaceted instrument for increasing urban resilience, improving microclimate regulation, and regenerating degraded urban environments.

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Given Maiduguri's semi-arid environment and rising urban population, incorporating urban farming into spatial planning frameworks is more than a desirable policy option, it is a climate obligation. These findings suggest that targeted policies and urban design interventions should prioritize the conversion of unused spaces into productive green zones that can provide climate, ecological, and social benefits.

Key Findings from the Simulation

Urban Heat Island Mitigation: Urban farming substantially decreases surface temperatures, so successfully minimizes the urban heat island effect. Urban climate: The installation of urban farming raises humidity and changes the urban microclimate, improving human comfort and supporting better plants.

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Summarily, to determine key variables such as Land Surface Temperature, Land Use/Land Cover, and Normalized Difference Vegetation Index, Chapter 4 provides a comprehensive analysis of satellite data from USGS Landsat 4, 7, and 8, utilizing the ArcGIS platform. This chapter methodically processes and analyses satellite imagery to obtain spatiotemporal data on NDVI, LULC, and LST in Maiduguri, Nigeria, covering the period from 1992 to 2022. Remote sensing methods applied to Landsat imagery allow for the extraction of pertinent vegetation indices and land surface characteristics.

Urban farming practices were comprehensively assessed by examining historical satellite imagery from Google Earth Pro (2002-2022) using GIS analysis and

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physical audits. Four active UF sites were assessed for each year, determining their sizes and perimeters to analyse changes in their geographical extent and layout, providing comprehensive insights into the evolution of urban farming in Maiduguri.

Additionally, the ENVI-met simulation was employed to assess the impact of urban farming on Maiduguri's microclimates, focusing on temperature reduction and humidity increase. Using structured data from prior land use/land cover mapping and NDVI analysis, different urban farming coverage scenarios (10%, 20%, and 30%) were simulated. The results highlighted changes in temperature and humidity, providing insights into urban heat island mitigation and urban climate improvement.

The analysis includes a thorough examination of temporal trends in LST, exposing variations in temperature over time and indicating potential relationships with changes in land use and urbanization. Similarly, variations in LULC categories were examined to identify modifications in Maiduguri's urban structure and land cover distribution. The NDVI assessment offers insights into vegetation dynamics and the distribution of green space, providing important details on the amount of urban greenery and its possible impact on regional microclimates. Overall, Chapter Four is a key part of the research, utilizing advanced geospatial methods and satellite data to provide a thorough understanding of the spatiotemporal dynamics shaping Maiduguri's urban landscape.

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4.12.2 Validation of ENVI-met Model Outputs Using NiMET and Ground Truth Data in Maiduguri

The quantitative evaluation of the ENVI-met model was carried out using a range of statistical error metrics, including the Root Mean Square Error (RMSE) with its systematic (RMSEs) and unsystematic components alongside the Mean Absolute Error (MAE) and Mean Bias Error (MBE). To validate the ENVI-met simulation outputs, observed temperature and humidity data from the Nigerian Meteorological Agency (NiMET) were compared with ground truth (GT) measurements collected across ten wards in Maiduguri. The MAE for temperature was calculated at 2.09°C, with a corresponding RMSE of approximately 2.10°C. For humidity, the MAE and RMSE were found to be 3.1% and 3.2%, respectively. The MBE values for both parameters were negative, indicating that the NiMET data slightly underestimated actual field conditions. These validation results support the integrity of the ENVI-met input data and the reliability of the simulation outputs. This validation strategy is consistent with the methodology used by Tsoka et al., (2018), who underlined the relevance of error metric analysis when evaluating ENVI-met's efficacy in reproducing microclimatic conditions during hot urban times, therefore, the current findings strongly support the effectiveness of urban farming as a viable urban heat island mitigation approach in Maiduguri. This is further reinforced by similar insights from previous studies (Fatma et al., 2020; A. Mohammed et al., 2023; Tsoka et al., 2018). The data used is presented in the appendix E.1.

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4.13 Urban Dwellers' Perspectives on Understanding and Perception of the UHI

4.13.1 Urban Dwellers' Perception on Urban Heat Islands Phenomenon

The survey results are thoroughly examined along five major points in this chapter. To provide context for the following findings, the demographic characteristics of the respondents are examined first. This provides insights into age, gender, occupation, and other pertinent factors. The second axis explores participants' awareness and comprehension of the UHI phenomenon and gauges how well-versed they are in its effects on urban environments. The third axis examines participants' attitudes and perceptions of urban farming and UHI mitigation, emphasizing their opinions on the advantages of both environmental cooling and locally sourced food supply. The fourth axis sheds light on perceived obstacles by exposing difficulties and barriers related to urban farming for UHI mitigation.

To conduct a thorough analysis of the data, the researcher used a variety of statistical techniques with the Statistical Package for the Social Sciences (SPSS) IBM SPSS Statistics 23. Descriptive statistical methods, such as calculating basic percentages, and visualizing the data with pie and bar charts were both used in the analysis. Furthermore, frequencies were utilized to better understand the distribution of categorical variables, and measures like mean, average mean, or grand mean were used to give a numerical representation of the central tendencies in the data. This multimodal strategy guarantees a close analysis of the research results, fusing numerical accuracy with visual cues to improve comprehension of the study results as a whole.

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It is important to highlight that for further analysis of the constructs, the dataset consisted of 52 responses across four constructs. A preliminary check for missing values showed that 94.83% of the data had less than 3% missing entries. According to Tabachnick et al., (2019), missing data under 5% is considered acceptable and unlikely to introduce bias. Furthermore, the missing data were determined to be Missing Completely at Random (MCAR). In line with the guidance by Jakobsen et al., (2017), complete case analysis was applied without imputation, as the missingness was minimal and not expected to affect the results.

4.13.2 Socio-demographic Characteristics of Respondents

Participants' demographic information was gathered through a structured questionnaire. One of the most important steps in determining whether the data was suitable for factor analysis was to compute the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy. The resultant KMO value of 0.648 is higher than the generally recognized cutoff of 0.6. This suggests that the variables contained in the socio-demographic element of the questionnaire constitute a sufficiently cohesive and reliable foundation for additional analysis, indicating that the dataset is deemed suitable for factor analysis. The data's resilience bolsters the reliability of using factor analysis to identify significant patterns and connections among the sociodemographic traits of participant.

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Table 4.16

Demographic Characteristics of Urban Dwellers

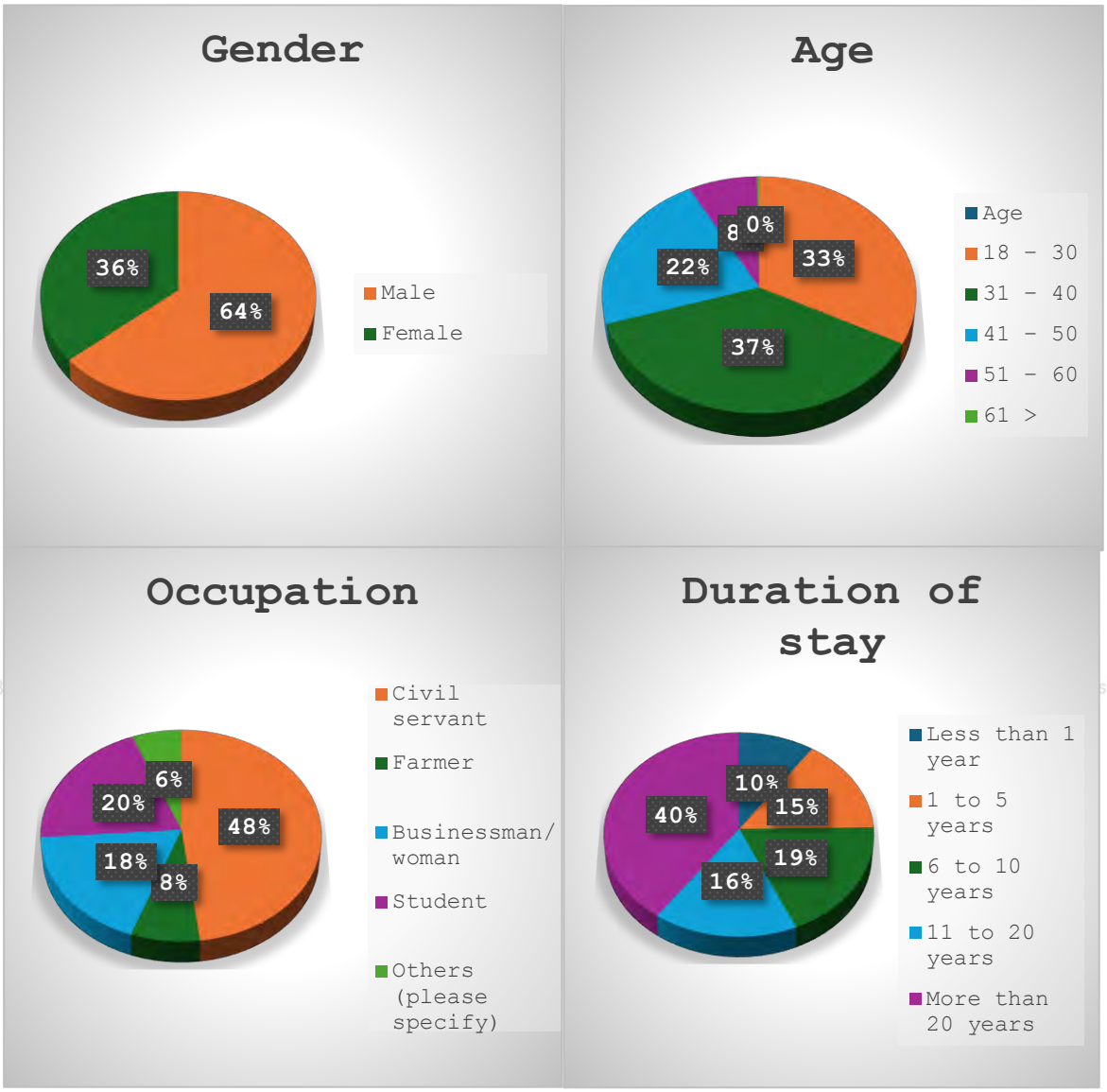
Items	Frequency (f)	Percentage (%)
Sex		
Male	254	63.8
Female	144	36.2
Age		
18 – 30	130	32.7
31 – 40	149	37.4
41 – 50	88	22.1
51 – 60	30	7.5
61 >	1	.3
Marital Status		
Married.	239	60.7
Single.	146	37.1
Others.	9	2.3
Occupation:		
Civil servant	191	48.0
Farmer	30	7.5
Businessman/woman	73	18.3
Student	80	20.1
Others (please specify)	24	6.0
Levels of Education:		
None Formal Education	19	4.8
SSCE/ O-Level	25	6.3
A-Level	57	14.4
Undergraduate	137	34.5
Post Graduate	159	40.1
Income per annum (before tax):		
Less than 100,000	170	10.2
100,000 - 500,000	122	88.7
500,000 - 1,000,000:00	58	.5
1,000,000 – 5,000,000	26	.3
5,000,000 and above	15	.3
Duration of stay in the locality		
Less than 1 year	38	9.6
1 to 5 years	60	15.2
6 to 10 years	74	18.7
11 to 20 years	65	16.4

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Figure 4.10

Graphic Presentation of Demographic Characteristics of urban dweller

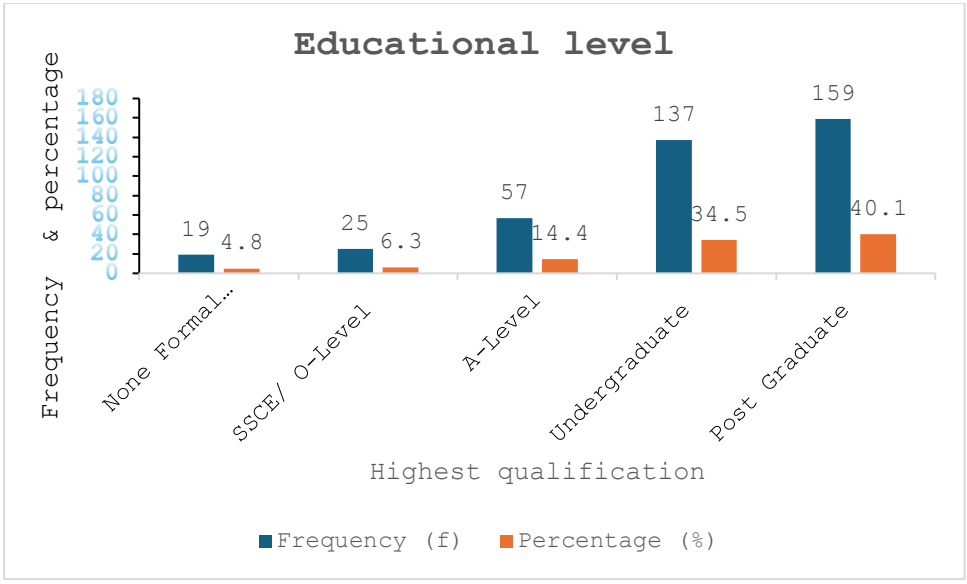


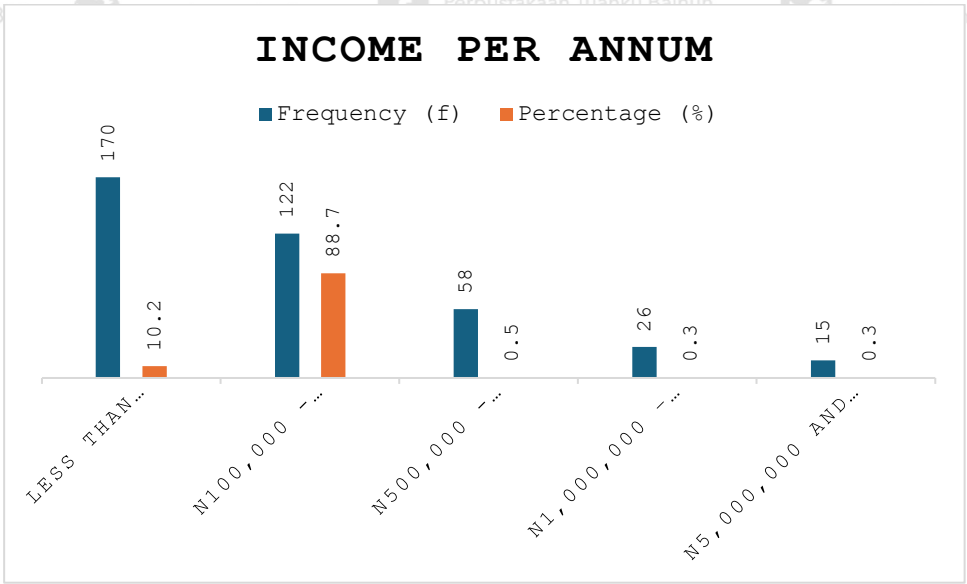
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Figure 4.11

Graphic Presentation of Demographic Characteristics of urban dwellers





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4.13.3 Demographic characteristics of urban dwellers

The socio-demographic characteristics of the respondents provide a detailed snapshot of the surveyed population. The sample exhibited an overrepresentation of men (63.8%) across all areas, encompassing both active and productive residents and households (Table 4.16). This skew towards middle-aged male participants suggests that men were more willing to participate in the survey, leading to their overrepresentation in the majority of the sample. This overrepresentation is attributed, in part, to cultural and religious inclinations within the urban populace. Specifically, cultural norms and religious practices, particularly in the context of married women, practically discourage interactions with strangers, especially adult males. This demographic skew highlights the importance of considering cultural and societal factors when designing and interpreting survey samples, emphasizing the need for diverse and inclusive representation in research efforts. With 90.2% of the respondents being under 50, the age distribution is biased towards people in this age range, indicating a comparatively young population. The fact that a sizable portion (61%) of this group is married reflects the significant role of families and respect for the institution in this community (Table 4.16).

With (40.1%) of the population having completed a postgraduate degree and 5% having received non-formal education, the reported findings demonstrate the educational diversity within the surveyed population. Significantly, all members of the community, regardless of their level of formal education, are literate, and many have committed the Quran to memory, demonstrating a strong Islamic influence ingrained in the community's history. This aspect of culture and religion has endured over time,

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existing before Nigeria was colonized. The rich Islamic heritage of Kanem Borno emphasizes the community's historical and cultural significance. All of these results highlight how important it is to recognize the distinct educational and cultural context of the community when establishing interventions or policies. A more nuanced understanding of the community's identity and values can be gained by acknowledging the significant influence of Islamic traditions and the dedication to memorizing the Quran. This thorough comprehension is essential for developing strategies that complement the unique qualities of the community and promote genuine involvement. The majority of participants (i.e., 50%) work in the civil service, suggesting a significant number of people who work in the public sector. The fact that only 8% of them work as full-time farmers suggests that they don't rely heavily on agriculture as their main source of income.

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The finding that nearly all of the respondents (99%) of them earn less than 500,000 naira annually points to a notable prevalence of low income in the surveyed population. This income level may be correlated with lower socioeconomic status and is suggestive of financial constraints. Given the higher cost of living in urban areas, it is likely that a significant proportion of the populace experiences financial difficulties and may be classified as impoverished urban inhabitants, given the low-income range. It draws attention to the necessity of focused initiatives, policies, or interventions to address economic disparities and raise this population's standard of living. A significant proportion of the respondents more than (75%) have lived in the area for more than ten years, indicating that permanent residency is common in the area (Figure 4.10). This long duration suggests a close relationship and deep roots for most of the urban dwellers in the region. An in-depth awareness of the local dynamics, interpersonal

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relationships, and cultural subtleties can be facilitated by such an extended stay. Those who have lived somewhere for a long time are probably well-integrated into the community, so it could also be a sign of stability and a sense of belonging. Understanding the stability of the community, possible shared experiences, and the effects of long-term residency on different facets of local life are all made possible with the help of this information. Taken together, these socio-demographic characteristics paint a picture of a predominantly youthful, literate, and married population with diverse educational backgrounds. The heavy reliance on civil service jobs, coupled with a minimal representation of full-time farmers and low annual income levels, suggests economic challenges within the community. The findings underscore the importance of understanding the socio-demographic context when designing interventions or policies to address the specific needs and challenges faced by this population.

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Table 4.17

Environmental Impact and Lifestyle Choices of urban dwellers

Items	Frequency (f)	Percentage (%)
Household appliances used at home kitchen appliances (e.g., refrigerator, oven, micro)	85	28.0
Laundry Appliances (e.g., washing machine, dryer)	2	.7
Electronic Devices (e.g., TV, computer, smartphone)	40	13.2
Heating and Cooling Systems (e.g., air conditioner, heater)	153	50.3
Other (please specify)	18	5.9
Car ownership or public transport?		
I own a car	110	28.5
I use public transport	246	63.7
Own a car/use public transportation.	20	5.2
I neither own a car nor regularly use public transportation.	8	2.1
Type of vehicles own		
Lorry	13	3.6
Van	12	3.4
Car	151	42.3
Tricycle (NAPEP)	112	31.4
Bicycle	69	19.3
Commuting distance to your workplace (per week)?		
0-15 km	165	44.6
15-30 km	113	30.5
30-45 km	57	15.4
45-60 km	35	9.5
Membership in environmental organizations		
Yes	40	10.3
No	347	89.7

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The survey population's transportation habits and car ownership data show a variety of patterns (Table 4.17). Roughly 28.5% of people are car owners, which is a sizable but not majority group. On the other hand, a significant 67.3% utilize public transport, demonstrating the widespread use of shared transport options. Additional information about vehicle kinds reveals that 42.3% of people own cars and 31.4% own tricycles, mostly for business use. This dual ownership points to a combination of community-based income-generating and personal transportation assets. When it comes to how far people commute to work, most people (44.6%) travel between 0 and 15 km, which suggests that a sizable percentage have relatively short commutes. In the meantime, 15.4% commute 30 to 45 km, and 30.5% commute 15 to 30 km. This provides a detailed picture of the commuting patterns over a range of distances. All of these results highlight how different the people surveyed had in terms of preferences and modes of transportation.

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In the context of environmental concerns and urban dwellers' lifestyle choices, as shown in (Table 4.17) the findings on ownership of cars and transportation behaviours have significant implications for mitigating UHIs. The strong inclination towards shared transport modes, which can reduce the release of heat and traffic-related accumulation of heat if they are environmentally friendly, is indicated by the substantial choice for public transport (67.3%). The dual ownership pattern highlights the mix of income-generating and personal transportation assets, with 31.4% owning tricycles for business use and 42.3% owning cars. This creates a need to balance the negative environmental effects. Tricycles, which are frequently used for short trips, have the potential to leave a different environmental impact than cars, which can contribute to

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localized heat due to their varied fuel types and emissions. Promoting eco-friendly modes of transport is essential for mitigating UHI effectively.

The distribution of commute distances reveals that a substantial percentage (44.6%) travels short commutes of between 0 and 15 km, which have lower emissions and less vehicle activity and contribute less to UHI. The 30.5% who commute 15 to 30 km, however, require special attention, highlighting the necessity of addressing longer commutes to reduce elevated heat emissions (Table 4.17). In the end, knowing transport patterns and preferences offers insightful information for UHI mitigation plans that emphasize the effects on the environment as well as urban dwellers' lifestyle choices. Optimizing commuting distances and promoting environmentally friendly, energy-efficient, and shared modes of transportation are crucial strategies for building resilient and environmentally conscious urban communities.

The survey result shows more than 60% of the respondents use electronic appliances frequently, especially cooling systems, which has some consequences for attempts to mitigate UHIs. Positively, the widespread use of cooling technologies indicates that residents are actively involved in activities that can lower temperatures. If these electronic appliances are energy-efficient, they may help mitigate the warming effects of UHI. Nevertheless, there might also be adverse effects. These cooling systems' use could lead to higher overall energy consumption and, as a result, higher release of greenhouse gases, which could make environmental problems worse if they mainly rely on non-renewable energy sources.

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This study confirms the results of another study by Sahu et al., (2014), which likewise claims that using electrical appliances to create artificial comfort raises the temperature and degrades the atmosphere. Both studies show how this method depletes natural resources, increasing greenhouse gas and air pollution emissions and having a detrimental effect on people's comfort and health. All of these studies point to a pressing need for alternative solutions to reduce the negative environmental effects of using these kinds of appliances and to create a home that is healthier and more environmentally conscious.

4.13.4 Awareness and Understanding of Urban Heat Island Phenomenon

The study intends to use a weighted average technique in this study to evaluate respondents' opinions of the urban heat island phenomenon. I'll weigh each question on the questionnaire according to how important I think it is to compute this. I will calculate the mean score for each item, multiply it by the associated weight, add up the weighted scores, and divide the total by the number of items. With more weight given to items deemed more important in offering insights into respondents' overall knowledge and understanding of the urban heat island phenomenon, this method allows for a more nuanced analysis.

In light of the statement regarding awareness of the urban heat island phenomenon, participants indicated a low level of perception (Table 4.18). The resulting average ratings suggest a prevailing lack of awareness among the participants regarding the urban heat island phenomenon. This implies that, as a group, participants

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generally do not perceive themselves as well-informed or conscious about this environmental phenomenon. The urban heat island phenomenon refers to the elevated temperatures observed in urban areas compared to their rural counterparts, often attributed to human activities and alterations to the natural environment. The indication of a low average perception of awareness among participants underscores a potential gap in public knowledge regarding this phenomenon.

The limited awareness of the urban heat island phenomenon among participants can be attributed to a multifaceted array of factors, encompassing inadequate environmental education, insufficient media coverage, regional disparities in the intensity of urban heat island effects, communication breakdowns in information dissemination, a perceived lack of relevance in daily life, and the competing priorities faced by individuals. A distinct challenge arises when considering urban dwellers who have endured the devastating impacts of insurgency for over a decade, as their unique circumstances may further impede their access to environmental information. Aghamohammadi et al., (2022) emphasize that active participation in mitigation efforts is largely dependent on stakeholders having a thorough understanding of how UHI affects society, the economy, and the environment. This is consistent with the survey's findings, which point to some variables that may have contributed to participants' low level of awareness, including poor environmental education, a lack of media coverage, regional variations in the effects of UHI, a breakdown in communication, a perception that the topic is unimportant in day-to-day life, and conflicting priorities. According to both sources, it is critical to address these issues to raise awareness among stakeholders and perspectives and promote focused and efficient action plans to mitigate the effects of UHI.

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Similarly, the respondent's assessment of their perceived familiarity or knowledge with the UHI phenomenon was deemed to be limited as the result obtained shows low perception (Table 4.18). The purpose of the question was to find out how much individuals thought they understood the idea of UHI. Without delving into the particulars of the respondent's real knowledge or expertise on the subject, it essentially concentrated on their subjective evaluation of their awareness or familiarity with the topic. This suggests that to improve respondents' and similar populations' awareness and understanding of UHI, focused educational initiatives or interventions may be necessary.

In the same vein, the respondent demonstrated a low level of perception of what a UHI is (Table 4.18). The inquiry sought to ascertain the respondent's viewpoint regarding the causes and origins of UHI by posing the idea as either a naturally occurring phenomenon or possibly impacted by human activity. The results of this study align with those of Aghamohammadi et al.'s study conducted in Malaysia (2022), wherein approximately fifty percent of the participants linked UHI to higher temperatures in urban areas as opposed to their rural counterparts. The results of both studies show that participants' awareness and comprehension of UHI are comparable, underscoring a common understanding that there is still an opportunity for growth in this area. This acknowledgment suggests that to effectively address the phenomenon, there is a collective need for improved education and awareness initiatives. The results are essential for comprehending how much the general public knows about UHIs. They emphasize the critical importance of improving low awareness through education and the need for well-informed conversations on mitigation efforts and focused environmental education initiatives.

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The survey results indicate that a significant majority of respondents hold the belief that human activities are responsible for the emergence of the urban heat island (Table 4.18). This measurement captures the prevailing perspective among respondents regarding the role of human actions in the formation of UHI. The question, which attributes the emergence of UHI to human activities, serves to assess individual beliefs, opinions, or attitudes regarding the extent of anthropogenic influence on urban heat islands. In this case, the respondents overwhelmingly perceive humans as being wholly responsible for the phenomenon, reflecting a strong acknowledgment of the connection between human activities and UHI formation. This finding is remarkably consistent with the research conducted by Ibrahim et al., 2019; Sahu et al., (2014), which highlights the critical role that human activity plays in contributing to the development of UHI. The opinions of the respondents are consistent with previous studies, highlighting a widespread understanding of how human actions impact the dynamics of urban temperature. This consensus between scientific findings and public viewpoints emphasizes how important it is to increase public awareness to address how human activity affects UHI. The findings' consistency with those of other studies has important ramifications for improving sustainable methods to reduce the effects of UHI and directing urban planning practices.

The survey's findings show a noteworthy pattern in how participants felt about the sources that first introduced them to the concept of urban heat islands (Table 4.18). This question does a good job of assessing the different media platforms, print, social media, television, etc. that people have used to learn about urban heat islands. By examining these sources, the question sheds light on the efficiency of different means of communication in spreading knowledge about environmental issues, especially

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urban heat islands, and serves as a useful gauge of the impact that media has on public awareness. By using these results, researchers can gain a deeper understanding of the influence and reach of media outlets, which can help them make more informed strategic decisions about educational programs and outreach associated with urban heat islands.

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Table 4.18

Responses on Awareness and Understanding of Urban Heat Island Phenomenon

Statements	Strongly Disagree 1 (%)	Disagree 2 (%)	Undecided 3 (%)	Agree 4 (%)	Strongly Agree 5 (%)	Mean	SD	Decision
To what extent do you agree with the statement: I have heard of the urban heat island phenomenon.	66 (17.1)	47 (12.2)	80 (20.7)	150 (38.9)	47 (11.1)	3.15	1.27	Low perception
To what extent do you agree with the statement: 'I have some ideas about the phenomenon referred to as the 'urban heat island.	41 (10.3)	76 (19.0)	81 (20.4)	154 (38.8)	45 (11.3)	3.22	1.18	Low perception
To what extent do you agree with the statement that urban heat island is a natural phenomenon?	51 (13.1)	77 (19.8)	59 (15.2)	142 (36.6)	59 (15.)	3.21	1.29	Low perception
To what extent do you agree that human activities are responsible for the emergence of the urban heat island (UHI)	36 (9.1)	47 (11.8)	73 (18.4)	114 (36.3)	97 (24.4)	3.56	1.23	High perception
I heard about the urban heat island in the print media, social media, and or Television	40 (10.2)	50 (12.8)	71 (18.1)	165 (42.1)	66 (16.8)	3.43	1.21	High perception
Have you heard anything about urban heat islands (UHIs) in your educational experiences?	57 (14.5)	60 (15.2)	76 (19.3)	136 (34.5)	65 (16.5)	3.23	1.29	Low perception
To what extent do you agree that urban heat island leads to increased temperatures in cities?	39 (9.9)	37 (9.4)	63 (16.0)	140 (35.6)	114 (29.0)	3.64	1.26	High perception
Urban heat islands increase the threats to human health posed by thermal stress.	40 (10.1)	38 (9.5)	79 (19.8)	133 (33.4)	108 (27.1)	3.58	1.26	High perception
The urban heat island phenomenon is an important issue for the urban populace.	39 (10.0)	48 (12.3)	63 (16.1)	158 (40.4)	83 (21.2)	3.51	1.23	High perception
Urban heat island (UHI) has become one of the major problems associated with the urbanization and industrialization of human society.	36 (9.0)	52 (13.0)	61 (15.3)	151 (38.0)	99 (24.8)	3.67	1.24	High perception

Note N = 400.

Weighted average = Sum of variables (weight) / sum of all weights

Decision = Weighted average = 34.2/10 = **3.42.**

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On the other hand, the results of the survey illustrate that, in the context of their educational experiences, the majority of respondents felt they were not exposed to or aware of information about urban heat islands, indicating low perception (Table 4.18). The inquiry particularly looks into whether participants have come across or heard about urban heat islands in the context of formal education, including fieldwork, field trips, and classroom interactions. These responses provide insightful information about the extent to which academic institutions support public education and awareness-building regarding environmental phenomena such as urban heat islands. The academic discipline and study level of the respondents are two possible influences on this pattern.

It has been observed from the survey's findings, that participants have a more acute understanding of urban heat islands concerning how they affect the well-being of the urban populace (Table 4.18). This result offers insightful information about the participants' perceptions and beliefs about the possible health risks connected to urban heat islands. The high level of awareness demonstrates a level of consciousness about the environmental and public health implications of elevated temperatures in urban areas and suggests that the respondents are aware of the links between urban heat islands and health outcomes. This result might be a sign of a population of respondents who are knowledgeable and involved in the problems caused by urban heat islands.

According to the survey's findings, participants have a more acute understanding of urban heat islands concerning how they affect people's health. This result offers insightful information about the participants' perceptions and beliefs about the possible health risks connected to urban heat islands. The high level of awareness

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demonstrates a level of consciousness about the environmental and public health implications of elevated temperatures in urban areas and suggests that the respondents are aware of the links between urban heat islands and health outcomes (Table 4.18). This result might be a sign of a population of respondents who are knowledgeable and involved in the problems caused by urban heat islands This is consistent with a 2019 study by Santamouris, which found that the interaction between local Urban Heat Islands brought on by fast urbanisation and global climate change poses a major threat to human well-being. This concern is supported by your study's findings, which show that people are more aware of the negative health effects of UHI. The increased consciousness highlights the pressing need for urban overheating to be addressed in city planning. All things considered, your research contributes valuable information to the ongoing discussion about creating resilient and sustainable cities, particularly by highlighting the participants' acute awareness of the health hazards associated with UHI.

The survey's findings show that respondent's perceptions of the significance of the urban heat island phenomenon in metropolitan settings are highly developed. According to this finding, respondents have strong opinions about the importance of urban heat islands as a problem for the environment in urban areas. The high degree of perception might be a result of knowledge about the possible negative effects of high temperatures in urban areas on the environment, public health, and the sustainability of urban areas as a whole. Simwanda et al., (2019) highlight UHI challenges in metropolitan areas, including heightened energy consumption, increased emissions, compromised water quality, and impacts on human health and comfort, which aligns with the respondent's opinions. This underscores the urgency of researching and

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addressing UHI's impacts on the well-being of urban environments and residents. Policymakers, urban planners, and environmental advocates who want to address and prioritize issues regarding urban heat islands in city planning and development may find this information to be helpful.

According to the survey results, participants also demonstrate a high degree of perception when it comes to the importance of the urban heat island as a threat related to industrialization and urbanization (Table 4.18). This result points to a strong consensus among respondents, indicating a mutual understanding of the significant influence of urban heat islands concerning industrial activity and urban development. Urbanization and industrialization contribute to environmental challenges, including air pollution, global warming, industrial waste, and rising urban temperatures, as asserted by studies (Azmi et al., 2021; Saaroni et al., 2018). Elevated urban temperatures are linked to the Urban Heat Island effect, emphasizing the need for sustainable urban development to address environmental and well-being concerns.

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Table 4.19

Perception and Attitude Towards Urban Heat Island Mitigation and Urban Farming.

Statements	Strongly D 1 (%)	Disagree 2 (%)	Undecided 3 (%)	Agree 4 (%)	Strongly A 5 (%)	Mean	SD	Decision
Urban residents cultivate crops for both food and promote environmental cooling.	55 (14.1)	47 (12.0)	53 (13.6)	174 (44.5)	62 (15.9)	3.36	1.13	Low perception
Many urban dwellers cultivate grasses and flowers to beautify and cool the environment.	25 (6.3)	45 (11.3)	49 (12.3)	187 (47.1)	91 (22.9)	3.69	1.31	High perception
Urban residents in this city are involved in growing crops and vegetation within the city.	40 (10.2)	66 (16,8)	61 (15.6)	159 (40.6)	66 (16.8)	3.37	1.23	Low perception
Most urban dwellers plant trees solely to cool the urban environment.	29 (7.3)	38 (9.6)	63 (15.9)	170 (43.0)	95 (24.1)	3.67	1.16	High perception
My involvement in growing crops primarily serves as a secondary occupation to support my family.	47 (12.0)	59 (15.0)	65 (16.5)	158 (40.2)	64 (16.3)	3.34	1.25	Low perception
The urban population supports cross ventilation in building design for natural cooling.	30 (7.6)	60 (15.2)	64 (16.2)	163 (41.3)	78 19.7	3.50	1.19	High perception
Urban residents use reflective materials on roofs and buildings for cooling and energy savings.	40 (10.2)	62 (15.9)	65 (16.6)	150 (38.4)	74 (18.9)	3.40	1.25	Low perception
Promoting crop cultivation, including hydroponics, aquaponics, and fish ponds, in urban areas is vital for microclimate regulation.	41 (10.3)	47 (11.8)	82 (20.6)	184 (46.2)	44 (11.1)	3.36	1.14	Low Perception

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Statements	Strongly D 1 (%)	Disagree 2 (%)	Undecided 3 (%)	Agree 4 (%)	Strongly A 5 (%)	Mean	SD	Decision
Human activities do not have a significant impact on mitigating the urban microclimate.	71 (18.1)	83 (21.1)	80 (20.4)	113 (28.8)	46 (11.7)	2.95	1.30	Low perception
Urban heat island effects are a serious threat that requires mitigation in urban centres.	25 (6.3)	48 (12.2)	80 (20.3)	166 (42.0)	76 (19.2)	3.56	1.12	High perception
Developed nations should take a significant role in mitigating urban heat islands.	41 (10.5)	36 (9.2)	53 (13.6)	151 (38.6)	110 (28.1)	3.65	1.27	High perception
To what extent do you agree with the statement that regularly irrigating vegetation, such as flowers and gardens, contributes to environmental cooling?	25 (6.3)	34 (8.6)	55 (13.9)	141 (35.7)	140 (35.4)	3.85	1.18	High perception
Significant societal transformations are necessary to address urban heat impacts.	34 (8.7)	30 (7.6)	63 (16.0)	180 (45.8)	86 (21.9)	3.65	1.16	High perception
Some people may prioritise their own interests over addressing rising urban temperatures.	39 (9.8)	52 (13.1)	67 (16.8)	164 (41.2)	76 (19.1)	3.47	1.22	Low perception
To what extent do you agree with the statement that the evidence supporting the existence of urban heat island effects is strong enough to warrant mitigation efforts?	20 (5.1)	40 (10.2)	101 (25.7)	151 (38.4)	81 (20.6)	3.59	1.08	High perception
There is a belief that the impact of human activity on microclimate is overstated.	30 (7.6)	78 (19.6)	72 (18.1)	165 (41.6)	52 (13.1)	3.33	1.15	Low perception
Access to tractors and fertilizers from the government at affordable and subsidized rates is available for our farming activities	54 (13.7)	83 (21.1)	61 (15.5)	126 (32.0)	70 (17.8)	3.19	1.33	Low perception

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Statements	Strongly D 1 (%)	Disagree 2 (%)	Undecided 3 (%)	Agree 4 (%)	Strongly A 5 (%)	Mean	SD	Decision
Supporting urban farming projects is a viable strategy for sustainable development and reducing urban heat islands.	31 (7.8)	39 (9.9)	43 (10.9)	171 (43.3)	111 (28.1)	3.74	1.19	High perception

Note N = 400,
Decision = Weighted average = 34.2/18 = **3.48.**

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According to the survey's result, there is a critical need for focused educational and communication initiatives given the surveyed population's low perception of the relationship between urban farming, crop cultivation, and environmental cooling. In order to close this disparity, community-wide enlightenment campaigns, educational initiatives, and engagement tactics should be put into place to emphasise urban farming's dual advantages of supplying food that is sourced locally and aiding in environmental cooling (Table 4.19). This study finds a critical gap in the surveyed population's perception of the association between farming in urban areas, like the cultivation of crops, and environmental cooling, in contrast to the findings reported Derkzen et al., (2017) which suggest widespread understanding of the importance of urban vegetation. The study emphasizes the critical need for targeted educational and communication initiatives to address this disparity. These programs seek to educate the public about the advantages of urban farming, which include its ability to cool the environment and supply locally sourced food. In order to establish an environment that is conducive to farming in cities, efforts should be concentrated on open and transparent channels of communication, community participation in planning, and possible policy changes. Through education and the presentation of effective cases, these programmes seek to change attitudes, strengthen community support, and encourage the uptake of sustainable urban farming methods. To measure the success of these initiatives and guarantee continual progress, it will be essential to conduct ongoing monitoring and assessment.

On the other hand, the survey's findings revealed that, there is a high degree of positive engagement and perception among participants with regard to the attitudes of urban dwellers towards actions that simultaneously improve the aesthetic beauty of

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their immediate surroundings and aid in environmental cooling. The findings imply that respondents are aware of the multipurpose nature of urban farming, in which people actively engage in the cultivation of plants for both decorative purposes and the purposeful aim of reducing heat to create a more comfortable urban environment (Table 4.19). This favourable opinion highlights how the urban populace understands and supports environmentally conscious landscaping techniques that provide aesthetic advantages and address environmental issues, demonstrating an all-encompassing approach to sustainable cities. This is consistent with a 2017 study by Derkzen et al., that found that people generally agree that green infrastructure (GI) can help adapt to climate change as long as it has multiple uses. Both statements emphasise the value of multifunctional green infrastructure (GI), which provides benefits related to environmental sustainability as well as recreational and aesthetic ones. This suggests that the surveyed participants felt positively about and supported GI.

The survey's findings show that respondents' perceptions of the level of community involvement in urban gardening and agriculture are relatively low. This implies that there might be a lack of knowledge or a lack of recognition regarding the desire or active participation of city people in growing plants and crops in urban areas. The results show that there may be a need for campaigns to raise awareness, support urban agriculture projects, and improve community involvement in gardening activities. According to a related study, community engagement is greatly impacted by the reasons behind urban agriculture (Azunre et al., 2019). In the global south, the primary drivers of household food security alongside income generation are economic factors. On the other hand, greater levels of community involvement may be seen in the global north, where drives frequently centre around leisure and environmental

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concerns. Low community involvement, as indicated by the survey results, may indicate that people in urban areas are not aware of or are not actively involved in growing plants and crops. The significance of taking into account various motivations as well as contexts when evaluating and promoting community involvement in urban agriculture is highlighted.

The study participants demonstrated a high level of awareness and comprehension regarding their beliefs or perceptions about the main driving force behind urban tree planting. This implies that the people who responded to the survey are aware of the widely held belief that most city people plant trees specifically to reduce the temperature of their urban surroundings (Table 4.19). Venter et al. (2020) provide support for this, highlighting the critical role that well-planned tree planting plays in reducing the negative health effects of high temperatures brought on by the UHI phenomenon. In conclusion, the participants exhibit knowledgeable viewpoints regarding the main driving force behind planting urban trees and their critical function in controlling land cover to minimize UHI-related health concerns. The results show that there is a broad agreement or understanding among the participants about what motivates people to plant trees in urban areas.

The study's findings show a notable divergence from Maiduguri's historical reliance on agriculture, demonstrating a low perception among participants about the profession of crop cultivation and its significance for providing for families. Despite its agrarian origins, this indicates a significant shift in the local population's mindset, pointing to a declining emphasis on agriculture as the main source of income. The results show how the community's dynamics are shifting and how traditional jobs might

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be losing ground or facing new attitudes, which emphasises the importance of taking changing viewpoints into account when discussing urban agriculture. However, across the globe, urban farming has taken many different forms. In the UK and Europe, for example, allotment gardens are essential food sources that are frequently handed down through the generations (Ramaloo et al., 2018). Notably, community gardens in Cuba with organic farming provided vital support to millions of people following the fall of the Soviet Union in 1989. Community gardening continues to be a common practice in many Asian villages. Community gardening saw a boom in Australia, first at Nunawading in Melbourne in 1977 and then at Callan Park in Rozelle, Sydney, in 1985. This historical development highlights the idea of community gardens' enduring quality and demonstrates their ancient roots in the relationship between food and communal cultivation.

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According to the survey results, the majority of respondents exhibit a high level of perception of cross-ventilation as a preferred design strategy for obtaining natural cooling in urban structures (Table 4.19). This implies that there is broad community agreement in favour of sustainable building techniques for resilience to microclimates. The results provide insightful information about the habits and views of the population surveyed, confirming a favourable position for architectural techniques that improve urban microclimate resilience and facilitate natural cooling. The community's strong opinion that cross-ventilation is a better design approach is consistent with accepted scientific knowledge. According to Ren et al., (2018), urban ventilation is essential for reducing the impact of the UHI. It is measured by a threshold value for the Sky View Factor (SVF) at a wind dynamic potential of 0.65. This scientific threshold emphasizes how important cross-ventilation and other strategic design elements are for promoting

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airflow and cooling in urban areas. Consequently, the inclination of the community towards sustainable building methods aligns with the scientific comprehension of the role that urban ventilation plays in constructing robust and microclimate-friendly urban architecture.

The results, which show that respondents' perceptions of their attitudes, awareness, adoption, as well as encouragement for the adoption of reflective materials in urban centres are low, offer important new information about how the community views and uses sustainable building materials. The low socioeconomic status and limited technological knowledge of urban dwellers may be the cause of the observed low levels of perception. It seems that this community may not prioritise energy efficiency measures like using reflective materials, unlike developed societies where they might be. Similarly, the findings of the survey indicate that urban dwellers do not support the idea that various crop cultivation practices, such as hydroponics, aquaponics, and fish ponds, should be promoted in urban areas because they are essential for managing the microclimate. According to the participants, urban dwellers therefore have a low opinion of the importance of promoting a variety of crop cultivation techniques for microclimate regulation. This suggests that the role that innovative agricultural techniques play in managing microclimates may not be fully understood or supported by the community.

The observed low perception among city dwellers of the importance of promoting different forms of crop cultivation, such as hydroponics, aquaponics, and fish ponds, for microclimate regulation may be influenced by the community's food crop priorities. Given that the vast majority of city dwellers are subsistence farmers,

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their emphasis on traditional food crops may overshadow recognition of alternative cultivation practices for microclimate management. The agricultural practices of the community, which are primarily focused on meeting immediate food needs, may contribute to a lack of knowledge and understanding of the potential benefits of innovative agricultural methods in the context of microclimate regulation.

Bhattarai & Adhikari, (2023) study highlights the increasing use of urban farming methods, such as hydroponics and aeroponics, in a variety of urban settings, including rooftops, balconies, and backyards (Table 4.19). Their research's main goals centre on addressing the need for locally produced food, enhancing environmental sustainability, and encouraging community empowerment. Remarkably, these results from Bhattarai and Adhikari's study offer an insightful background to the low opinion that city people expressed in our research about the significance of advancing various crop cultivation techniques, including cutting-edge approaches like hydroponics as well as aquaponics, for controlling microclimates. As a result, more information and awareness-raising may be required to highlight the extra advantages of specific cultivation methods for controlling the microclimate in urban settings.

The results demonstrate that respondents' perceptions of human activity's contribution to mitigating the microclimate in cities could be higher (Table 4.19). This suggests that there may be doubt or a need for more confidence among those surveyed regarding the efficacy of human interventions for managing and enhancing the microclimate conditions in urban centres. Established records have shown that non-vegetated permeable pavements such as water retention pavements are an example of an effective anthropogenic strategy that lowers the heat island effect by absorbing less

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heat. Moreover, taking into account the heat emissions caused by human activity in urban areas using morphological indices helps control high temperatures. A comprehensive and environmentally responsible approach to urban development is emphasized by the promotion of green resilient Infrastructure (GRI) and the identification of regions appropriate for Blue-Green Infrastructures (BGI) through the monitoring of natural ecosystems. There is a perception gap among respondents, although the evidence provided by (Almaaitah et al., 2021; Cai et al., 2023; C. Wang et al., 2021a) overwhelmingly supports these mitigation approaches. To develop strategies, policies, and educational programmes that can promote a more informed and constructive community perspective on the contribution of human activities in mitigating city microclimate challenges, it is imperative to comprehend and address the factors contributing to this low perception.

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A combination of factors could explain respondents' low perception of the impact of human activities on urban microclimate mitigation (Table 4.19). Scepticism may be worsened by a lack of awareness, a lack of information on effective approaches, and a potential scarcity of technological knowledge. Prioritisation of immediate needs, cultural influences, and historical urban development practices that may or may not have prioritised microclimate considerations all have the potential to shape perceptions. Challenges in resources, both financial and infrastructural, as well as gaps in communication and governance potency, may contribute to the perception that human activities have had little impact on improving the urban microclimate. Combating these issues through targeted education, communication, and campaigns for community engagement can help to foster a more positive and informed perception within the community.

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Urban heat island impacts are becoming a serious and urgent threat, necessitating proactive urban mitigation measures. Rising surface temperatures driven by urbanisation and the growing built environment are associated with a range of unfavourable outcomes, according to research by (Agathangelidis et al., 2019; Tong, 2021; Ye et al., 2018). These ramifications go beyond extreme weather-related risks and include increased rates of death and morbidity, especially in relation to cardiovascular and pulmonary diseases, kidney problems, and mental health conditions. The survey results are consistent with a high perception across respondents, despite scientific evidence underscoring the urgency of addressing UHIs to protect public health and ensure the resilience of urban communities (Table 4.19). It is clear that the public is aware of the gravity of UHI effects and the pressing need for purposeful action to solve these problems in urban areas. The findings demonstrate a widespread perception of the possible hazards linked to high temperatures in urban environments and mirror the participants' robust concurrence regarding the importance of taking proactive measures to alleviate the consequences of heat islands in towns and cities.

The high perception that participants had of this indicates a strong belief that more economically developed countries should play a significant role in addressing and mitigating the effects of UHI indicates a recognition of the global nature of this environmental challenge (Table 4.19). Despite the fact that UHI is a local phenomenon that affects cities all over the world, the community emphasises the importance of a global effort to mitigate its effects. Filho (2018) emphasises that addressing the issues caused by UHI in emerging nations necessitates focused attention on important socioeconomic factors. An effective strategy for mitigating urban heat island effects must include efforts that enhance resource access, lessen healthcare disparities, improve

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urban planning, raise educational awareness, address livelihood challenges, and promote social equity. The high view that participants have of this environmental challenge's global nature is clear, highlighting the important role that economically developed nations should play in combating and minimizing UHI effects. Under this cooperative strategy, developed countries will contribute through social equity-promoting policies, sustainable urban development methods, improved healthcare infrastructure, and inclusive policies.

The community's strong belief that more developed nations ought to contribute significantly to the mitigation of UHI most likely originates from an understanding of the global scope of UHI impacts and the interdependence of environmental issues. Given the differences in resources and capacities, respondents might consider developed countries to be important partners in successful mitigation initiatives. Expectations for international aid, these nations' leadership roles in climate change initiatives, and their historical emissions responsibility may all have an impact on the expectation that they should take the lead. Furthermore, the community may believe that the participation of developed countries is necessary to address UHI and further environmental goals by offering financial support, technological solutions, and scientific expertise.

The community's recognition of the strength of the evidence is reflected in the high perception among respondents that there is substantial proof supporting the presence of urban heat island effects and that this evidence justifies proactive measures to mitigate its impact (Table 4.19). This encouraging response shows that the public is aware of the strength of the evidence supporting the existence of heat islands in cities

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and the pressing need to take preventative action to lessen their effects. The community is informed and supportive of initiatives meant to address the problems presented by urban heat islands, as evidenced by the nuanced understanding that reflects a shared understanding of the necessity for mitigation efforts. There may have been several reasons for the respondents' strong belief that mitigation efforts are warranted given the evidence of urban heat island effects. Community involvement, direct experiences with rising temperatures, and noticeable changes in the surrounding environment probably all play a part in the community's awareness of the problem. The positive response could be further reinforced by public education, health concerns, successful local initiatives, and a dedication to environmental sustainability and community values. Furthermore, a greater understanding of more general climate change concerns may be impacting the urgency of mitigation efforts. The community's acknowledgment of the evidence about urban heat islands is indicative of an informed and proactive approach toward mitigating the effects of rising temperatures in urban areas.

The survey result indicated a positive response with a high perception from the urban populace indicates a strong agreement among respondents regarding the statement that regularly irrigating vegetation, such as flowers and gardens, contributes to environmental cooling (Table 4.19). This suggests that the community recognizes and believes in the cooling effects associated with the consistent watering of plants. The high perception likely reflects an understanding within the urban population that well-maintained and irrigated green spaces play a role in mitigating heat and contributing to a cooler environment. Such insights are valuable for urban planning and environmental initiatives that involve the promotion of greenery and sustainable landscaping practices to enhance local microclimates. There are probably some reasons

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why Maiduguri's urban population has such a high opinion of the beneficial effects of routinely irrigating plants on ambient cooling. The locals may be aware of the link between cool surroundings and well-watered plants. This is especially true given the cultural customs and local values that place a high value on green spaces, which are especially important in an agrarian society like Maiduguri and personal gardening experiences.

A constructive community perspective on the extent of changes necessary in societal practices and policies is indicated by the high perception among those surveyed regarding the need for societal shifts in order to effectively address the impacts of urban heat (Table 4.19). To address the issues raised by urban heat, it appears that the community recognises the importance of more significant changes in areas like urban planning, environmental regulations, and community behaviours. This increased awareness emphasises how crucial it is to work together and make structural adjustments to lessen the effects of increased temperatures in urban areas. To inform and shape future initiatives and policies to enhance the resilience of cities to heat-related challenges, it is imperative to comprehend the community's optimistic stance on societal transformations. The survey result showing a high perception among respondents regarding the need for societal shifts to effectively address the impacts of UHI aligns well with Piroozfar & Farr, (2022) imperative for strategic and visionary research. The research's emphasis on socio-morpho-cultural change indicates an understanding of the relationship between urban development, social behaviour, and environmental effects. This aligns with the community surveyed viewpoint regarding the degree of societal practice and policy changes required to address UHI. To effectively mitigate urban heat island effects, both sources emphasise the

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significance of holistic and transformative approaches. They also stress the necessity of comprehensive strategies that include technological as well as infrastructural solutions along with an increased awareness of social, morphological, and cultural dynamics.

The city's distinct environmental context and cultural heritage may contribute to Maiduguri's high respondents' perception of the necessity of societal changes to alleviate the effects of urban heat. Given their agrarian lifestyle, Maiduguri people may have a strong bond with the land and a keen sense of environmental changes. Due to the society's historical reliance on agriculture, residents may be more aware of the need to address urban heat and the significance of fundamental adjustments to preserve the local environment. Furthermore, locals may see societal changes as consistent with their values if their culture emphasises harmony with nature. Extreme temperatures experienced by the area, which are typical of a semi-arid climate, supporting the community's demand for radical measures that respect and take into account Maiduguri's unique cultural identity and natural surroundings.

Respondents' strong recognition of the potential conflicts between personal concerns and more general environmental issues is indicated by their high perception of the idea that people might put their own interests ahead of solving the problems brought on by rising temperatures in urban areas (Table 4.19). These findings show that urban residents are aware of the conflicts and competing priorities that could impede group efforts to mitigate the effects of rising temperatures. The statement conveys the idea that not everyone may prioritise the collective efforts that are required to effectively address the problems caused by rising temperatures in urban areas. This knowledge is essential for developing approaches and strategies for communicating that

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can reconcile the needs of environmental stewardship as a group with individual interests. There could be a number of reasons for the high perception among participants that people might put their own interests ahead of addressing the rising temperatures in cities. This perception may be influenced by immediate concerns such as economic stability, the conviction that individual efforts are futile, as well as competing interests.

Several studies on the Urban Heat Island phenomenon indicates a strong link to human activity, specifically urbanisation, which raises surface temperatures by warming the atmosphere and increasing carbon emissions (Janet et al., 2022; M. Santamouris, 2020). This scientific understanding is consistent with the survey results, which show that the community generally has a low perception of the excessive influence of human activity on microclimate change. The results highlight the need to close the gap between scientific understanding and public opinion and the necessity of raising public awareness and providing education about the complex interplay between human activity and regional climates (Table 4.19). This implies an opportunity for residents to participate in programmes meant to promote a better knowledge of how human activity affects microclimate modifications and the wider effects on urban settings. We can improve public comprehension and enthusiasm for comprehensive efforts to mitigate the effects of changes caused by human activity on local climates by addressing this knowledge gap.

There could be some reasons for the community's low perception response to the idea that human activity exaggerates its impact on microclimate change, including varying levels of awareness and belief systems. People's perspectives are influenced by

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their personal, cultural, and educational backgrounds, which results in a wide range of beliefs about how much human activity affects microclimate. The survey results, which indicate that farmers generally have a negative opinion of government support, especially when it comes to affordable access to tractors and fertilizer, are consistent with the findings of an interesting study carried out in Lagos, Nigeria by Lawanson et al., (2015).

This study emphasizes the challenges that urban farmers face as weather patterns fluctuate, such as rising temperatures, altered rainfall patterns, and changes to traditional farming methods. These changes brought on by the climate have resulted in lower yields and, in the worst situations, the destruction of harvests. These difficulties are made worse by things like the inability to let the land rest, financial limitations, restricted access to fertilizers, and restricted use of better irrigation techniques. This complex impact highlights the pressing need for comprehensive support systems and adaptive strategies to address the complicated difficulties that farmers face in the context of climate change. It also highlights the significance of community education, enhanced resource accessibility, along with the development of farming practices that are climate resilient.

This may be the consequence of poor information sharing about the resources that are subsidized, challenges obtaining those resources, or discontent with the amount and calibre of support that is offered. Although these initiatives within agricultural policies to support local farmers and promote food security have potential benefits, there may be obstacles to their effective implementation. To close these gaps, inform policy changes, strengthen communication approaches, and ultimately improve support

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programmes to better serve the wishes of local farmers, the community's specific concerns must be understood. On the other hand, Nogeire-McRae et al. (2018) pointed out that increasing funding for urban farming (UF) projects demonstrates an increasing passion in the sustainability of urban growth. The research highlights UF's potential to act as an interface linking socioeconomic and healthcare systems, promoting opportunities for learning and societal engagement, and supporting conservation objectives like nutrient recycling and preservation of biodiversity, even though its costs and benefits to society as a whole are still not fully understood. This fits in perfectly with the survey findings, which show that most respondents acknowledged that funding and support for urban farming initiatives is beneficial and successful (Table 4.19). Convergence between survey perceptions and research insights highlights the need for a more thorough comprehension of the social implications of UF, underscoring the significance of well-informed decision-making and ongoing support for its diverse effects on urban sustainability.

The high-level perception response implies an understanding of the benefits of urban farming, which go beyond environmental concerns and include creating jobs, local food security, and community resilience. The positive perception shows that urban farming is seen by the community as a comprehensive approach that fits in with larger development objectives, demonstrating a shared understanding of its potential to build more resilient, sustainable, and liveable towns and cities.

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4.13.5 Challenges and Barriers of Urban Farming for Urban Heat Island Mitigation

Table 4.20

Challenges and Barriers of Urban Farming for Urban Heat Island Mitigation

Statements	Strongly D 1 (%)	Disagree 2 (%)	Undecided 3 (%)	Agree 4 (%)	Strongly A 5 (%)	Mean	SD	Decision
A lack of knowledge and expertise hinders successful urban farming initiatives.	41 (10.5)	48 (12.2)	43 (11.0)	160 (40.8)	100 (25.5)	3.59	1.28	High perception
Public perception and awareness play a crucial role in the success of urban farming projects for UHI mitigation.	19 (4.8)	39 (9.8)	64 (16.1)	185 (46.6)	90 (26.7)	3.73	1.07	High perception
Financial grants and incentives are easily accessible for people or communities looking to start urban farming projects to reduce urban heat islands.	46 (11.7)	99 (25.1)	62 (15.7)	140 (35.5)	47 (11.9)	3.11	1.24	Low perception
Low-interest loans and financing options are easily accessible for urban farmers looking to develop and expand their heat island mitigation efforts through farming.	49 (12.3)	103 (25.9)	76 (19.1)	123 (31.0)	46 (11.6)	3.04	1.24	Low perception
Urban farmers can easily obtain or lease the necessary machinery and tools for their heat island mitigation projects.	43 (10.9)	97 (24.6)	72 (18.3)	136 (34.5)	46 (11.7)	3.11	1.22	Low perception
High-quality seeds or seedlings that are resilient to heat stress, urban environmental conditions, and fertilizers are accessible.	45 (11.3)	92 (23.1)	67 (10.1)	158 (39.7)	36 (9.0)	3.12	1.20	Low perception

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Statements	Strongly D 1 (%)	Disagree 2 (%)	Undecided 3 (%)	Agree 4 (%)	Strongly A 5 (%)	Mean	SD	Decision
Access to water resources is a crucial factor influencing urban farming for UHI mitigation.	31 (7.9)	50 (12.8)	53 (13.6)	174 (44.6)	82 (21.0)	3.58	1.18	High perception
Soil quality and contamination issues affect the feasibility of urban farming as a UHI mitigation strategy.	25 (6.3)	51 (12.9)	48 (12.1)	178 (44.9)	94 (23.7)	3.67	1.16	High perception
Land availability is a significant challenge to urban farming.	28 (7.2)	54 (13.8)	40 (10.2)	160 (40.9)	109 (27.9)	3.69	1.22	High perception
Land ownership and regulations pose challenges for urban farming in UHI mitigation.	23 (5.8)	43 (10.9)	48 (12.2)	186 (47.1)	95 (24.1)	3.73	1.12	High perception
Seasonality and climate variability impact the effectiveness of urban farming as a UHI mitigation strategy.	24 (6.1)	31 (7.9)	69 (17.6)	188 (48.0)	80 (20.4)	3.69	1.07	High perception
Market access and distribution channels are important considerations for urban farming.	25 (6.3)	30 (7.6)	57 (14.4)	176 (44.4)	108 (27.3)	3.79	1.12	High perception
Community engagement and participation are vital for the success of urban farming initiatives to mitigate UHIs.	20 (5.1)	33 (8.4)	46 (11.7)	185 (47.0)	110 (27.9)	3.84	1.08	High perception
Effective policies and governance structures are necessary to support urban farming as a UHI mitigation strategy.	20 (5.1)	26 (6.6)	40 (10.1)	183 (46.2)	127 (32.1)	3.84	1.08	High perception

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According to the survey's findings, an overwhelming majority of respondents believed that a lack of knowledge and experience in the development as well as the sustainability of urban farming initiatives posed challenges or obstacles (Table 4.20). This result reveals the respondents' thoughts, convictions, or personal experiences regarding the variables impacting the difficulties or achievements of urban farming projects. The high perception indicates that participants view a lack of knowledge and experience as a major obstacle to the successful implementation and long-term sustainability of urban farming initiatives The research on challenges in urban farming conducted by (Maharjan & Kaushal, 2022; Tuijl et al., 2018) closely aligns with the findings obtained from the respondents. The respondents shared the opinion that one of the biggest barriers to the development and long-term viability of urban farming projects is a lack of knowledge and experience.

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This is in line with Kaushal et al.'s focus on the challenges of sustainability and economic viability in urban farming, which highlights the need of focused training, skill development, and teamwork. Similarly, Tuijl et al. found that urban residents' lack of basic knowledge and skills was impeding the growth of urban farming initiatives. The common threads in these studies emphasize how crucial it is to address gaps in knowledge and expertise to support the development and adaptability of urban farming methods. This alignment points to a common understanding of the main obstacles that need to be overcome with thorough and well-planned interventions. This understanding is useful for comprehending the particular difficulties encountered by people engaged in or impacted by urban farming, and it can direct focused interventions, educational programmes, or legislative changes meant to remove these alleged obstacles.

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In the same vein, the survey result shows a high perception among the participants, the positive and supportive attitude among the participants indicates that the community recognizes the critical role that public awareness as well as positive perceptions play in the success of urban farming initiatives (Table 4.20). Good public perception and increased awareness foster cooperation, support, and involvement in the community. The efficacy and sustainability of urban farming initiatives depend on community engagement, which fosters collaboration between project stakeholders and the community. Success is more likely when the community is aware of the objectives and advantages of urban farming for reducing urban heat island effects and has positive opinions about it. Furthermore, the public's support can play a significant role in helping urban farming initiatives overcome obstacles and hurdles. In order to create an environment that is favourable to the effectiveness of urban farming initiatives aimed at mitigating UHI, it is important to emphasise the interrelated nature of community involvement, knowledge, and positive perceptions.

A significant outcome of the study is that participants thought it was hard to get grants and incentives to start urban farming projects that would lessen the impact of UHI, shown in (Table 4.20). This observation raises concerns about a perceived lack of funding, pointing to potential roadblocks that individuals or communities may face when trying to use urban farming to lower UHI. The results highlight the need for focused interventions to remove these alleged obstacles, like raising funds through advocacy, expediting the application process, or raising awareness of the financial support that is available. Recognising and resolving these issues are critical first steps in creating an atmosphere that

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is more conducive to urban farming projects that aim to reduce urban heat island effects. Similarly, another important finding of the study is that respondents felt there was little financial support available for urban farming initiatives that attempted to mitigate Urban Heat Islands (Table 4.20). This was especially true when it came to low-interest loans and financing options. This result highlights perceived difficulties in obtaining the required financial resources. It evaluates participants' views, knowledge, or experiences regarding the financial aspects of creating and growing urban farming initiatives for UHI mitigation. The impact of this negative opinion points to possible obstacles that could prevent urban farming projects from expanding and succeeding. Policymakers and other stakeholders must comprehend the underlying causes of this perception in order to implement targeted interventions aimed at increasing financial resource accessibility and creating a more encouraging atmosphere.

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These important findings of the study, which is that participants have trouble getting funding for urban farming projects especially those that try to minimize the effects of UHI resonates with the issues raised by Lawanson et al., in 2015. Lawanson's observations regarding the challenges of financing urban agriculture are supported by a 2012 study conducted in Malaysia by Islam & Siwar, which found that financial considerations significantly influenced the decision to implement urban farming. These consistent results highlight the widespread difficulty in obtaining funding for urban farming projects around the world. The results highlight the need for focused interventions to remove these alleged obstacles, like raising funds through advocacy, expediting the application process, or raising awareness of the financial support that is available.

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Recognising and resolving these issues are critical first steps in creating an atmosphere that is more conducive to urban farming projects that aim to reduce urban heat island effects.

According to the survey results, respondents had a negative opinion of how simple it is for urban farmers to buy or rent the equipment and supplies they need to carry out heat island mitigation initiatives (Table 4.20). In order to mitigate UHI by means of urban farming, this assessment gauges participants' beliefs, awareness, or experiences regarding the practical aspects of purchasing necessary equipment. The low perception indicates that the respondents thought it would be difficult to get the equipment and tools they needed for their UHI mitigation projects. In order to identify potential obstacles, whether they be related to availability, affordability, or awareness, it is imperative to comprehend the reasons behind this perception. Additionally, targeted strategies to enhance the practical elements of obtaining the required machinery for urban farmers involved in UHI mitigation efforts must be developed.

The results of the survey indicate that respondents have a low perception of the current system's capacity to give urban farmers convenient access to high-quality plant seeds and seedlings that are resilient to high temperatures, urban environmental variables, and fertilizers (Table 4.20). This implies that there is a significant divide or dissatisfaction among participants regarding the current urban farming support system. The report offers several solutions to address this, including a thorough review of the current system, direct farmer consultation to identify issues, and the implementation of targeted modifications. A more responsive and efficient system assisting urban agriculture may also result from a

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more open and cooperative approach to the creation and execution of projects with urban farmers.

The results of the survey show that participants had a very positive perception of the availability of water for agriculture in cities and UHI mitigation. The essential function of water in urban cultivation and its role in reducing the effects of UHI was clearly understood by the respondents. This is in perfect accordance with the findings of Lin et al.'s (2023) research, which highlights the importance of water in improving the urban thermal environment. The study emphasizes the value of adding water features to urban landscapes as a useful tactic for cooling and enhancing general thermal conditions in cities, and it shows how effective it is to build water corridors in Fuzhou to mitigate the UHI effect. The results point to a favourable comprehension of the relationship between sustainable urban farming and the availability of water resources. The significance of water for crop well-being as well as cooling effects was emphasised in participant comments. The survey's recommendations include building on this positive perception to further support urban farming techniques that use less water and investigating focused interventions that target any areas that were found to need assistance or improvement. Overall, the findings highlight the potential for well-informed approaches and laws meant to improve water access in order to greatly aid in the successful mitigation of urban heat island effects through urban farming.

Participants' positive perception of the actions utilized to combat contamination and poor soil quality in urban farming to reduce the impact of Urban Heat Islands (Table 4.20)

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aligns with Humaida's 2023 work. Humaida promotes education and awareness campaigns and highlights the critical need for tackling soil concerns for Urban Heat Island mitigation. The favourable survey responses imply that respondents acknowledge the significance of these initiatives. Participants responded positively to Humaida's emphasis on proper composting, efficient crop rotation, and soil conservation techniques. This suggests that they recognize the importance of holistic techniques for managing soil for responsible and environmentally friendly urban farming, which helps to mitigate urban heat island effects and promotes overall environmental health.

Similarly, the results of the survey indicate that participants have a strong perception of the significant challenge that comes with the scarcity of land for urban farming (Table 4.20). This suggests that the majority of respondents are aware of and accept the difficulties in locating appropriate land for farming within cities. The positive perception points to a common knowledge of the obstacles urban farmers encounter when trying to obtain the land needed for farming, raising livestock, or other activities. This knowledge is essential for developing plans and regulations that support sustainable urban agriculture and address the constraints of space. The results highlight the value of creative thinking, community involvement, and teamwork in overcoming the obstacle of available land in the realm of urban farming.

Participants' positive perception of the actions utilized to combat contamination and poor soil quality in urban farming to reduce the impact of UHIs aligns with that of (Humaida et al., 2023). Humaida’s study promotes education and awareness campaigns

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and highlights the critical need for tackling soil concerns for Urban Heat Island mitigation. The favourable survey responses imply that respondents acknowledge the significance of these initiatives (Table 4.20). Participants responded positively to Humaida's emphasis on proper composting, efficient crop rotation, and soil conservation techniques. This suggests that they recognize the importance of holistic techniques for managing soil for responsible and environmentally friendly urban farming, which helps to mitigate urban heat island effects and promotes overall environmental health. This increased awareness highlights how urgent it is to remove ownership and regulatory barriers in order to enable urban farming to be successfully integrated into larger-scale UHI mitigation initiatives.

The study reveals that the majority of respondents had a positive opinion of the impact of seasonal characteristics and variations in climate on how well urban farming mitigates urban heat island effects shows that people are aware of how closely related climatic conditions and agricultural practices are (Table 4.20). The recognition that critical elements of urban farming, including crop growth periods, water availability, and general efficiency, are impacted by seasonal variations and unpredictable climate trends points to a thorough comprehension of the difficulties presented by climatic variability. Unpredictable weather events, erratic precipitation patterns, and extreme temperatures are acknowledged as possible barriers to sustaining dependable and regular farming practices in an urban setting. This increased awareness highlights the significance of resilient and adaptable tactics in urban farming and the requirement for climate-smart agricultural methods to maximize the benefits of sustainable urban agriculture-based UHI mitigation initiatives. Direct experiences, firsthand observations, and increased awareness all

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contribute to the respondents' strong opinion that seasonality and climate variability have an impact on how well urban farming mitigates urban heat island effects.

The participants' positive perception of the importance of distribution networks and market accessibility for urban farming is consistent with Sikora et al., (2019) focus on these elements' pivotal roles. The view expressed by Sikora et al. lends credence to the idea that effective market accessibility as well as distribution networks are necessary for urban farmers to successfully engage and communicate with urban consumers. The congruence between the perspectives of the participants and the results of Sikora et al. reinforces the comprehension that these factors are essential to the prosperity and durability of urban farming endeavours. The participants' understanding of the financial and practical aspects of urban agriculture is emphasised by this consensus, which also highlights the necessity of having established networks to connect urban farmers with consumers, markets, and distribution networks. The participants' high perception of the importance of market access and distribution channels for urban farming likely stems from a recognition of the economic viability, community engagement, and food security benefits associated with efficient access to markets. The belief that well-organized distribution channels contribute to logistical efficiency, environmental sustainability, and community resilience further supports their positive view.

The study's results are consistent with Hussain et al.'s (2019) emphasis on community participation. The importance Hussain et al. placed on community participation is echoed by the study's finding that a high perception of public opinion on civic

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engagement positively impacts urban farming initiatives (Table 4.20). This is equally supported by (Yusoff et al., 2017). They emphasize how important it is to include residents in understanding viewpoints, match community demands with urban farming, and give locals a voice in decision-making, especially when it comes to issues of environmental justice. In order for urban farming projects to be successful and to be in line with local needs and values, both sources stress how important community involvement is. This favourable opinion implies that the respondents are aware of how community involvement supports resilient and sustainable urban farming methods, which in turn helps to reduce the impact of urban heat islands. The results highlight how important it is to foster community involvement, support, and collaboration as essential elements for productive urban farming initiatives meant to address more general environmental concerns.

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As indicated by their high perception of its significance, the study participants broadly acknowledge the critical role that effective policies and governance structures play in advancing urban farming as a strategy for minimizing Urban Heat Islands (Table 4.20). This is consistent with Mancebo's (2018) claim that initiatives aimed at mitigating urban heat island effects must be supported and maintained by efficient regulatory frameworks. The participants' overall consensus highlights the critical need for an environment of supportive governance to support the expansion and sustainability of urban farming initiatives, underscoring the significance of well-crafted policies to mitigate the effects of UHI. All of these complex factors point to the critical role that well-thought-out laws and governance frameworks play in fostering an atmosphere that is favourable to the success of urban farming projects that aim to reduce urban heat island effects.

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Table 4.21

Initiative and Adaptation Measures for UHI Mitigation

Statements	Strongly D 1 (%)	Disagree 2 (%)	Undecided 3 (%)	Agree 4 (%)	Strongly A 5 (%)	Mean	SD	Decision
Maiduguri residents are aware of programs/initiatives involved in tree planting and other vegetation in urban areas to mitigate UHI.	43 (10.9)	49 (12.4)	56 (14.2)	164 (41.6)	82 (20.8)	3.49	1.25	Low perception
Many Maiduguri residents' have observed or participated in urban farming projects aimed at reducing the urban heat island effect.	39 (9.8)	78 (19.6)	62 (15.6)	161 (40.6)	57 (14.4)	3.30	1.22	Low perception
Maiduguri residents are familiar with cool roof initiatives, which involve using reflective materials to reduce heat absorption on rooftops.	32 (8.1)	73 (18.5)	71 (18.0)	146 (37.1)	72 (18.3)	3.39	1.21	Low perception
There is a belief among urban dwellers in Maiduguri that urban farming, such as rooftops, and community gardens, can contribute to cooling the urban environment.	38 (9.6)	54 (13.6)	70 (17.7)	155 (39.1)	79 (19.9)	3.46	1.22	Low perception
Community involvement is considered crucial for the success of urban farming initiatives aimed at mitigating UHI in Maiduguri.	26 (6.6)	41 (10.4)	58 (14.7)	187 (47.3)	83 (21.0)	3.66	1.12	High perception
Most Maiduguri residents believe that education and awareness campaigns about urban farming can encourage more urban dwellers to participate in UHI mitigation effort.	28 (7.1)	43 (10.9)	48 (12.1)	184 (46.5)	93 (23.5)	3.68	1.15	High perception
Maiduguri residents are familiar with agricultural practices designed to withstand high temperatures.	29 (7.5)	44 (11.3)	73 (18.8)	167 (43.0)	75 (19.3)	3.55	1.15	High perception
Many Maiduguri residents have taken steps to adopt heat-resilient landscaping practices, like planting shade trees, at their residential quarters or workplaces.	32 (8.1)	46 (11.6)	55 (13.9)	161 (40.7)	102 (25.8)	3.64	1.21	High perception
Some individuals believe that the current urban farming initiatives in Maiduguri are not effectively reducing the impact of the UHI.	34 (8.6)	69 (17.5)	84 (21.3)	142 (35.9)	66 (16.7)	3.35	1.20	Low perception
Maiduguri residents are aware of the efforts of (NGOs) that promote urban farming as a strategy to mitigate urban heat islands.	28 (7.1)	49 (12.4)	66 (16.7)	140 (35.4)	113 (28.5)	3.66	1.21	High perception

Note N = 400,

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Decision = Weighted average = 35.18 / 10 = **3.52.**

The low perception among residents for tree planting programs targeted at mitigating urban heat islands is another indication provided by the survey results that point to a significant knowledge and understanding gap among the Maiduguri community (Table 4.21). This ignorance is consistent with the larger ecological problems that Borno State faces, which are marked by concerning rates of careless tree-trimming and a consequent lack of natural regeneration as a result of environmental desiccation. Remarkably, there is still a significant and random rate of cutting down trees with these difficulties. Shettima et al. (2017) implemented an urban tree-planting scheme in 1986 that offered green cover to cities on the edges of deserts, realizing the need for action to counteract the negative effects of cutting down trees and promote sustainability. Enhancing the effectiveness and impact of such initiatives in reducing the environmental challenges in the area requires addressing the knowledge gap in the community. To raise community support and highlight the advantages of planting trees and adding vegetative cover to reduce urban he at islands, this awareness gap must be eliminated.

Likewise, the low level of participation that Maiduguri residents perceive to exist in urban farming initiatives meant to mitigate the impact of heat islands on cities points to possible obstacles or restrictions in community awareness and engagement with sustainable urban practices. To mitigate the urban heat island effect, the measure evaluates how much the community actively participates in and gains from initiatives incorporating agriculture and green spaces. The low perception may suggest that more outreach, communication, or educational initiatives are needed to educate locals about the value and

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advantages of urban farming in reducing heat island effects. It might also draw attention to the need of removing any hurdles or impediments that prevent the community from actively participating in these kinds of projects. There could be a number of reasons for Maiduguri residents' low opinion of their involvement in urban farming initiatives to lessen the impact of heat islands in cities, including a lack of awareness, poor accessibility, socioeconomic or cultural influences, a breakdown in communication, and a lack of benefits being perceived.

Furthermore, the study reveals a significant disparity in Maiduguri residents' awareness and understanding of cool roof programmes meant to reduce urban heat islands. The results show that there is a low level of perceived familiarity with the specific technique of using reflective surfaces on rooftops to lower urban temperatures by reducing heat absorption. Surveys were used as the study's methodology to collect data, and respondents from all demographic groups expressed a lack of awareness. The analysis identifies some possible causes for this ignorance, such as a communication breakdown and possible socioeconomic or cultural influences. Maiduguri's low socioeconomic status, low level of technological advancement, and the traditional characteristics of the built environment all seem to have an impact on the low awareness of cool roof initiatives intended for mitigating heat islands in urban areas among the local population. Cultural beliefs that place a higher priority on other factors than environmental initiatives may contribute to the limited information dissemination caused by an absence of visual representation and inadequate communication channels. Financial limitations might also cause resources and attention to be diverted away from sustainable practices.

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Moreover, there may be a knowledge gap in the community about the cooling effects of urban agriculture, as evidenced by the low perception of belief among Maiduguri residents that urban farming methods, such as rooftop gardens as well as community gardens, can help to cool the urban environment (Table 4.21). This measurement raises the possibility that people are unaware of the advantages this type of urban farming practices has for the environment. This reported lack of awareness is also attributed to insufficient educational initiatives centred on sustainable practices and the absence of proactive community involvement. These difficulties are made worse by language barriers, which highlights the necessity of presenting information in languages that are widely understood. To tackle these complex issues, a focused and culturally aware strategy is needed, along with the involvement of local leaders, local avenues for communication, and improved educational programmes to close the knowledge gap and promote a thorough comprehension of Maiduguri's cool roof initiatives' advantages. Communication, inadequate educational programmes, or cultural factors shaping the community's views regarding the role of farming in cities in cooling the city's atmosphere could all be contributing factors to this low perception. It might be necessary to make focused efforts to improve communication channels, disseminate information, and the advantages of adding green areas to Maiduguri's urban landscape for sustainable development.

Maiduguri's high perception for the significance of active community engagement and participation in urban farming initiatives can be ascribed to some factors, including good communication, evident outcomes from earlier efforts, cultural congruence, grassroots involvement in choice-making, educational initiatives, and strong local

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leadership (Table 4.21). The importance of community involvement and active engagement in urban farming initiatives lies in identifying critical success factors. A sense of ownership is fostered by educating and raising awareness within the community through effective communication. Critical components include prior success, cultural congruence, grassroots participation in decision-making, educational programs, and capable local leadership. The cornerstone for the sustainability and long-term viability of urban farming projects is built by actively involving residents in decision-making processes, coordinating initiatives with regional needs, and acknowledging accomplishments. The factors that have been reported underscore the crucial role that communication, participation in the community, and local leadership play in attaining enduring impact in urban agriculture (Maharjan & Kaushal, 2022; and Tuijl et al., 2018).

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In addition, the high perception in the survey regarding residents' acknowledgment of the potential impact of educational and awareness campaigns in motivating individuals to actively participate in initiatives aimed at mitigating urban heat islands through urban farming indicates a positive and widespread understanding within the community (Table 4.21). The survey suggests that residents recognize the effectiveness of educational efforts in encouraging engagement in sustainable practices. This favourable perception bodes well for the success of future educational and awareness campaigns, as it reflects a community that values information dissemination as a catalyst for increased participation in urban farming and heat island mitigation efforts in Maiduguri. The combination of these elements produces a community that is aware of and proud of its part in making Maiduguri's urban farming projects successful. Campaigns that integrate cultural relevance and address local

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issues, in addition to community engagement as well as leadership support, help create a community that understands the value of education in promoting active engagement in urban farming efforts for heat island mitigation initiatives.

There is a general understanding and engagement with agricultural methods that are resilient in Maiduguri, as evidenced by the high perception across the general population regarding the community's understanding and awareness of methods of farming specifically adapted for continued success in the region's high temperatures (Table 4.21). This encouraging reaction implies that locals are not only informed of these specialised methods but also think they work well for dealing with the problems brought on by the high temperatures in the area. This positive view highlights the community's adaptability to the local climate and resilience, demonstrating a shared understanding of climate-resilient and sustainable farming methods in Maiduguri. Some factors probably contribute to Maiduguri residents' high perception of their understanding and appreciation of farming practices adapted to high temperatures. The climate of the area, which is marked by constant high temperatures, calls for a thorough understanding of agricultural techniques that can withstand these circumstances. Residents are familiar with practical methods because of the community's rich farming history, which includes traditional farming practices that have been passed down through the generations. Their years of practical experience have given them an extensive knowledge of climate-resilient agricultural practices, which is enhanced by their local expertise.

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The high perception of heat-resilient landscaping, among respondents on practices like planting shade trees, being actively implemented by Maiduguri residents in their immediate surroundings suggests a strong and diligent engagement in focusing on the challenges brought about by high temperatures (Table 4.21). This implies that people are committed to working together to implement concrete actions that will lessen the effects on the local environment. The urban dwellers decision to embrace heat-resilient landscaping techniques, particularly the planting of shade trees, reflects a shared understanding of the importance of natural adaptation and a commitment to creating more healthier and sustainable living spaces in response to Maiduguri's unique climate.

A small number of participants in the survey voiced doubts about the ability of Maiduguri's present urban farming initiatives to lessen the negative consequences of the urban heat island phenomenon. The low perception suggests a lack of awareness and confidence among certain persons regarding the ability of these actions to effectively address the implications of localized warming (Table 4.21). This realization emphasizes how critical it is to address issues, enhance communication, and possibly reassess or improve urban farming techniques to better meet the needs and expectations of this specific community group.

A strong and widespread acceptance within the community is indicated by the respondents' high perception of Maiduguri residents' awareness of the initiatives and activities carried out by non-governmental organizations aimed at supporting urban farming as a strategy for helping combat and minimize the urban heat island phenomenon

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(Table 4.21). This positive perception highlights a positive understanding of the function of non-governmental organizations in addressing the difficulties posed by heat islands in cities, particularly in Maiduguri, and suggests that the locals are well-informed about the activities of NGOs in promoting and executing urban farming methods for sustainable development.

Furthermore, it is worth noting that, although the primary data sources for this study included GIS and remote sensing datasets, Google Maps imagery, and ENVI-met simulation outputs, a supplementary questionnaire was also administered to capture community perceptions regarding urban farming and the UHI effect. Descriptive statistics were employed to summarize the responses, providing an overview of general trends and participant characteristics. These statistics are essential for identifying patterns, particularly in survey data (León-Mantero et al., 2020). Additionally, the weighted average technique was used to aggregate Likert-scale responses, offering a more nuanced interpretation of community attitudes by accounting for the relative importance of different responses (Boone & Boone, 2012; Ramachandran & Kumar, 2021). These statistical methods were well-suited for the exploratory nature of the questionnaire and effectively complemented the geospatial and simulation analyses.

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4.13.6 Summary

Chapter Four features an integrated analysis that uses remote sensing, simulation modeling, and survey-based research to examine the effectiveness of urban farming as an approach for reducing Urban Heat Island in Maiduguri, Nigeria. It looked at both the physical dynamics of land surface modification and the socio-environmental implications of urban farming adoption.

Satellite imagery from USGS Landsat missions (Landsat 5, 7, and 8) was processed with the ArcGIS platform to derive key environmental variables such as Land Surface Temperature (LST), Land Use/Land Cover (LULC), and the Normalized Difference Vegetation Index (NDVI). These data were processed to illustrate the spatiotemporal evolution of Maiduguri's urban environment from 1992 to 2022. Remote sensing techniques enabled the extraction of vegetation indices and thermal properties critical to understanding UHI dynamics across time.

Urban farming practices were also analyzed through a geospatial audit of historical imagery from Google Earth (2002–2022), finding four important urban farming sites every year. Farm sizes and perimeters were measured to examine spatial changes in urban agriculture, providing insights into its geographical expansion and structural evolution. To evaluate the microclimatic impact of urban farming, the ENVI-met model was utilized. This high-resolution 3D simulation tool facilitated a thorough assessment of temperature and humidity variations in three urban farming coverage scenarios (10%, 20%, and 30%)

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within a typical high-density area. The model's input data came from previous LULC and NDVI evaluations. The simulation findings showed meaningful decreases in surface temperature and increases in relative humidity, confirming urban farming's cooling potential as a promising natural approach for UHI mitigation in Maiduguri's semi-arid climate.

In addition, a structured survey was given out to a representative sample of Maiduguri's urban residents to assess their knowledge, perceptions, and practices regarding UHI and urban farming. The survey examined respondents' sociodemographic factors (age, gender, education, occupation, income), how they live (energy usage, disposal of waste, transportation), and environmental habits. It also assessed awareness and comprehension of UHI causes and effects, as well as challenges to implementing urban farming as a mitigation method, such as limited land access, water scarcity, financial constraints, and regulatory concerns.

Furthermore, this survey looked at public attitudes regarding environmental sustainability and urban greening activities, such as desire to participate in community-based projects, practice urban farming, and support green infrastructure. These findings shed light on public readiness for urban climate adaptation and identified potential for governmental action and community participation. In general, Chapter Four presents a thorough, multidisciplinary evaluation of UHI mitigation through urban farming. It combines spatial analysis, empirical modeling, and community-level perspectives to support the Maiduguri plan for sustainable urban growth and climate resilience.

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CHAPTER 5

DISCUSSION, SUMMARY AND CONCLUSION

5.1 Introduction

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This chapter covers the summary and conclusion of the entire research work conducted by the researcher on urban heat island mitigation through urban farming using remote sensing in Maiduguri, Nigeria. It also provides recommendations that can be pursued by all stakeholders. The study was conducted in Maiduguri, the Borno State capital in northeastern Nigeria. The research encompasses the introductory and general background of the study, a review of various related literature, a general background of the study area, demographic characteristics of the respondents, an analysis of research findings, interpretation, presentation of results, and conclusions. The study employed a quantitative approach, integrating three methods to acquire robust data and provide a comprehensive analysis. GIS and RS data were first utilized, with Landsat satellite data acquired from the USGS for three decades from 1992 at ten-year intervals. These Landsat data were

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interpreted and visualized on the ArcGIS platform, generating data on LST, LULC, and NDVI.

Urban farming practices were comprehensively assessed by examining historical satellite imagery from Google Earth Pro (2002-2022) using GIS analysis and physical audits. Pertinent data were obtained through a survey focused on residents' perceptions and understanding of the UHI phenomenon associated with urban farming for UHI mitigation, using four hundred structured questionnaires. The ENVI-met simulation model was employed to assess the impact of urban farming on Maiduguri's microclimates, focusing on temperature reduction and humidity increase.

The statistical tools used in the study included mean, standard deviation, and weighted average. The analysis of the results from the Landsat data and imagery reveals a rising temperature in the city, establishing the existence of the urban heat island phenomenon. Multi-temporal satellite image analysis classified LULC classes, illustrating trends and magnitudes over the study period, which were demonstrated in tables and visually presented. NDVI maps were also presented. The study has further provided a quantitative understanding and awareness of the urban heat island effects and their mitigation through an urban farming approach. Furthermore, the study documented the perceptions and attitudes of urban dwellers towards urban heat islands and identified various challenges and barriers to urban farming for UHI mitigation.

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5.2 Researcher's Discussion and Further Argument

Employing an integrated approach that utilized remote sensing analysis, geospatial modeling, and social survey data, this study examined the role of urban farming as a technique for mitigating the Urban Heat Island effect in Maiduguri, Nigeria. The research covered three decades (1992–2022) and evaluated land use dynamics, surface temperature patterns, as well as the spatial distribution of urban farming, residents' awareness of UHI, and the potential of urban farming as a mechanism for climate adaptation.

5.2.1 Assessing the Level of Urban Farming Practice and the UHI Phenomenon in Maiduguri

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Between 1992 and 2022, urban farming in Maiduguri developed steadily. However, this development was driven not by official urban strategy, but by local adaptation techniques to economic hardship, food shortages, and conflict-related forced relocation. Four recurring urban farming sites were identified each year by geospatial assessments using Google Earth Pro imagery (2002-2022), demonstrating a consistent and steadily expanding pattern of agricultural land usage within the urban landscape. This is consistent with the findings of Jantakat et al., (2019), who tracked urban farming over time using Google Earth data and found that farm plots expanded steadily and that spatial usage was stable in Asian metropolitan areas. Their research backs up the use of remote sensing to identify robust but unofficial urban farming patterns.

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These locations were primarily concentrated in the northeastern part of the city, with occasional clusters in the middle and southern urban periphery. The measured rise in farm sizes, as well as the continuous usage of these plots, indicate a consistent reliance on urban farming as a source of income and subsistence.

Figure 4.8a shows that in 2002, farming sites were spread out yet noticeable, particularly in the northeast, with some scattered portions in the south and central areas. By 2012 (Figure 4.8b), there was a considerable decrease in these farmlands, particularly in the southern and central urban zones, as a result of increased residential development and the expansion of impervious surfaces. However, the 2022 map (Figure 4.8c) shows an improvement or stabilization of farming activity, particularly in the northeastern corridor, where proximity to river channels ensured a steady water supply. This environmental advantage has helped farming in cities withstand expanding infrastructure and climatic strains.

Similar to growth and changes in urban farming, an analysis of Land Surface Temperature (LST) data from Landsat 5, 7, and 8 for the years 1992, 2002, 2012, and 2022 revealed a consistent increase in surface temperature over time, confirming the existence and worsening of the Urban Heat Island phenomenon. This result aligns with that of Humaida et al., (2023), who found that excessive human activity, CO_2 emissions, and vegetation loss were the main causes of UHI intensification in metropolitan areas that were expanding quickly. Their research demonstrates that the main cause of urban heat stress is the challenges of green infrastructure, which are made worse by dense growth. Figures 4.4

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to 4.7 illustrate that the spatial pattern associated with elevated LST areas is similar to areas with intense urban development and low vegetative cover.

In 2002, UHI patterns were obvious, with higher surface temperatures reaching up to 25.66 °C in densely populated regions with scant vegetation (Figure 4.5). By 2012, these hot zones had extended greatly, and the highest LST went up to 34.29 °C, demonstrating higher heat retention in urban cores due to impermeable materials and loss of green space (Figure 4.6). The 2022 statistics (Figure 4.7) suggest further intensification, with maximum LST reaching 34.38 °C. Although some thermal hotspots appeared dispersed (most likely due to developing vegetation patches or changes in urban planning), temperature elevation remained spatially stable and broad.

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The temperature profile graphs during the study years (see Figure 4.9) regularly show peaks in densely populated areas and depressions in vegetated or farming zones, emphasizing the microclimatic benefits of green spaces and cultivated land. Areas where urban farming persisted, notably along riverbanks and open peri-urban areas, had lower LST values than adjacent developed areas. This temperature variance validates vegetation's cooling impact and emphasizes urban farming's potential contribution to UHI reduction. These results concur with those of Zvolen et al., (2022), who discovered that average LSTs in urban green spaces (UGS), including agricultural land, were up to 3.5°C lower than those in built-up regions. According to their research, green spaces play a major role in reducing heat stress, particularly on hotter days and during heat waves. The importance of urban farming as a thermal regulation technique was further supported by the fact that the

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temperature differences between vegetated as well as non-vegetated zones were greatest during hot seasons.

In general, the spatial analysis reveals a significant connection between plant loss, rising surface temperatures, and the spatial growth of built-up regions. Urban farming, despite its informal and irregular distribution, has contributed to the reduction of localized heat stress by retaining vegetative cover and encouraging land usage that promotes environmental sustainability.

5.2.2 Analyzing Spatiotemporal Trends in LULC, LST, and NDVI (1992–2022)

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The spatiotemporal analysis of Maiduguri from 1992 to 2022 illustrates a significant relationship between land use/land cover (LULC) change, vegetation declines reflected by NDVI, and rising land surface temperatures (LST), all of which point to an intensifying Urban Heat Island (UHI) effect throughout the three-decade time period. Between 1992 and 2022, Maiduguri saw significant LULC transformation. Vegetation and farmland accounted for 53.8% of the landscape in 1992, but had rapidly fallen to 31.3% by 2012, owing mostly to urbanization, land clearing, and infrastructural development. Built-up areas have more than doubled, rising from 6.3% (7054.89 km²) in 1992 to 11.3% (12458.25 km²) by 2022. Urban growth is centered along important corridors such as the University of Maiduguri, Bulumkutu/Ngomari, Dikwa Road, and Baga Road, replacing natural and agricultural environments.

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In a similar vein, the percentage of bare land increased from 33% in 1992 to 51.7% in 2012, indicating extensive vegetation removal and continuous land degradation, which had a direct impact on thermal dynamics throughout the city. In 1992, the maximum LST ranged from 13.88°C to 32.48°C, with cooler zones observed around vegetated areas and water bodies. By 2002, the maximum LST had increased to 40.71°C, and the minimum also increased to 17.77°C, indicating a clear shift towards heat intensification linked to urban sprawl and vegetative loss. The most extreme heat conditions occurred in 2012, when the maximum LST reached 49.11°C, which was the peak of UHI intensification during the period under review. In 2022, the maximum LST slightly decreased to 47.80°C, the minimum temperature remained high at 21.79 °C, indicating continued background warming and heat retention.

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The yearly average temperature patterns provide additional support for these findings. Table 3.1 shows the citywide average temperature increased from 30.68 °C (1992-2002) to 31.69 °C (2012-2022). Tamsu Ngamdua (32.03 °C), Gwange I (31.90 °C), and Mairi (31.67 °C) wards had the highest mean temperature values, indicating concentrated UHI hotspots as shown in Figures 3.2 and 4.6. The thermal increase corresponds to vegetation loss, as determined by NDVI analysis. NDVI values ranged from –0.53 to 0.46, with greater values recorded in 1992, notably in the southern areas of the city wherein vegetation was still dominant. NDVI values has steadily declined over time, notably in the central and northern sections, indicating a considerable reduction in vegetation health and covering. This tendency was particularly obvious in the 2012 and 2022 maps, where only fragmented regions with high NDVI values remained. Notably,

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there is a constant inverse relation between NDVI and LST, since low vegetation cover areas often have higher surface temperatures, validating the previously recognized correlation between vegetation density and thermal regulation. UHI index analysis adds to these conclusions.

In 2002, UHI readings varied from 2.72 °C to 25.66 °C, with the highest intensities found in the city center. Around 2012, the index reached 34.29 °C and stayed high until 2022, with values ranging from 8.36 °C to 34.38 °C. These spatial patterns show not only the endurance but also the outward expansion of UHI intensity into hitherto peripheral areas as urbanization expanded. The analysis aligns with previous studies. Bello (2021) and Ladan et al. (2023) observed higher temperature anomalies in Maiduguri, connected to diminished vegetation and enhanced urban growth. Buba and Ibrahim (2018) also observed a general warming trend in northern Nigeria, with even less urbanized areas experiencing significant temperature increases. Jimme et al. (2016) and Mayomi & Mohammed (2014) reported that daily temperatures in Maiduguri frequently exceed 40 °C, especially in March and April, which corresponded to the extreme LST readings found in 2012.

Similar patterns were noted by Olanrewaju (2018) in Abuja, where surface temperatures rose from 24.3 °C in 1987 to 32.54 °C in 2014 as built-up areas grew and greenery decreased by 35.63%. Additionally, Rehman et al. (2022) reported a 25.18% increase in higher LST zones, which they directly attributed to the loss of vegetation and the growth of impermeable surfaces.

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Generally, these results show that Maiduguri has seen fast urbanization, which has serious environmental repercussions. The replacement of vegetated and agricultural land with impermeable built-up surfaces has resulted to increased heat storage and reduced cooling capacity, contributing to a quantifiable and geographically growing UHI effect. The combined patterns of LULC, NDVI, and LST during the research period confirmed by this analysis are the main causes of the city's thermal variations during the research period.

5.2.3 Assessing Urban Residents' Knowledge and Perceptions of UHI and Its Mitigation through Urban Farming.

The survey results highlight an important gap in residents' awareness and understanding regarding the Urban Heat Island phenomena and the role urban agriculture can play in its mitigation. As shown in Table 4.18, knowledge of UHI remains low, which is influenced by variables such as limited environmental education, inadequate media coverage, and prolonged local insecurity. Despite this, respondents overwhelmingly acknowledge the relevance of human activities in promoting UHI formation, which is consistent with the findings of Ibrahim et al. (2019) and Sahu et al. (2014), who corroborate anthropogenic factors as important to urban heat dynamics. However, a significant gap exists between citizens' perception of urban farming's importance in food security along with their understanding of its environmental cooling advantages.

Table 4.19 shows that the relationship between crop cultivation and microclimate regulation is poorly understood. This conclusion contradicts Derkzen et al. (2017), who

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found universal appreciation for urban vegetation's ecological services. Similarly, low perceived community involvement in urban farming operations indicates low awareness and participation, stressing the importance of targeted education, communication, and collaboration efforts to promote understanding of urban farming's multiple benefits for climate mitigation and growing food (Table 4.19).

Furthermore, respondents have a low perception of new production methods such as hydroponics and aquaponics, which have been found to improve sustainability and urban microclimate control (Bhattarai & Adhikari, 2023). The lack of excitement for such technologies shows an information vacuum that might be filled through awareness campaigns emphasizing their environmental benefits and applicability to small urban environments. The survey also reveals low confidence in the efficacy of human interventions, such as green and blue-green infrastructure, in improving urban microclimates (Table 4.19). This is contrary to the substantial scientific evidence that supports anthropogenic mitigation efforts. Studies by Almaaitah et al. (2021), Cai et al. (2023), and Wang et al. (2021a) showed the effectiveness of permeable sidewalks, vegetated surfaces, and nature-based designs in reducing urban heat.

The disparity between this evidence and public perception highlights the critical need for public education and policy integration to promote trust in and implementation of such measures. Furthermore, while Table 4.20 demonstrates broad agreement on the importance of effective governance and policies to advance urban farming, key implementation challenges were identified. These include lack of knowledge and technical

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capability, limited financial resources, and insufficient institutional backing, consistent with issues highlighted by Maharjan & Kaushal (2022), Tuijl et al. (2018), and Lawanson et al. (2015). The low perception of urban tree planting programs (Table 4.21), notwithstanding historical interventions such as Shettima et al.'s 1986 afforestation project, emphasizes the importance of integrated education for the public and urban greening techniques.

Thus, while urban residents in Maiduguri acknowledge human roles in UHI formation and value urban farming in principle, their lack of awareness of its broader environmental benefits and mitigation potential necessitates integrated capacity development, financial investment, and targeted communication techniques to fully realize its potential in sustainable urban planning.

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5.2.4 Evaluating the Effectiveness of Urban Farming in Reducing Urban Heat Island Impact.

To examine the prospect of urban farming as an Urban Heat Island (UHI) mitigation technique in Maiduguri, this study applied ENVI-met simulations to model three scenarios of urban farming coverage 10%, 20%, and 30% across a typical high-density residential area. Model inputs were collected from prior LULC and NDVI analysis to ensure realistic baseline surface attributes. The purpose was to investigate how changes in vegetative cover affected microclimatic indicators such as Land Surface Temperature (LST) and relative humidity (RH). Figure 4.18 depicts the ENVI-met simulation results for all three scenarios,

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focusing on the regional distribution of surface temperature and humidity. Table 4.15 presents the average LST and RH values for each condition. The findings clearly show that increased urban farming coverage resulted in measurable improvements in the microclimate. Surface temperatures decreased by 0.5, 1.0, and 1.5°C for 10%, 20%, and 30% vegetation situations, respectively. Similarly, relative humidity rose by 2.0%, 4.0%, and 6.0% in the same conditions.

Despite climatic variations between desert (Dubai) and semi-arid (Maiduguri), both studies demonstrate that vegetative ground cover is an effective technique for heat mitigation in fast urbanizing regions. Increased humidity in Maiduguri's ENVI-met simulations may also be attributed to plant-mediated evapotranspiration. This technique not only provides thermal relief but also enhances human comfort, particularly in arid and dry places where low humidity worsens heat stress. Cortes et al. (2022) in the Philippines found that ground-level greenery reduced temperatures by 0.5 °C to 1.1 °C compared to rooftop vegetation and improved ambient moisture. The influence of urban farming on vegetal density is further supported by NDVI comparisons before and after simulation.

As illustrated in Figure 4.19, NDVI values in modeled plots increased from 0.1-0.2 (indicating bare land or scant vegetation) to 0.3-0.5, indicating moderate plant density. This greening impact suggests not only increased heat efficiency but also improved ecological health and surface resilience. These findings are consistent with those of Iaria and Susca (2022), who highlighted the importance of the Leaf Area Index (LAI) in managing urban microclimates. Their findings show that boosting LAI greatly improves temperature

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moderation by 10% to 90% based on the greening strategy emphasizing the relevance of vegetation density. Thus, the ENVI-met simulation findings provide solid empirical support for the efficacy of urban farming as a multifaceted intervention.

Heat Regulation: Lower LST through enhanced albedo and evapotranspiration. Hydrological Improvement: Increased humidity via soil and plant transpiration. Ecological Regeneration: NDVI improvements showing recovery of degraded land. These benefits extend beyond climate regulation. metropolitan farming also promotes environmental justice by enhancing microclimates in low-income or disadvantaged metropolitan areas. It promotes biodiversity, adds to urban aesthetics, and creates livelihood opportunities, notably for IDPs in Maiduguri. The consistency of these findings with previous research from Dubai (Mohammed et al., 2023), the Philippines (Cortes et al., 2022), and Europe (Iaria & Susca, 2022) adds to the overall validity and scalability of urban farming as a UHI mitigation method. Regardless of geography or development context, increased vegetal cover decreases thermal stress, increases humidity, and regenerates urban ecosystems.

With Maiduguri's current population expansion, land degradation, and heat stress, incorporating urban farming into urban development and climate resilience planning is no longer a choice; it is a climatic a necessity. Policies must prioritize converting vacant, bared or degraded locations in cities into productive, green farming areas. These areas provide environmental, social, and economic benefits, resulting in a more resilient and sustainable urban environment.

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5.3 Summary

This section provides an extensive summary of the whole research process, including the study's history, literature evaluation, methodology, and the socio-environmental backdrop of Maiduguri, Nigeria. It describes the respondents' demographic features, the key research findings, analytical interpretations, and provides conclusions and policy recommendations. The study examined the importance of urban farming as a sustainable, nature-based technique for minimizing the Urban Heat Island (UHI) impact in Maiduguri, using an integrated methodology that included geospatial analysis, ENVI-met simulations, and social survey data.

To examine long-term environmental dynamics, the study used four cloud-free Landsat imagery from 1992, 2002, 2012, and 2022, obtained from USGS Earth Explorer and processed with ArcGIS. The footage captured by the TM-4, ETM+ 7, and OLI/TIRS-8 sensors was analyzed to determine Land Surface Temperature, Land Use/Land Cover classifications, and Normalized Difference Vegetation Index. This enabled a comprehensive spatiotemporal study of changes in urban land cover and temperature trends over a thirty-year period.

Urban farming trends were assessed using historical Google Earth data (2002-2022), which was supplemented by GIS-based measurements of farming site extents and configurations. Four repeating sites were found and evaluated each year, indicating a consistent increase in urban agricultural activities throughout the city, notably in the

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northeast. The ENVI-met simulation program analyzed three urban farming scenarios (10%, 20%, and 30% vegetation coverage) to evaluate microclimatic advantages, indicating considerable temperature decreases (0.5-1.5°C) and humidity improvements in greener situations.

The LULC change analysis revealed large increases in built-up areas and decreases in vegetative cover, which contributed to raised LST and worsened UHI conditions. The definition and characterization of five unique land use types revealed strong trends in urban development and environmental degradation over time.

In addition, survey data obtained from 400 households shed light on public understanding and perceptions of UHI and urban farming. The findings revealed a lack of formal awareness of UHI, but an increasing appreciation for the significance of urban agriculture in promoting food security and environmental sustainability. The findings highlight the importance of focused public education and policy integration.

The popularity of urban farming in Maiduguri has grown steadily over the past 30 years, fuelled by socioeconomic pressures, relocation, and food shortages. At the same time, rising LST values confirm the development and strengthening of the UHI effect in densely inhabited areas.

Spatiotemporal investigation of LULC and LST using GIS and remote sensing revealed significant decreases in green cover and increases in impervious surfaces. These

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trends are significantly correlated with rising LST, emphasizing the importance of land use change in urban warming.

The majority of people recognized the environmental and livelihood benefits of urban farming, despite lacking formal awareness of the UHI phenomenon. This creates an opportunity for public awareness campaigns and grassroots climate adaptation initiatives. Urban farming has proven successful in mitigating UHI. The ENVI-met simulations proved the ability of urban farming to reduce localized surface temperatures and increase humidity. These findings support urban agriculture as a cost-effective climate resilience approach with added benefits for air quality, health, and urban sustainability.

The findings show that urban farming, when supported by inclusive urban policy and strategic planning, has significant potential for UHI mitigation in semi-arid cities such as Maiduguri. The study offers actual evidence for incorporating green infrastructure into urban development to address both environmental and social issues.

5.4 Implications and Recommendations

The findings demonstrate the importance of urban farming as a cost-effective and sustainable method for minimizing the effects of Urban Heat Island (UHI) in fast urbanizing, semi-arid cities like Maiduguri. Despite its informal nature, urban farming has

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shown ecological resilience and adaptation to microclimate potential. To realize its full potential, a coordinated policy response is required.

i. Policy Integration and Formal Recognition.

Urban farming should be formally included in Maiduguri's urban planning and climate adaptation plans. Policies must ensure secure land tenure, fair land allocation, accessibility to irrigation infrastructure, and technical capacity development for urban farmers.

ii. Strengthening green infrastructure.

Green spaces including community gardens, urban green belts, horticulture, and agroforestry systems should be valued in residential and commercial designs for cities. These modifications can dramatically reduce surface temperatures and improve urban microclimates, as evidenced by the ENVI-met simulations in this study.

iii. Public Awareness and Education.

Targeted educational initiatives should promote awareness about the UHI phenomena, the importance of urban vegetation in regulating the environment, and the numerous ecosystem services supplied by urban farming. Promoting climate literacy can help communities take ownership of green projects.

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iv. Infrastructure and Technological Support.

Funding should be directed toward low-tech, high-impact urban agriculture methods (e.g., irrigation farming, hydroponics, rainwater gathering). Infrastructure that promotes smallholder and community-based farming, particularly in heat-vulnerable areas, should be expanded.

v. Research and Monitoring Systems.

Develop robust systems for monitoring land use/land cover (LULC) changes and tracking the impact of urban farming initiatives on land surface temperature as well as vegetation indices (e.g., NDVI). These data-driven tools will improve decision-making and allow for ongoing review of climate resilience approaches.

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vi. Collaborative Governance and Multisector Action.

A multistakeholder approach is important. Urban farming should be institutionalized through collaboration among government agencies, urban planners, non-governmental organizations (NGOs), academic institutions, and community-based organizations. Such collaborations can strengthen its contributions to food availability, environmental sustainability, as well as urban thermal comfort.

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5.5 Conclusion

This study used a quantitative, integrated method to evaluate the role of urban farming as a UHI mitigation technique in Maiduguri, Nigeria, using remote sensing analysis, geospatial modeling, and social survey data. Over a 30-year period (1992-2022), the study investigated land use and land cover dynamics, land surface temperature trends, the spatial evolution of urban farming, residents' awareness and perceptions of UHI, and the viability of urban farming as a localized climate adaptation strategy.

The study found that urban farming in Maiduguri has grown gradually over the last thirty years, mostly due to social pressures such as economic hardship, food shortages, and insurgency-related relocation. Although not explicitly integrated into urban planning policies, agricultural activities have persisted in specific sites, particularly near waterways, exhibiting both spatial persistence and ecological importance. This expansion has coincided with a significant increase in land surface temperatures throughout the city, particularly in densely populated areas, confirming the formation and intensification of the Urban Heat Island (UHI) phenomenon.

While respondents showed a basic understanding of anthropogenic contributions to UHI, survey results revealed a lack of awareness of the relationship between urban farming and temperature moderating. Despite this disparity, the majority of participants complimented urban agriculture for its food security benefits and stated a readiness to support sustainable farming activities. This emphasizes the potential for targeted awareness

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efforts and policy integration to promote urban farming's dual benefits as a source of income and a tool for the mitigation of local climate change.

The ENVI-met simulation results show that urban farming with 10%, 20%, and 30% land-use scenarios reduces surface temperatures by 0.5 °C to 1.5 °C and improves humidity levels. These findings are consistent with worldwide studies, demonstrating the efficacy of vegetated land uses in modifying urban microclimates. Furthermore, the observed increase in NDVI values throughout the modeled scenarios demonstrates urban farming's potential to improve ecological resilience and contribute significantly to UHI mitigation efforts.

Therefore, these findings demonstrate that urban farming, when carefully supported and integrated into city planning, can be a powerful, low-cost approach for addressing UHI in semi-arid cities such as Maiduguri. The study not only adds reliable information to the expanding body of research on nature-based climate mitigation strategies, but it also promotes inclusive urban policies that acknowledge the environmental, economic, and social benefits of green infrastructure for the sustainability of cities.

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APPENDICES

Appendix A: Respondents Questionnaire

This appendix presents the questionnaire used in a Maiduguri, Nigeria study. 400 questionnaires were distributed among urban dwellers in the twenty-two wards of Maiduguri. The administration of these questionnaires adhered to established scientific protocols to ensure the accuracy and reliability of the data collected. The primary objective of this questionnaire was to assess the respondents' socio-economic characteristics and evaluate their awareness and understanding of the Urban Heat Island (UHI) phenomenon. Additionally, the study aimed to investigate the potential of urban farming as a strategy for mitigating the effects of UHIs in Maiduguri.

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Dear Sir/Madam,

I am Tijjani Abubakar Ladan, a Ph.D. candidate from the Faculty of Human Science, Department of Geography and Environment I am working on research related to Urban Heat Island Mitigation Through Urban Farming Potentials in Maiduguri Metropolis Northeastern Nigeria. Your assistance in completing the enclosed questionnaire will be invaluable for this study. Rest assured that all the information you provide will remain completely anonymous and confidential. The questionnaire covers four sections, including personal data, urban microclimate, urban farming, and local adaptive measures in your community. Your honest responses are highly appreciated. Participation is voluntary, and you may choose to answer the questions that are most suitable for you. The insights gathered from this research will be used for future studies and recommendations, contributing to a deeper understanding of urban dwellers' perceptions and helping formulate effective strategies to address one of the major urban environmental challenges. Thank you very much for your valuable assistance.

Yours sincerely,

Tijjani Abubakar Ladan
tjaladan@gmail.com

+601128964362, +234 803753587

SECTION 1: Demographic and Personal Information

1. Sex

☐ Male ☐ Female

2. Please indicate your age bracket:

18 – 30	

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31 - 40	
41 - 50	
51 - 60	
61 >	

3. Marital Status.

i. Married. ☐ ii. Single. ☐ iii. Others. ☐

4. Occupation:

i. Civil servant ☐

ii. Farmer ☐

iii. Businessman/woman ☐

iv. Student ☐

v. Others (please specify): ----------

5. Levels of Education:

i. None Formal Education ☐

ii. SSCE/ O-Level ☐

iii. A-Level ☐

iv. Undergraduate ☐

v. Post Graduate ☐

6. How many years have you been residing in this locality?

i. Less than 1 year ☐
ii. 1 to 5 years ☐
iii. 6 to 10 years ☐
iv. 11 to 20 years ☐
v. More than 20 years ☐

7. Which categories of household appliances do you use at home? (Select all that apply)

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i. Kitchen Appliances (e.g., refrigerator, oven, microwave) ☐

ii. Laundry Appliances (e.g., washing machine, dryer) ☐

iii. Electronic Devices (e.g., TV, computer, smartphone) ☐

iv. Heating and Cooling Systems (e.g., air conditioner, heat ☐

v. Other (please specify): _____

8. Do you have a car, or do you regularly use public transport?

i. I own a car ☐

ii. I use public transport ☐

iii. I own a car and regularly use public transportation. ☐

iv. I neither own a car nor regularly use public transportation. ☐

9. Which of the following types of vehicles do you currently own? (Select all that apply)

i. Lorry
ii. Van
iii. Car
iv. Tricycle (NAPEP)
v. Bicycle

10. If yes, what is your approximate commuting distance to your workplace (per week)?

i. 0-15 km ☐

ii. 15-30 km ☐

iii. 30-45 km ☐

iv. 45-60 km ☐

v. 60 km and Above ☐

11. Please indicate your approximate income per annum (before tax):

i. Less than 100,000 ☐

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ii. 100,000 - 500,000 ☐

iii. 500,000 - 1,000,000:00 ☐

iv. 1,000,000 – 5,000,000 ☐

v. 5,000,000 and above

12. Are you a member of any environmental organizations (e.g., Friends of the Earth, Worldwide Fund for Nature, GERI, Green Hub, Herwa Community Development Initiative)?

i. Yes

ii. No

13. If your response is Yes, (please specify) your organization's name.

_____

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Now please indicate how much you agree or disagree with the following general statements by ticking one cell on each row:

SECTION 2: Awareness and Understanding of Urban Heat Island Phenomenon

Strongly Disagree	**Disagree**	**Undecided**	**Agree**	**Strongly Agree**
1	**2**	**3**	**4**	**5**

	Statements	**1**	**2**	**3**	**4**	**5**
1	To what extent do you agree with the statement: I have heard of the urban heat island phenomenon.					

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2	To what extent do you agree with the statement: 'I have some ideas about the phenomenon referred to as the 'urban heat island.					
3	To what extent do you agree with the statement that urban heat island is a natural phenomenon?					
4	To what extent do you agree that human activities are responsible for the emergence of the urban heat island (UHI)					
5	I heard about the urban heat island in the print media, social media, and or Television					
6	Have you heard anything about urban heat islands (UHIs) in your educational experiences?					
7	To what extent do you agree that urban heat island leads to increased temperatures in cities?					
8	Urban heat islands increase the threats to human health posed by thermal stress.					
9	The urban heat island phenomenon is an important issue for the urban populace.					
10	Urban heat island (UHI) has become one of the major problems associated with the urbanization and industrialization of human society.					

Further comment_____

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SECTION 3: Perception and Attitude Towards Urban Heat Island Mitigation and Urban Farming

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
1	2	3	4	5

	Statements	1	2	3	4	5
1	Urban residents cultivate crops for both food and promote environmental cooling.					
2	Many urban dwellers cultivate grasses and flowers to beautify and cool the environment.					
3	Urban residents in this city are involved in growing crops and vegetation within the city.					
4	Most urban dwellers plant trees solely to cool the urban environment.					
5	My involvement in growing crops primarily serves as a secondary occupation to support my family.					
6	The urban population supports cross ventilation in building design for natural cooling.					
7	Urban residents use reflective materials on roofs and buildings for cooling and energy savings.					
8	Promoting crop cultivation, including hydroponics, aquaponics, and fish ponds, in urban areas is vital for microclimate regulation.					

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9	Human activities do not have a significant impact on mitigating the urban microclimate.					
10	Urban heat island effects are a serious threat that requires mitigation in urban centers.					
11	Developed nations should take a significant role in mitigating urban heat islands.					
12	To what extent do you agree with the statement that regularly irrigating vegetation, such as flowers and gardens, contributes to environmental cooling?					
13	Significant societal transformations are necessary to address urban heat impacts.					
14	Some people may prioritize their interests over addressing rising urban temperatures.					
15	To what extent do you agree with the statement that the evidence supporting the existence of urban heat island effects is strong enough to warrant mitigation efforts?					
16	There is a widespread belief that the impact of human activity on microclimate change is overstated.					
17	Access to tractors and fertilizers from the government at affordable and subsidized rates is available for our farming activities					

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18	Supporting urban farming projects is a viable strategy for sustainable development and reducing urban heat islands.					

Further comment_____

SECTION 4: Challenges and Barriers of Urban Farming for Urban Heat Island Mitigation

Strongly Disagree	**Disagree**	**Undecided**	**Agree**	**Strongly Agree**
1	**2**	**3**	**4**	**5**

Statements		**1**	**2**	**3**	**4**	**5**
1	A lack of knowledge and expertise hinders successful urban farming initiatives.					
2	Public perception and awareness play a crucial role in the success of urban farming projects for UHI mitigation.					
3	Financial grants and incentives are easily accessible for people or communities looking to start urban farming projects to reduce urban heat islands.					
4	Low-interest loans and financing options are easily accessible for urban farmers looking to					

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	develop and expand their heat island mitigation efforts through farming.					
5	Urban farmers can easily obtain or lease the necessary machinery and tools for their heat island mitigation projects.					
6	High-quality seeds or seedlings that are resilient to heat stress, urban environmental conditions, and fertilizers are accessible to urban farmers.					
7	Access to water resources is a crucial factor influencing urban farming for UHI mitigation.					
8	Soil quality and contamination issues affect the feasibility of urban farming as a UHI mitigation strategy.					
9	Land availability is a significant challenge to urban farming.					
10	Land ownership and regulations pose challenges for urban farming in UHI mitigation.					
11	Seasonality and climate variability impact the effectiveness of urban farming as a UHI mitigation strategy.					

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12	Market access and distribution channels are important considerations for urban farming.					
13	Community engagement and participation are vital for the success of urban farming initiatives to mitigate UHIs.					
14	Effective policies and governance structures are necessary to support urban farming as a UHI mitigation strategy.					

Further comment_____

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Please indicate to what extent do you agree or disagree with the following statements

SECTION 5: Initiative and Adaptation Measures for UHI Mitigation

Strongly Disagree	**Disagree**	**Undecided**	**Agree**	**Strongly Agree**
1	**2**	**3**	**4**	**5**

Statements		**1**	**2**	**3**	**4**	**5**
1	Maiduguri residents are aware of programs/initiatives involved in tree planting and other vegetal cover in urban areas to mitigate urban heat islands.					

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2	Many Maiduguri residents' have observed or participated in urban farming projects aimed at reducing the urban heat island effect.					
3	Maiduguri residents are familiar with cool roof initiatives, which involve using reflective materials to reduce heat absorption on rooftops.					
4	There is a belief among urban dwellers in Maiduguri that urban farming, including practices such as rooftop gardens and community gardens, can contribute to cooling the urban environment.					
5	Community involvement is considered crucial for the success of urban farming initiatives aimed at mitigating urban heat islands in Maiduguri.					
6	Most Maiduguri residents believe that education and awareness campaigns about urban farming can encourage more urban dwellers to participate in heat island mitigation efforts.					
7	Maiduguri residents are familiar with agricultural practices designed to withstand high temperatures.					
8	Many Maiduguri residents have personally taken steps to adopt heat-resilient landscaping practices, such as					

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	planting shade trees, at their residential quarters or workplaces.					
9	Some individuals believe that the current urban farming initiatives in Maiduguri are not effectively reducing the impact of the urban heat island phenomenon					
10	Maiduguri residents are aware of the efforts of (NGO) Non-governmental organizations that promote urban farming as a strategy to mitigate urban heat islands.					

Further comments_____

Thank you for your participation. Your insights will contribute to the research on Urban Heat Island mitigation using an Urban Farming approach. If you have any additional thoughts or comments regarding the issues addressed in this questionnaire or any feedback on the questionnaire itself, please share them with the researcher.

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Appendix B: Respondent's Information Sheet And Informed Consent Form

RESPONDENT'S INFORMATION SHEET AND INFORMED CONSENT FORM

Please read the following information carefully and do not hesitate to discuss any questions you may have with the researcher.

1. Urban Heat Island Mitigating Using Urban Farming Approach in Maiduguri, Nigeria
2. I am a Ph.D. candidate conducting a study on the topic named above, you may wish to participate, but we want to ensure that you are fully informed about the study before you make a decision.
3. Please read the questions and tick as appropriate or indicate how much you agree or disagree with the following general statements by ticking one cell on each row.
4. This questionnaire is for the selected head of household in Maiduguri.
5. Urban residents' attitudes and perceptions towards urban farming can be better understood, which will promote greater participation in green initiatives. can help local government officials and stakeholders implement efficient UHI mitigation and sustainable urban development strategies. It will serve as a baseline for further studies.

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The study encourages participation in sustainable practices by the community. For locals, urban farming can open up new economic opportunities. This research can aid in identifying the potential financial advantages and opportunities linked to urban farming, promoting socioeconomic growth.

6. Some respondents may be uncomfortable answering questions about their income, environmental practices, or community involvement. If you find any question uncomfortable, participation is entirely voluntary, and you may skip any questions or stop at any time.

7. Participants are further protected and data security is protected by ethical guidelines and approvals from the appropriate authorities.

8. For further information or inquiries please contact Tijjani Abubakar Ladan at tjaladan@gmail.com +601128964362, +234 8037535876.

9. CONSENT

I …… Identity Card No. …… address…… ……... ……..hereby voluntarily agree to take part in the research stated above *(clinical /drug trial/video recording/ focus group/interview-based/ questionnaire-based).

I have been informed about the nature of the research in terms of methodology, possible adverse

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effects, and complications (as written in the Respondent's Information Sheet). I understand that I have the right to withdraw from this research at any time without giving any reason whatsoever. I also understand that this study is confidential and all information provided about my identity will remain private and confidential.

I* wish/do not wish to know the results related to my participation in the research

I agree/do not agree that the images/photos/video recordings/voice recordings related to me be used in any form of publication or presentation (if applicable)

Signature ……..…… Signature ……..…….

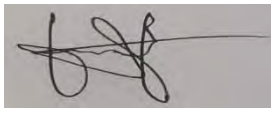
(Respondent) (Witness)

Date:……..

Name:…….…..

I/C No. :…….…..

I confirm that I have explained to the respondent the nature and purpose of the above-mentioned research.

Date 05/10/2023…..…… Signature 

…..…….

(Researcher)

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Appendic C1: Ethical Compliance

UNIVERSITI PENDIDIKAN SULTAN IDRIS
SULTAN IDRIS EDUCATION UNIVERSITY

35900 TANJONG MALIM
PERAK DARUL RIDZUAN, MALAYSIA

TEL: +605 450 6000 / 450 6661
FAKS: + 605 4582778
EMEL: ocd@upsi.edu.my

PUSAT PENGURUSAN PENYELIDIKAN DAN INOVASI

Rujukan Tuan :
Your Reference
Rujukan Kami :UPSI/PPPI/PYK/ETIKA(M)/Jld. 17 (210)
Our Reference
Tarikh : 5 Disember 2023
21 Jamadilawal 1445H

Tijjani Abubakar Ladan
Faculty of Human Science
Sultan Idris Education University

Dear Sir/ Madam,

APPROVAL OF HUMAN RESEARCH ETHICS COMMITTEE SULTAN IDRIS EDUCATION UNIVERSITY

Reference number	:	**2023-0210-01**
Date of Approval	:	**4 December 2023 – 3 December 2024**
Research Title	:	**Urban Heat Island Mitigation Using Urban Farming Approach in Maiduguri, Nigeria**

With all due respect I refer to the above matter.

2. Please be informed that the Research Ethics Committee Meeting No. 11/2023 held on 4 December 2023 has **approved** your application for the proposed research activities.

3. The approved research period is valid until **3 December 2024**. The Research Ethics Committee must be informed for any changes made on the research. However, the implementation of the research activities is subject to the decision by the Ministry of Higher Education (KPT) from time to time based on the latest development of COVID -19 in the country.

4. In this regard, the University congratulates and hopes that you will be able to conduct research in accordance with established research ethics.

Thank you.

"MALAYSIA MADANI"
"BERKHIDMAT UNTUK NEGARA"
"PENERAJU KEBITARAAN PENDIDIKAN"

Yours sincerely,

(PROFESSOR DR. NUR IKHWAN BIN MOHAMAD)

s.k. Deputy Vice-Chancellor (Research and Innovation)
Director of Research and Innovation Management Center
Deputy Dean (Research and Innovation) Faculty
Researcher Files

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Appendic C2: Ethical Compliance

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INSTITUTE OF GRADUATE STUDIES

Ref. No. : UPSI/IPS-3/475.5
Date : 27 September 2023

Assoc. Prof. Dr. Tan Mou Leong
GeoInformatic Unit, Geography Section, School of Humanities

Universiti Sains Malaysia

11800 Penang
Pulau Pinang

Prof./Assoc.Prof./Dr./Mr./Mdm.,

APPOINTMENT AS ASSESSOR FOR INSTRUMENT VALIDATION

With reference to the above matter.

2. Please be informed that the student as stated below is under the supervisory of Associate Professor Dr. Mohd Hairy bin Ibrahim, Sultan Idris Education University (UPSI) :

Name	:	**Ladan Tijjani Abubakar**
Matric	:	**P20192001208**
Faculty	:	**Faculty Of Human Sciences**
Research	:	**Urban Heat Island Mitigating Strategy Using Urban Farming Approach in Maiduguri, Nigeria.**

3. Thus, we need your expertise in assisting the research to be more significant and relevant. Herewith the related document for your further action. Any enquiry or inconvenience, you may contact the researcher at **08037535876** or email to **tjaladan@gmail.com**

Your coorperation regarding this matter is highly appreciated. Thank you.

"MALAYSIA MADANI"
"BERKHIDMAT UNTUK NEGARA"
"PENERAJU KEBITARAAN PENDIDIKAN"

Yours Sincerely,

(PROFESSOR DR. RAJA NOR SAFINAS BINTI RAJA HARUN)
Dean, Institute of Graduate Studies

c.c Student's : P20192001208
: UPSI/IPS-3/475.5

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Appendix D: Reliability

1) Awareness and Understanding of Urban Heat Island Phenomenon

Case Processing Summary

		N	%
Cases	Valid	377	94.3
	Excluded	23	5.8
	Total	400	100.0

a. List wise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.774	8

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2) Perception and Attitude Towards Urban Heat Island Mitigation and Urban Farming.

Case Processing Summary

	N	%
(Valid	365	91.3
ε Excluded	35	8.8
ς Total		
ε	400	100.0
s		

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

Reliability Statistics

Cronbach's Alpha	N of Items
.800	13

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Perception and Attitude Towards Urban Heat Island Mitigation and Urban Farming.

Case Processing Summary

	N	%
Valid	378	94.5
Excluded[a]	22	5.5
Total	400	100.0

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

Reliability Statistics

Cronbach's Alpha	N of Items
.800	13

3) Challenges and Barriers of Urban Farming for Urban Heat Island Mitigation

Case Processing Summary

	N	%
Valid	383	95.8
Excluded[a]	17	4.3
Total	400	100.0

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

Reliability Statistics

Cronbach's Alpha	N of Items
.782	10

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Appendix E: Validation data

E.1: Validation of ENVI-met Model Outputs Using NiMET and Ground Truth Data in Maiduguri

Wards	NiMET tempt (°C)	GT tempt (°C)	NiMET Hum (%)	GT Hum (%)
Bolori I	31.32	33.40	41%	47%
Gwange III	31.50	33.36	43%	46%
Hausari	31.65	33.59	39%	41%
Lamisula	32.10	34.30	41%	44%
Mafoni	31.65	33.46	41%	43%
Maisandari	31.31	33.82	43%	46%
Galtimari	31.00	34.10	40%	44%
Old Maiduguri	31.80	33.76	41%	43%
Mairi	32.00	34.10	43%	46%
Tamsu Ngamdua	32.90	34.20	41%	44%

Source: The Nigerian Meteorological Agency (NiMet), Maiduguri Office, 2023 and field work

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E.2: Accuracy Assessment of Landsat-Derived LULC Maps Through GPS-Based Field Validation

Ward	Lat	Long	Ground truth Lat	Ground truth Long
Bolori I	11°59′53″ N	12°56′21″ E	11°59′51″ N	12°56′19″ E
Gwange III	11°55′24″ N	13°4′22″ E	11°55′23″ N	13°4′21″ E
Hausari	11°56′41″ N	13°2′9″ E	11°56′46″ N	13°2′15″ E
Lamisula	11°56′51″ N	13°3′11″ E	11°56′50″ N	13°3′17″ E
Mafoni	11°57′30″ N	13°1′57″ E	11°57′35″ N	13°2′2″ E
Maisandari	11°53′48″ N	12°59′31″ E	11°53′53″ N	12°59′38″ E
Galtimari	11°53′7″ N	13°2′55″ E	11°53′12″ N	13°3′1″ E
Old Maiduguri	12°1′19″ N	13°3′47″ E	12°1′24″ N	13°3′50″ E
Mairi	11°54′34″ N	13°8′3″ E	11°54′39″ N	13°8′9″ E
Tamsu Ngamdua	11°54′32″ N	13°18′36″ E	11°54′36″ N	13°18′41″ E

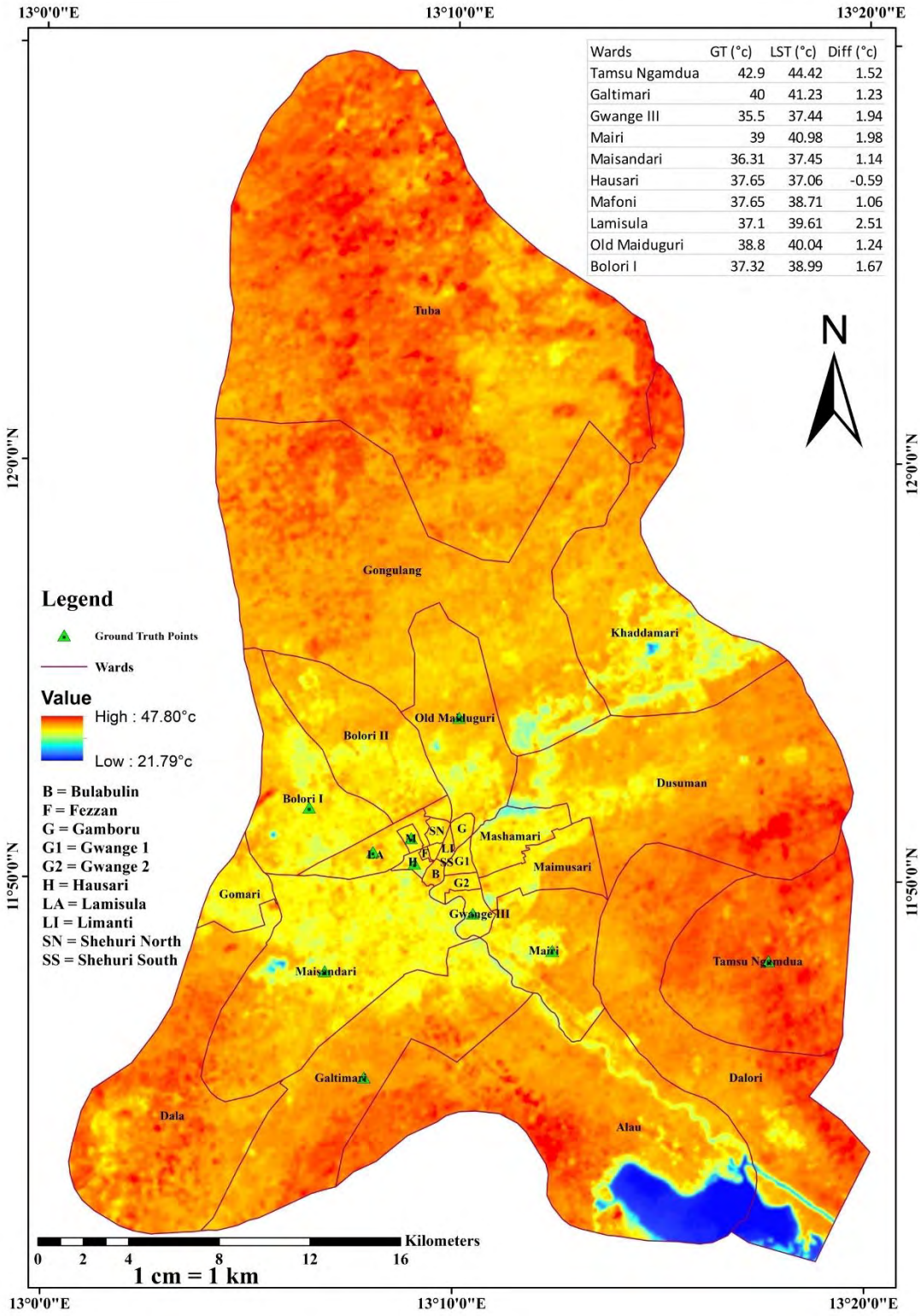
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In order to validate satellite-derived Land Surface Temperature (LST) and Land Use/Land Cover (LULC) data, ground truth data was gathered using GPS-referenced points within a few chosen wards in Maiduguri. Accurate temperature observations were confirmed by the GPS-coordinated temperature data, which nearly matched the LST values with variations ranging from 1.06°C to 1.98°C. The LULC maps' validity was further supported by field observations at these GPS locations that also corresponded with the identified land cover types. This robust relationship between remote sensing outputs and ground truth data supports the assessment of urban farming as a practical method of reducing the effects of urban heat islands and lends credence to the spatiotemporal analysis as seen in E. 3 and similarly reinforces E. 2.

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E.3: Surface Temperature and Land Use/Land Cover Using Ground Truth Data in Maiduguri



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Appendix F: Publications

Appendix F: Publications

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Exploring Public Perceptions of Urban Heat Island in Maiduguri: A Preliminary Study

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Abstract

The Urban Heat Island (UHI) effect is a new challenge for the residents of this semi-arid city, which is plagued by heightened temperature and dryness and is still recovering from a ten-year insurgency that disrupted livelihoods and raised security concerns. This study assesses urban dwellers' awareness and perception of the UHI phenomenon, and how it affects their livelihood. which is a crucial component of modern urbanization. An in-depth comprehension of the UHI phenomenon and its effects is essential for guiding efficient planning and putting appropriate mitigation strategies into practice in a given locality. This study used a quantitative methodology, involving the distribution of 400 questionnaires and the analysis of the results using descriptive statistics in (SPSS) IBM SPSS Statistics 23. The participants indicated a low degree of familiarity and awareness regarding UHI, which is attributed to factors like inadequate education regarding the environment and limited communications being recognized as contributing factors. The high perception that human activity is the main factor contributing to UHI is consistent with scientific findings, highlighting the necessity of bridging the knowledge gap between the general public and scientific research. participants showed heightened comprehension of the health risks attributed to UHI, and a sizable portion reported receiving little information about UHI in educational settings. The study emphasizes the value of integrated urban planning, education, and communication in addressing UHI-related issues for sustainable and resilient cities.

Keywords: Urban heat Islands, Urban dwellers, Perceptions, Awareness.

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The Potential of Urban Green Infrastructure in Mitigating Urban Heat Island in the Semi-Arid Regions

Abstract

Cities and towns around the world are at a crossroads as a result of a variety of urban challenges, including urban heat islands. Urban greening as a potential strategy for reducing urban heat is receiving increased attention due to the combined trends of urban heat island intensification and global climate change. This article brings to the fore, the significance of Green Infrastructure forms deployed in cities and assesses how they help in the mitigation of the phenomenon in the semi-arid regions. The objective of this review paper is to create a better knowledge and understanding of the benefits of green infrastructure in this region. This will contribute to the understanding of how urban dwellers utilize different forms of vegetation in an urban context and help geographers, engineers, ecologists, sociologists, and professionals in urban design towards better city planning, revitalization as well as gentrification. Understanding the terms used to describe urban greenery and vegetation within the scope of the study, as well as their definitions, is necessary to comprehend the scope of the discussion of green infrastructure and urban heat islands in this article. The review shows, that increased vegetation has been extensively documented as the most efficient approach for reducing urban heat islands. The study adopted a narrative review of the literature on articles from peer-reviewed journals that fall under the purview of the study.

Keywords: Green Infrastructure, Urban Heat Islands, Semi-arid Regions

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A Geographical Review of Urban Farming and Urban Heat Island in Developing Countries

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Abstract.

Cities in developing countries are heavily involved in urban agricultural activities, and a lot of research has been done to address the challenges in this regard. However, several studies have proposed taking advantage of them in reducing the impact of urban heat islands (UHIs), which are manifested as a consequence of stringent changes in energy use, human settlement patterns, industry, transportation, and population growth. Data for this study were obtained from a literature search of existing academic journals, the domain of agriculturally related organizations, and books; the investigation was mainly based on developing nations. Best practices of scholarly work did the review. Authors stand posited. Urban farming has been employed in cities mainly as a food source while also catering to the changing needs of the urban dweller's lifestyles. There is an urgent need to investigate the potentials of urban farming not just as food crops but as green infrastructure in ameliorating urban heat island intensities in our cities.

Keyword: Review; urban farming; urban heat island; developing countries

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PROCEEDINGS OF 13TH INTERNATIONAL ACADEMIC CONSORTIUM FOR SUSTAINABLE CITIES (IACSC) 2022 12TH - 13TH SEPTEMBER UNIVERSITI SAINS MALAYSIA, PENANG

Understanding the Urban Heat Island Effect in the Semi-Arid Regions

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Abstract

Effective and pragmatic techniques, policies, and technological responses to increased temperatures in urban heat islands (UHIs) to meet sustainable development of towns and cities rely heavily on proper planning and implementation of these processes, as well as stakeholders' understanding and perceptions of the phenomenon. A significant amount of study has been conducted to minimize its influence on the urban environment and its inhabitants in the global north and south. However, few studies exist on the impact of urban heat islands in the semi-arid regions. Data for this study were gathered through a search of reputable existing scholarly journals and books, with a focus on semi-arid regions. The review was carried out in accordance with scholarly best practices. In the midst of the climate crisis, 1.1 billion people live in the already dry and hot semi-arid environment, making them among the world's poorest and thus vulnerable to the changing warmer urban climate. A thorough understanding of the concept of UHIE is crucial. This review aims to educate key stakeholders and the urban dwellers about the mechanisms that lead to the emergence of the urban heat island phenomenon and its consequences in order to develop and implement a mitigation strategy via research and continuous engagement and communication among all stakeholders.

Keywords: Urban Heat Islands, Semi-Arid Regions, Warm Drylands Introduction

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