University of Nairobi

Faculty of Engineering

Department of Geospatial and Space Technology

GEOSPATIAL ASSESSMENT OF THE ROLE OF URBAN GREEN INFRASTRUCTURE IN MITIGATING URBAN HEAT ISLAND: A CASE STUDY OF GREATER MONROVIA DISTRICT, LIBERIA

Yekeh F. Howard

F56/39031/2021

Research Report submitted for the Degree of Master of Science in Geographic Information Systems (GIS), in the Department of Geospatial Engineering and Space Technology at the University of Nairobi.

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DEPARTMENT OF GEOSPATIAL & SPACE TECHNOLOGY

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By

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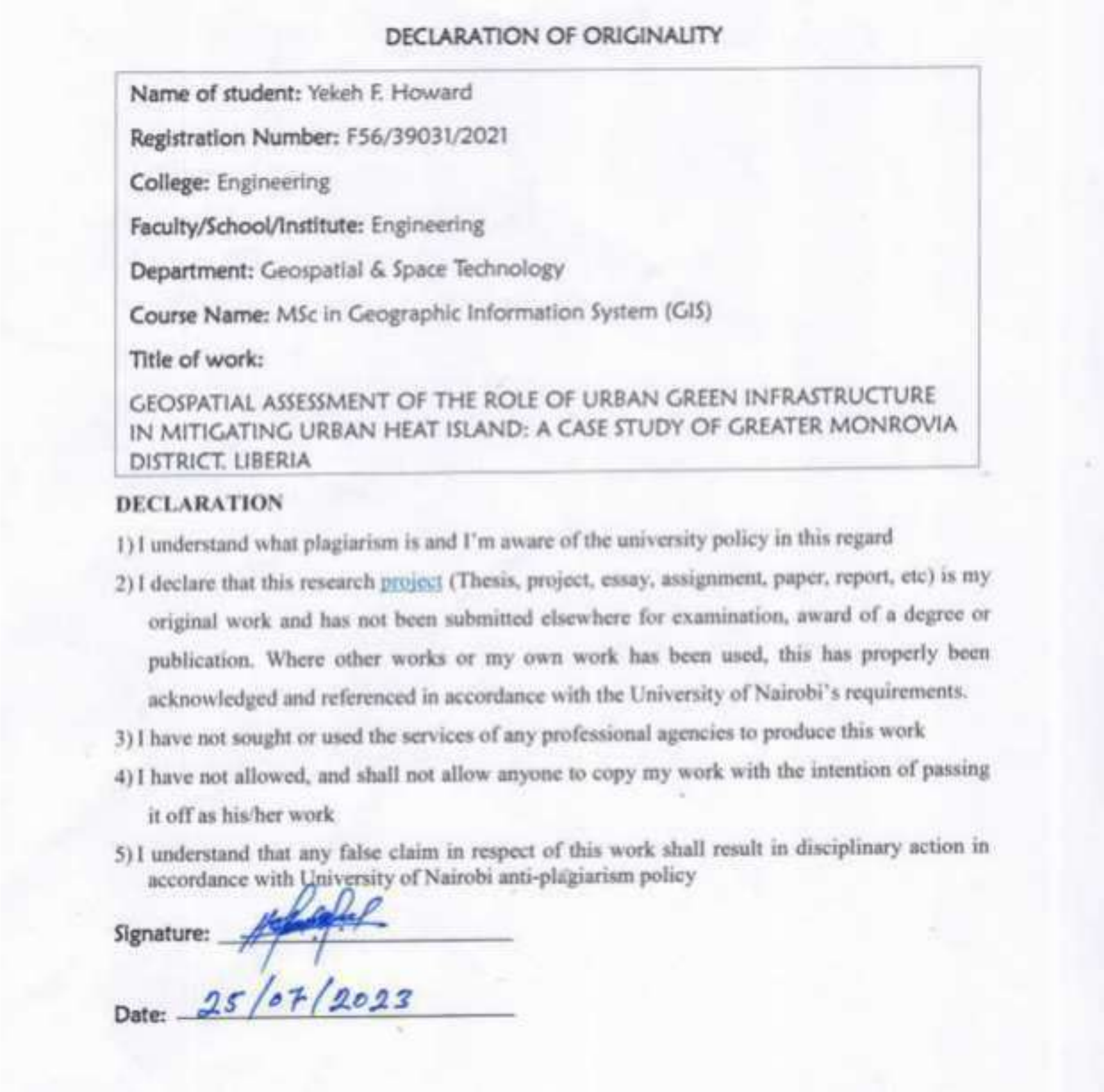

DECLARATION OF ORIGINALITY

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I dedicate this work to my family for believing me.

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LIST OF ABBREVIATIONS

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BT	Brightness Temperature
CA-ANN	Cellular Automata-Artificial Neural Network
DN	Digital Number
ERDAS	Earth Resources Data Analysis System
ETM+	Enhanced Thematic Mapper plus
GoL	Government of Liberia
LISGIS	Liberia Institute of Statistics and Geo-Information Services
LSE	Land Surface Emissivity
LST	Land Surface Temperature
LSTM	Long Short-Term Memory
LULC	Land Use-Land Cover
MIR	Medium-Infrared
MSS	Multispectral Scanner System
NDBI	Normalized Difference Built-up Index
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
OLI	Operational Land Imager
SUHI	Surface Urban Heat Island
SVM	Support Vector Machine
TM	Thematic Mapper
TOA	Top of Atmospheric
UGI	Urban Green Infrastructure
UHI	Urban Heat Island
UHII	Urban Heat Island Intensity Indicator
USGS	United States Geological Services
UTM	Universal Traverse Mercator
WGS	World Geodetic System

ABSTRACT

Concerning the quality of life and the wellbeing of the general public, the Urban Heat Island (UHI) phenomenon has progressively become a significant matter. Several prominent cities worldwide are presently encountering the UHI phenomenon, which happens when urban regions have elevated air and surface temperatures in comparison to their surrounding rural and peri-urban areas. For instance, in Greater Monrovia District, rapid urbanization and related LULC change have led to the creation of UHI effect. However, studies demonstrating the contributions that Urban Green Infrastructure (UGI) can make in reducing LST towards mitigating urban heat island effect in Greater Monrovia District are still lacking. In this regard, the study aimed to assess the role that UGI has played in mitigating UHI in Greater Monrovia District, Liberia for the period 1991-2020, by determining the trends of LULC in Greater Monrovia District, evaluating the link between LULC and LST in Greater Monrovia District, and examining the consequences of the relationship between LST and LULC on UHI in Greater Monrovia District. To this effect, a geospatial analysis was conducted using Landsat images for study area, for 1991-2020. Using ArcGIS software, the images were cropped, pre-processed, enhanced, and colour composited followed by LULC classification, extraction of LULC classes and generation of LULC maps. Additionally, LST was retrieved, NDVI and Emissivity calculated and LST maps created. Thereafter, threshold temperatures were estimated and intensity of UHI calculated by subtracting the LST of the least urbanized reference area (vegetated) from that of the UHI area. The results of this analysis showed that; there has been significant increase in built-up areas from 14.6% in 1991 to 36.1 in 2020, while other LULC classes have reduced in size; bare land from 90% in 1991 to 0% in 2020, shrubland from 49.2% in 1991 to 8.3% in 2020, mangroves from 26.3% in 1991 to 18.5 in 2020 and waterbodies from 32.5% in 1991 to 27.5%. Notably, grassland recorded a slight increase from 17.5% in 1991 to 18.7% in 2020. This could be attributed to the decrease in shrubland. The results also show that the built-up areas have higher mean LST (42^0C) as compared to land areas under vegetation (shrubland 37^0C, grassland 35^0C and mangroves 33^0C) and waterbodies (30^0C). Moreover, the vegetation index negatively correlated with LST, demonstrating the role of UGI in mitigating UHI by providing the cooling effect. The built-index on the other hand, positively correlated with LST pointing to the contribution of built-up areas to UHI effect by raising LST. The study concluded that, the conversion of natural and semi-natural lands into impervious surfaces have led to the rise in LST and formation of UHI, and therefore recommends the development of UGI within the study areas to mitigate UHI effect. The study also recommends the adoption and implementation of urban planning policies promoting the development of UGI in every development project.

CHAPTER I
INTRODUCTION

1.1 Background of the Study

In recent times, there has been a rapid increase in urbanization across the globe (Leeson, 2018; Sun *et al.* 2020; Jarah *et al.* 2019). This has been largely linked to economic demands which has seen rapid increase in urban population as more people migrate to the urban areas from rural areas (United Nations, 2020). Notably, the increase in urban populations has led to the continued growth of infrastructures, economy and social amenities of urban areas (ibid). A technical report published by World Bank in 2022, indicates that: 50% of world population which represents resides in urban areas today. Furthermore, World Bank projected in this report that by 2045 the global urban population will grow by 50% to 6 billion (World Bank, 2022). The developing countries just like their developed counterparts have also experienced increased urbanization, and Liberia is no exception. Notably, urban population growth in Liberia for the year 2021 was reported at 3.3% (World Bank, 2018).

While urbanization has been contributed to by expansion of urban population, rapid and sustained urban population influx and growth has caused Land Use Land Cover (LULC) changes in the urban areas (Du *et al.* 2019; Zhou *et al.* 2021; Zungu, 2018). Xu *et al. (*2019) stated that rapid growth of urban areas has resulted in the substitution of semi-natural and natural land covers with built-areas. This has been attributed to an increasing number of people that require land for settlement and infrastructural development, such as the construction of paved surfaces and roads. As a result, the disintegration and fragmentation of natural and semi-natural environments have transformed urban areas into new ecosystems, where man-made obstructions and built-areas (e.g., roads, buildings, and grey areas) are interspersed with small, isolated green spaces (Lerman *et al.* 2020), thus, causing significant effects to the urban environment with respect to loss of ecosystem services and loss of biodiversity, which eventually affects human well-being (Zambrano *et al.* 2019). In addition, as Liang *et al.* (2019) note, rapid urbanization has led to increased air pollution and increased solid waste generation.

It should be noted that, conversion of natural greenery area to impervious surfaces due to urbanization normally cause rural/urban ecological and micro-climatic imbalance (Kafy *et al.* 2021; Sodoudi *et al.* n.d.). For example, roads, commercial and residential buildings, concrete structures, pavements among others, reduce urban vegetative cover hence contributing to Urban Heat Island (UHI) effect (Zhou & Chen, 2018; Vujovic *et al.* 2021; Cheela *et al.* 2021). As an example, Odindi *et al.* (2015) explain that impervious surfaces absorb and hold more solar radiation, preventing the loss of long-wave sky radiation during clear solar heating. In addition, the uneven urban terrain hinders wind movement, leading to reduced convective heat loss, while decreased vegetation index and thermal inertia constrain heat loss from latent heat flux (ibid). All these factors work together to cause the emergence of the UHI phenomenon. Westendorff, (2020) and Carpio *et al.* (2020) describe UHI as a complex phenomenon that occurs in cities around the world.

Generally, UHI occurs when the heat absorbed by the impervious surfaces during the day is retained and slowly released during the night (Athukorala & Murayama, 2021; Westendorff, 2020; Monteiro *et al.* 2020). The microclimatic conditions within the urban landscapes due to UHI affect plant growth, energy consumption, air quality, animal life and even the well-being of urban dwellers (Priya & Senthil, 2021; Elliott *et al.* 2020). According to Zak *et al.* (2020), UHI is a phenomenon that occurs in metropolitan regions. It happens when the urban area's temperature rises significantly compared to the surrounding peri-urban neighborhoods. As a result, the UHI effect causes higher temperatures in urban areas than in the neighboring peri-urban regions (Vujovic *et al.* 2021). According to van der Schriek *et al.* (2020) and Tewari *et al.* (2019) UHI effect is projected to be aggravated eventually due to changes in climate. However, the severity of the intensity of UHI effect will depend mainly on a city's location and characteristics such as; level of industrialization, size and population density, traffic density and pattern and seasonality of the climate (Tzavali *et al.* 2015). For instance, Monrovia being a coastal city situated along the Atlantic Ocean is ordinarily hot and therefore, the severity of UHI effect would be higher than non-coastal cities.

Elevation of UHI has been linked to a decrease in Urban Green Infrastructure (UGI) (Marando *et al.* 2022; Balany *et al.* 2020). However, creation and conservation of UGI as a way to mitigate UHI helps to promote cooling island effect (Elliott *et al.* 2020; Westendorff, 2020; Shafiee *et al.* 2020; He, 2022; Lehmann, n.d). Pauleit *et al. (*2017) defined UGI as a complex system of green spaces that are partially or entirely covered in vegetation, providing diverse social, economic, and environmental advantages to urban regions. UGI comprises of water area, forestry, nature protection site e.g., arboretum, national parks, game reserves, and botanical gardens, agriculture land, linear green spaces, recreational parks and gardens, community gardens, school yards, cemeteries, picnic areas, green walls, lawns, roadside vegetation, green roofs, among others (Priya & Senthil, 2021; Johansen, 2021). UGI forms a green network that not only makes urban area more resilient, but also has significant socio-ecological benefits (Ayele *et al.* 2021; Johansen, 2021; Pauleit *et al.* 2019).

According to Baniya *et al.* (2018) UGI regulates high temperature in populated urban areas and their surroundings, thus plays a crucial role in mitigating the UHI effects, that is, UGI not only decreases the temperature but also reduces pollution in the urban areas, while increasing their environmental quality and resilience. As Balany *et al.* (2020) notes, UGI through albedo effects of objects, and evapotranspiration of plants can reduce temperature in urban areas. According to Keeler *et al.* (2019) UGI is a key environmentally-friendly solution for the UHI effect, supported by vegetation which through evapotranspiration increases relative humidity and help prevent heat build-up by creating shades (ibid). Furthermore, UGI act as habitat for urban biodiversity, provides clean air to the public, reduce heat during dry seasons, offer societal services for the well-being of urban residents and improves ground water holding (Coutts & Hahn, 2015). It should be highlighted that not all UGI are expected to offer equal levels of mitigation against the urban heat island effect (Mexia *et al.* 2018; Marando *et al.* 2019).

As Liberia’s metropolitan areas continue to develop, especially Monrovia city, which is the country’s capital, there has been rapid conversion of natural land, including back filling of wetlands to impervious surfaces which has resulted in the development of UHI. This cast a doubt on the environmental sustainability of Monrovia city with respect to land use management and planning. Against this background, and while taking cognizant of the need to manage UHI for the future sustainability of Monrovia city, the study sought to undertake a geospatial assessment of the role of UGI in mitigating UHI.

1.2 Problem Statement

Concerning the quality of life and the wellbeing of the general public, the UHI phenomenon has progressively become a significant matter. Several prominent cities worldwide are presently encountering the UHI phenomenon, which happens when urban regions have elevated surface and air temperatures in comparison to their surrounding rural and peri-urban areas (Zak *et al.* 2020).

Despite cities offering many opportunities for improved standards of living, their current growth patterns are unsustainable, and are contributing to UHI effect, that is, valuable green infrastructure and their associated ecosystem services are being lost (Arshad *et al.* 2022). Furthermore, green infrastructures are usually the last pieces of project plan to be implemented by city developers, and often face cut budgets that leads to unsuccessful installation and management of such infrastructure (Dushkova & Haase, 2020).

Overtime, the implication of UHI effect for both biodiversity and human wellbeing has become more obvious in Greater Monrovia District, for example, being a coastal district that is generally hot aggravates the potential impact of UHI effect on human and biodiversity. For instance, there has been consequences for city dweller's thermal comfort in particular children, the elderly, and city dwellers with respiratory and cardiovascular problems (Singh *et al.* 2020).

However, studies demonstrating the contributions that UGI can make in reducing LST towards mitigating UHI effect in Greater Monrovia District were still lacking. In this regard and in order to address this gap, a detailed, citywide geospatial assessment of the function of UGI in mitigating UHI effect was conducted to support the implementation of policies that promote sustainable urban planning through creation and maintenance of UGI.

1.3 Research Questions

1.3.1 Main Question

What role has UGI played in mitigating UHI in Greater Monrovia District, Liberia for the period 1991-2020?

1.3.2 Specific Questions

The main question is guided by three specific questions;

1. What are the trends of LULC change in Greater Monrovia District for the period 1991-2020?
2. What is the relationship between LULC change and LST in Greater Monrovia District for the period 1991-2020?
3. What are the consequences of the relationship between LULC change and LST on UHI in Greater Monrovia District for the period 1991-2020?

1.4 Research Objectives

1.4.1 General Objective

To assess the role that UGI has played in mitigating UHI in Greater Monrovia District, Liberia for the period 1991-2020.

1.4.2 Specific Objectives

The general objective is divided into the following three specific objectives;

1. To determine the trends of LULC in Greater Monrovia District for the period 1991-2020.
2. To establish the relationship between LULC and LST in Greater Monrovia District for the period 1991-2020.
3. To examine the consequences of the relationship between LULC and LST on UHI in Greater Monrovia District for the period 1991-2020.

1.5 Justification of the Study

The geospatial assessment generated information that can be used to; (i) inform the amendments of urban planning policies in Liberia towards effective landscape planning and management, (ii) initiate the development of UGI in Greater Monrovia District and other districts undergoing similar LULC in order to address UHI effect, and (iii) make important contribution both locally and globally on the role of GIS and Remote Sensing in sustainable urban planning towards sustainable cities.

1.6 Scope of the Study

The focus of this geospatial assessment was to evaluate the impact of UGI in reducing the UHI effect, using geospatial methods. As such, the geospatial analysis was limited to changes in LULC and variations in LST in the Greater Monrovia District between 1991 and 2020. However, due to financial limitations, the research only covered the Greater Monrovia District, and other districts in Liberia experiencing comparable land use changes that could exacerbate the UHI effect were not considered.

CHAPTER II

LITERATURE REVIEW

2.1 Urbanization and LULC change

The need to accommodate the demands of a growing urban population and promote economic progress has driven an unparalleled growth of urban areas (Nath *et al.* 2021). Nevertheless, the unregulated pace of urban expansion has led to a rise in the transformation of urban green spaces into impervious surfaces, as more built-up areas emerge (Mundhe & Jaybhaye, 2014). In this regard, a number of scholars including; Liu & Weng, (2013); Mundhe & Jaybhaye, (2014), Sajjad & Iqbal, (2012); Maheng *et al.,* (2021); Yu *et al.*, (2022) and Patra *et al.,* (2018) have conducted studies to determine how urbanization has impacted urban LULC change.

Liu & Weng, (2013), while assessing how urbanization-induced LULC changes can be effectively quantified using landscape metrics in Indianapolis, Indiana, USA, used two Landsat 5 TM images (1989 and 2000), and two (ASTER) images (2000 and 2006), and identified LULC types including; water, wetlands, urban grasslands, agriculture, barren lands and forest, which they used to generate two Landsat-derived maps and two ASTER-derived LULC maps. The duo then calculated a series of landscape metrics which they used to compare the maps, where they found that urbanization had contributed remarkably to LULC changes in Indianapolis, where forests became more disaggregated, while agricultural lands decreased. However, grassland did not only increase slightly in size, but also improved in connectedness and aggregation level.

Similarly, Mundhe and Jaybhaye (2014) conducted a study that examined how LULC changes has been affected by urbanization in Pune city, India. Their research, which was published in the *International Journal of Geomatics and Geosciences*, involved a spatio-temporal analysis of four decades of LULC changes from 1973-2011 data from Landsat MSS (1973), Landsat TM (1992), Landsat ETM+ (2001), and Landsat TM (2011). Through on-field validation and a hybrid classification method, the researchers discovered that the urbanized parts of Pune city had increased to 155.99 km² from 28.50 km², representing a 43.43% change in LULC. Additionally, they observed a reduction in agricultural land, fallow land, vegetation, and water bodies.

Sajjad & Iqbal (2012) conducted a study in Dudhganga watershed, India, which aimed to examine how LULC has been affected by urbanization. The study, which was published in the *international journal of urban science,* utilized multi-temporal Landsat data for 1991 and 2010 to estimate land absorption coefficient and land consumption ratio. Based on their findings, the authors reported a significant decrease of 32.41km2 in agricultural land, accompanied by a dramatic increase of 50.56km2 in built-up area from 1991 to 2010. The expansion of Srinagar city was identified as the main cause of urbanization in the downstream of the watershed, resulting in the reduction of agricultural land. The authors highlighted the potential risk of severe degradation of the watershed if the current trend continues and recommended formulation of effective land use policies to address the issue.

Additionally, Maheng *et al.,* (2021) in a study conducted in Jakarta, Indonesia on how urbanization affects landscapes patterns, reported that changes in landscapes patterns due to urbanization have reduced runoff regulation by (11.5%), temperature regulation by (12.4%) and carbon sinking by (10.4%), implying that, growth of urban areas have not only led to loss of or changes in green spaces, but also altered its ecological services.

Similarly, Yu *et al.,* (2022) in a geospatial assessment that explored urbanization patterns of Chengdu city, classified Landsat Images (2004-2018) using Support Vector Machine (SVM) classifier, with a kappa coefficient of 0.90 and an accuracy of 0.94, and found out that; Chengdu city had expanded from 80.43 km^2 in 2004 to 210.50 km^2 in 2018, with an increasing reliance on conversion of vegetation area.

Lastly, Patra *et al.,* (2018) in a study published in the Journal of Urban Management , and that geospatially assessed how LULC changes are affected by urbanization of Howrah Municipal Corporation, India, computed LULC changes and NDBI using remote sensing and GIS techniques, where they indicated that; there were evidence of built-up expansion from south-eastern to north-eastern part of the Corporation. Additionally, they noted that; there were evidences of shrinkage or urban sprawl which showed that built-up areas were expanding thus causing environmental degradation in the Corporation. Patra *et al.,* concluded the study by recommending that the findings inform designing of necessary policies and regulations to address such urban sprawl and its associated environmental impacts.

2.2 Impacts of LULC change on LST

The LULC alterations and its associated negative impacts on LST due to rapid urbanization have been documented by Amir Siddique *et al.* (2021), and the resultant harm to urban ecosystems has raised significant concerns. As a result, various studies have been conducted, including those by Dhar *et al.* (2019), Le-Xiang *et al.* (2006), Ahmed *et al.* (2020), Karakuş, (2019); Wang *et al.,* (2023) and Fatemi & Narangifard, (2019), to investigate how LST is affected by LULC change.

Dhar *et al.* (2019) conducted a study in Rajarhat Block, West Bengal, used Sentinel 2A (2016), Landsat 8 OLI (2016), and Landsat 5 TM(1990), and multi-spectro-temporal satellite data to evaluate how LST is affected by LULC. They mapped land use land cover and estimated LST using thermal infrared data and found that there was an increase in LST by 1.5^0C due to a loss of 13 km^2 of vegetation associated with LULC changes.

Similarly, Le-Xiang *et al.* (2006) carried out a geospatial assessment in Zhujiang Delta and evaluated the impact of LULC change on LST. They used multi-temporal Landsat ETM+ and Landsat TM data to measure urban expansion and the related decline in tree cover, and used the TIR bands of the data to retrieve LST. They noted that LST had increased by 4.56^0C in the newly built-up parts of Zhujiang Delta due to a strong and unbalanced urban development. Le-Xiang *et al.* concluded that for analysis and monitoring of urban growth patterns and their related impacts on land surface temperature, the application of GIS and remote sensing techniques were the most effective approaches.

On the other hand, Ahmed *et al.* (2020) studied LST in Potiskum, Yobe State, Nigeria, using meteorological data and remotely sensed data obtained from Landsat 8 OLI images (2008-2015) and Landsat 7 ETM+ images (2003-2008). They found that there was little expansion of urbanized area between 2003 and 2008 compared to 2008 to 2015, and suggested that good policies and afforestation could help combat the rise in temperature in urban areas, contributing to low LST values.

Similarly, Karakuş, (2019) in a study that assessed the impacts of LULC changes on LST in Sivas City Center, and that was published in *Asia-Pacific Journal of Atmospheric Sciences*, used Landsat Images (1989-2015) to study the relationship between LULC, NDVIA and LST in Sivas city centre and its environs, where he found that; built-up areas increased significantly in size, while vegetated land and bare lands decreased in size over the same period. Consequently, the built-up areas recorded highest LST, while a fluctuating trend was seen in the urban built-up surface temperature.

Wang *et al.,* (2023) in a study on how LST is affected by urban land changes, in Guangzhou, China, monitored and predicted the changes in urban growth patterns (LULC) on LST from 1989 to 2021, using Cellular Automata-Artificial Neural Network (CA-ANN) and Long Short-Term Memory (LSTM) based Whale Optimization Algorithm (WOA), and found out that; an increase in urban areas by 63% causes an upsurge of high LST (≥34 °C) areas by 652 km^2. Wang *et al.,* concluded the study by indicating that; the findings of the study can provide effective mitigating measures for designing smart cities as well as valuable guidelines for ensuring environmental-friendly green cities.

Lastly, Fatemi & Narangifard, (2019), in a study published in the *Arabian Journal of Geosciences,* and that assessed how LST and NDVI are affected by LULC changes in Shiraz City, used a multi-temporal dataset consisting of two sets of Landsat TM images from 1986-2011, and four Landsat images to investigate the relationship between LST and NDVI. The duo also retrieved LULC,LST and NDVI in ERDAS IMAGINE 9.2 image processing software, where they found out that; the residential parts of the city had experienced significant increase to 13.17 km^2 , while land areas under vegetation had decreased to 4.6 km^2 and barren lands to 8.63 km^2 during the same period. Evidently, the negative correlation between vegetation and LST caused by lower vegetation quality was less significant in 2011 compared to 1986, while the correlation between vegetation and LST in summer was higher than other seasons.

2.3 Urbanization and Urban Heat Island

Rapid urbanization coupled with increased urban growth and development has significantly resulted in exacerbation of the UHI phenomenon (Li *et al.* 2018). Nonetheless, effective urban planning can aid in reducing the UHI effect (Zhou & Chen, 2018). To this end, studies have been conducted on urbanization and UHI as well as the integration of UGI to mitigate the UHI effect (Zhou & Chen, 2018; Uddin *et al.* 2022; Abdulateef & Al-Alwan, 2022; Marando *et al.*, 2022; Leal Filho *et al.* 2021).

Zhou & Chen (2018) conducted a study in Wuhan City, China, using statistical data on LULC changes from 1965-2008 to assess how urbanization through alteration of LULC have contributed to urban heat island. They found that the UHII of Wuhan City increased to 0.4 °C from 0.2 °C on average.

In another study, Uddin *et al.* (2022) assessed UHI effects brought about by changes in urban areas in Dhaka City, Bangladesh, from 2001-2017. They used MODIS data to calculate the expansion of the city and statistical methods to estimate changes in urban temperature. They found a 25.33% increase in Dhaka city's land surface area and 76.65% increase in city's the population resulting in an increase in temperature of roughly 3°C in some parts of the city compared to its bordering communities. They concluded that without mitigation practices, the UHI effect in the city would increase, leading to higher public health risks.

Abdulateef & Al-Alwan, (2022) in a study conducted in Risafa municipality, Baghdad city, that used ENVI-met to assess the how Surface Urban Heat Island (SUHI) can effectively be reduced using urban green infrastructure, measured different surfaces' temperatures in two models using base case scenario, and found out that, in both models, urban green infrastructure had an apparent role in reducing surface temperature. Moreover, Abdulateef & Al-Alwan reiterated that the cooling effect brought about by incorporating UGI scenarios was similar in the two models, which further confirmed that UGI would contribute greatly to reducing SUHI in Baghdad City. However, the cooling effect is largely dependent on the types of UGI.

Relatedly, Marando *et al.* (2022) conducted geospatial assessment in Europe to develop a model for regulating microclimate through urban green infrastructure (UGI) in 601 European cities and assess its effectiveness in mitigating UHI. The model simulated the differences in temperature s between scenarios with and without vegetation and extrapolated UGI's role in reducing UHI in different urban contexts. The authors found that UGI could lower urban temperatures up to 2.9°C and by an average of 1.07°C. They also indicated not less than 16% of tree cover was needed to attain a 1°C decrease in temperature since the regulation of microclimatic conditions is dependent on the amount of vegetation that enables evapotranspiration. Marando *et al.* concluded by recommending widespread adoption and implementation of UGI to ensure healthy living conditions for urban residents.

Lastly, Leal Filho *et al.* (2021) in an article that emerged from a review and analysis of 14 case studies from cities spread across 13 countries of different climatic zones and geographical regions, on the role of UGI in mitigating UHI as well their negative impacts on urban dwellers, found out that; under certain conditions, urban green infrastructure may mitigate UHI and equally address its potential impacts on city dwellers. However, Leal Filho *et al.* revealed that; the lack of uniformity in the impacts of UHI which highly dependent on the peculiarities of various urban morphology, pose challenges linked to the role of UGI in regulating the microclimatic conditions unique to each city.

2.4 Research Gap

On the basis of the reviewed literature, it was apparent that most of the studies on urbanization-induced LULC change and associated UHI effect had been conducted in Asia particularly China, India and Bangladesh, and their findings could not be generalized to other regions like West Africa especially Liberia considering the huge disparities in urban population size, extent of urban development, and extent of air pollution which collectively contribute to the development of UHI phenomenon. Furthermore, some of these studies were based on already existing urban green spaces such as parks, and therefore, could not be generalized for a district like Greater Monrovia that do not have designated green spaces.

CHAPTER III

MATERIALS AND METHODS

3.1 Study Area Description and Land Use

The assessment was carried out in Greater Monrovia District in Liberia, a country in the West African region. Administratively, Greater Monrovia district is in Montserrado County, and borders Atlantic Ocean to the south (GoL, n.d.). Geographically, Greater Monrovia District lies between latitude 10°42'42.546''W and longitude 6°17'43.685''N, and occupies approximately 196 km^2. The study area map is shown in Figure 3.1. Greater Monrovia District experiences tropical monsoon climate with wet and dry seasons, and have an average annual temperature of 25^{0}C (World Bank, 2021). The rainy season is from May to October while the dry season is from November through April (ibid). Since 2000, there has been an increase in rural-urban migration that has led to increased urban population in Greater Monrovia District (Hove *et al.* 2013). This has been attributed to Monrovia being the country's economic, financial and cultural center, thus attracts people who are in search of greener pastures and government services, including but not limited to basic social services, social amenities, employment, and education (ibid). The current population of Greater Monrovia District is estimated to be 1,623,000, and it is considered the most populous district in Liberia (LISGIS, 2022). In terms of land use, commercial and residential areas intersperse throughout the district, although the district surrounds a mangrove swamp which is a Ramsar protected site (Lloyd *et al.* 2016).

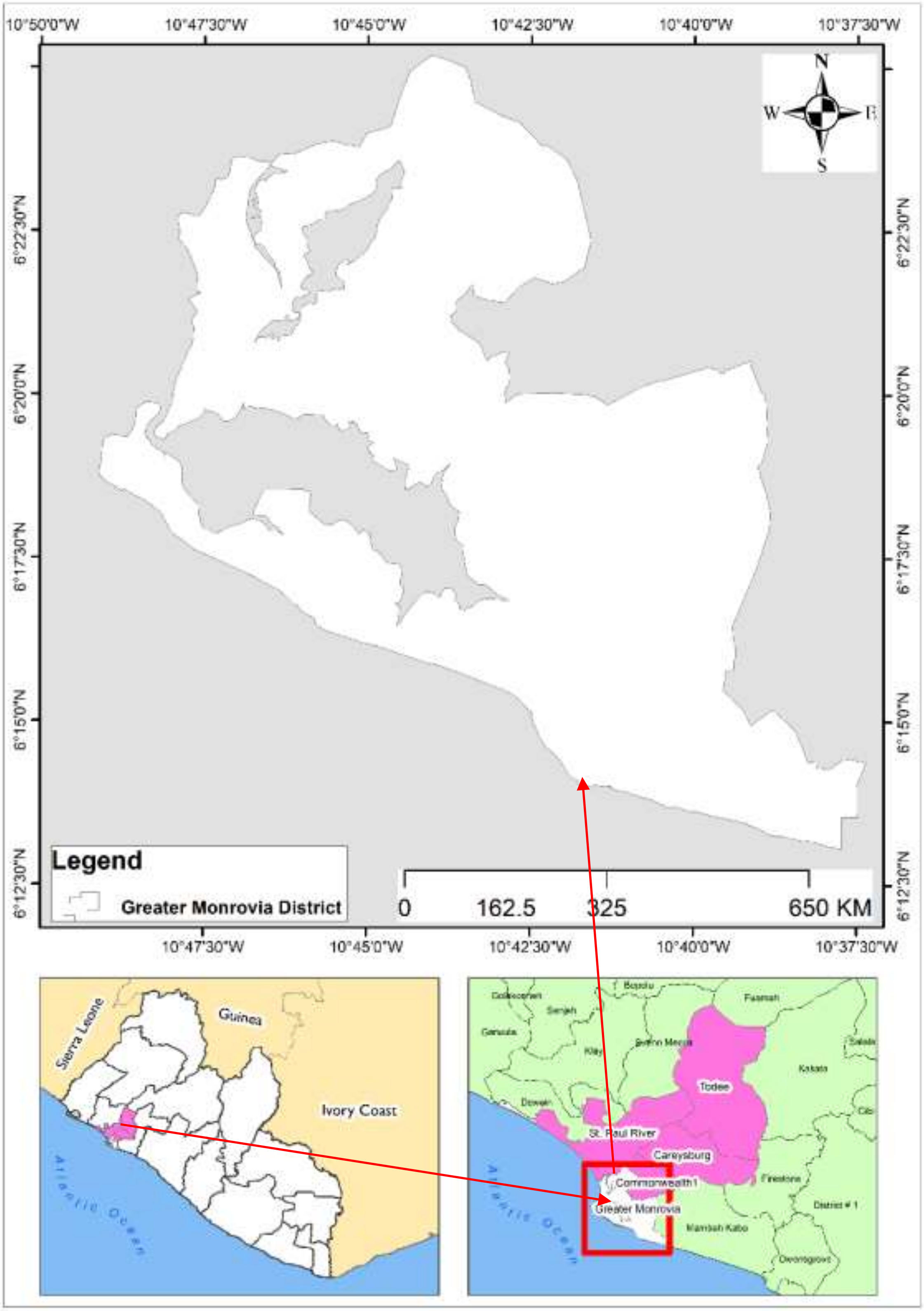


Figure 3.1: Map of the study site
Source: Author

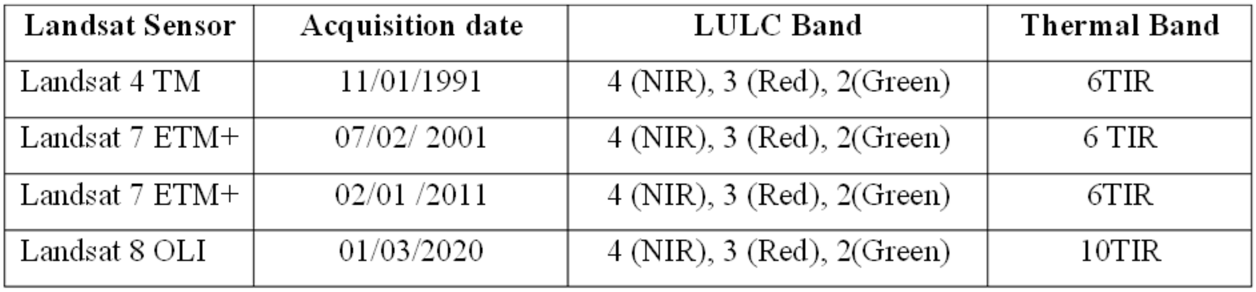
3.2 Methodology

The methodology adopted in this study consisted of a five-step procedure involving data acquisition, image processing, LULC classification, retrieval of LST, determination of NDBI, and determination of UHI as described below. Figure 3.2 shows a framework of the methodology.

3.2.1 Data Acquisition

The satellite images for the study were obtained from 1991 to 2020, at a 10-year interval for the years 1991, 2001, 2011 and 2020 as base years to evaluate and interpret LULC changes. Cloud free Landsat 4 TM (1991), Landsat 7 ETM+ (2001 and 2011), and Landsat 8 OLI (2020) of the Greater Monrovia District, with path 200 and row 56, was obtained from the USGS website. The acquired data with WGS_1984 was projected to UTM projections specific to Liberia; WGS_1984-_UTM_Zone_29N. Table 1 shows a summary of the satellite imagery acquired for the study. It is worth noting that; data acquisition mostly depended on data availability, suitability, and quality.

Table 3.1: Satellite Imagery acquired in the study



Landsat Sensor	Acquisition date	LULC Band	Thermal Band
Landsat 4 TM	11/01/1991	4 (NIR), 3 (Red), 2(Green)	6TIR
Landsat 7 ETM+	07/02/ 2001	4 (NIR), 3 (Red), 2(Green)	6 TIR
Landsat 7 ETM+	02/01 /2011	4 (NIR), 3 (Red), 2(Green)	6TIR
Landsat 8 OLI	01/03/2020	4 (NIR), 3 (Red), 2(Green)	10TIR

Source: Author

3.2.2 Image Processing

The downloaded images were cropped to limit the scope of spatial analysis to the study area, thereafter they were pre-processed for atmospheric and geometric correction. The images were enhanced to improve visual contrast, and then colour composited using geoprocessing tool that generates Red, Green and Blue (RGB) raster dataset, from a multiband raster dataset.

3.2.3 LULC Classification

Supervised-classification approach entailing creation of training sites defined by a six-classification system including; built-up area, waterbodies, bare land, mangroves, grassland, and shrub land, was applied in the study. To obtain land use and land surface characteristics for each year from 1991 to 2020, the study used images from Landsat 4 TM, Landsat 7 ETM+ and Landsat

8 OLI. ArcGIS software was utilized to perform the classification of land use and detect changes, using Near Infrared, Red and Green bands combination. The supervised classification approach helped determine the total area in square kilometers for each land class and track any changes in land use. The number of correctly classified pixels were divided by total number of validations sets in each class to perform an accuracy assessment, to ensure efficient classification of pixels into the correct land cover classes. Finally, the LULC maps were generated.

3.2.4 Retrieval of LST

To obtain LST data, the study used Landsat 4 TM (1991), Landsat 7 ETM+ (2001 and 2011), and Landsat 8 OLI (2020) thermal bands 6 and 10 by applying a set of equations through a raster image calculator in ArcGIS. The process followed a five-step procedure involving the calculation of Top of Atmospheric (TOA) spectral radiance($L\lambda$), which was converted to Brightness Temperature (BT), the generation of Normalized Difference Vegetation Index (NDVI), calculation of Land Surface Emissivity (LSE), and calculation of LST.

The first step involved calculation of $L\lambda$, and conversion of the images from Digital Number (DN) to $L\lambda$ to get the actual reflectance from the earth's surface. The second step involved converting the $L\lambda$ to BT using a specific formula (Equation 3.1).

$$BT = \frac{K_2}{ln[(K_1/L\lambda)+1]} - 273.15 \tag{3.1}$$

Where;

BT = TOA Brightness temperature in Kelvin

Lλ = Spectral Radiance (Watts/ (m2*sr* μm)

K1 & K2 = Band specific thermal conversion constants from the metadata for band 6 and band 11

The third step in the process involved calculating the NDVI using Equation 3.2. The NDVI values ranged from -1.0 to +1.0 and allowed for determination of vegetation cover in different land cover types. The determination of NDVI was important as it allowed subsequent determination of the Proportion of vegetation (Pv) and emissivity (ε).

$$NDVI = \frac{NIR\ Band - R\ Band}{NIR\ Band + R\ Band} \qquad (3.2)$$

Where;

NIR is the near infrared band values for the multispectral image (Band 4)

RED is the red band value of the image (Band 3).

In the fourth step, LSE was calculated using NDVI to estimate LST. Based on Planck's law, LSE adjusted blackbody radiance to allow for prediction of emitted radiance, as it showed how efficiently thermal energy is transmitted from the surface into the atmosphere.

In the fifth step, LST was obtained by using the BT of bands band 10 for Landsat 8 (OLI) and band 6 for Landsat TM and ETM+ and along with LSE derived from NDVI, following the formula described in Equation 3.3.

$$T_s = \frac{BT}{\{1+[\lambda BT/_{p}) ln \varepsilon_{\lambda}]\}} \qquad (3.3)$$

Where;

Ts is the Land Surface Temperature in Celsius (°C)

BT is at- sensor Brightness Temperature (^{0}C),

λ is the average wavelength of band 6 and 11 (for Landsat 4, 7 and 8 respectively),

ελ is the emissivity.

ρ will be calculated as shown in Equation 3.4.

$$p = h\frac{c}{\sigma} \qquad (3.4)$$

Where;

σ is the Boltzmann constant (1.38 × 10−23 J/K),

h is Planck's constant (6.626 × 10−34 Js)

c is the velocity of light (2.998 × 108 m/s)

It is important to note that the LSTs were assessed for each image, and trends in the datasets observed. A comparison of the intensity of the UHI from 1991 to 2020 was conducted to understand changes in the temperature of the study area. To simplify data processing, analysis, and interpretation, LST was classified into four categories: very low, low, high, and very high.

3.2.5 Determination of Normalized Difference Built-up Index (NDBI)

NDBI was determined to illustrate urban development overtime by mapping built-up changes, using Equation 3.5. A spectral response of built-up area that has higher reflectance in MIR wavelength range than in the NIR wavelength range was used to determine NDBI.

$$NDBI = \frac{MIR\ Band - NIR\ Band}{MIR\ Band + NIR\ Band} \tag{3.5}$$

Where;

MIR is the mid infrared band values for the multispectral image (Band 5)

NIR is the near infrared band value of the image (Band 4).

3.2.6 Determination of Urban Heat Island

To determine the UHI, threshold temperatures were estimated using the equations shown in Equations 3.6 and 3.7. The intensity of the UHI was then calculated by subtracting the LST of the least urbanized reference area (vegetated) from that of the UHI area.

$$LST > \mu + (0.5\ \sigma) - \text{refers to UHI area} \tag{3.6}$$

$$0 < LST \leq \mu + (0.5\ \sigma) - \text{denotes non-UHI area} \tag{3.7}$$

Where;

μ is the mean LST value of the study area,

σ is the standard deviation of the LST.

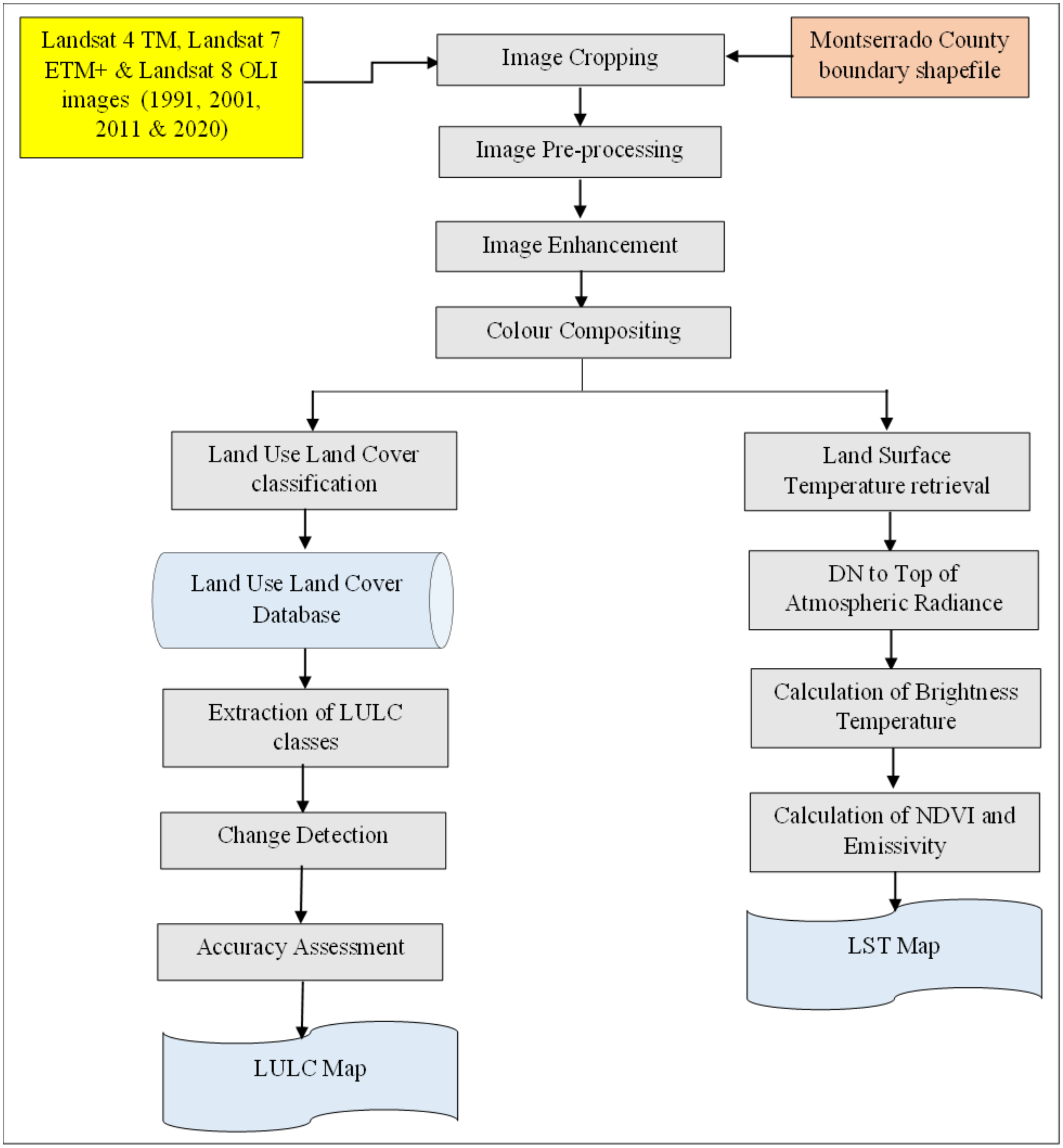


Figure 3.2: Framework of the methodology

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Land Use Land Cover change analysis

The study assessed the trends in LULC change in Greater Monrovia District for the period 1991-2020 and found out significant trends in the changes in the land use land cover. Evidently, the land under built area increased tremendously from 1991- 2020 while the other land use land cover types decreased significantly over the same period (Figure 4.1).

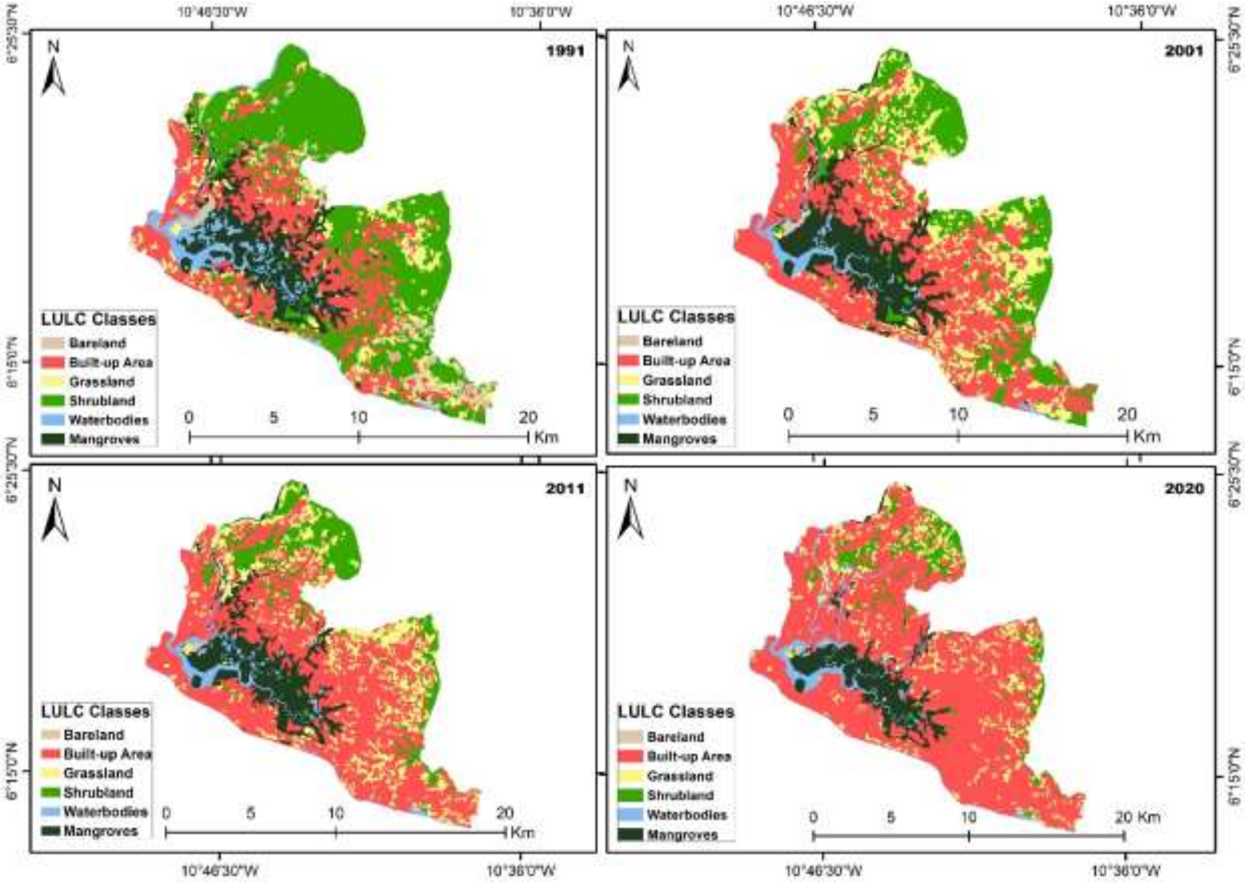
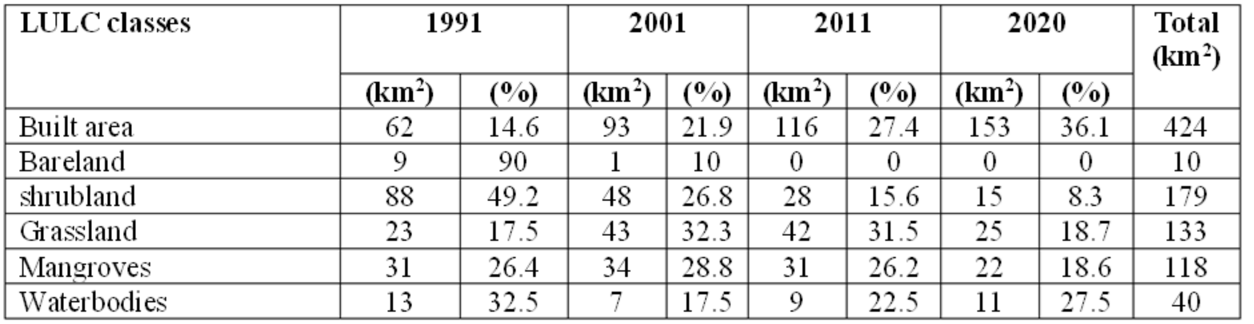


Figure 4.1: Land Use Land Cover maps of Greater Monrovia District for different years

The LULC of the year 1991 shows that the study area had a built-up land with a total area of 62km^2 (14.6%), a bare land with a total area of 9km^2 (90%)' vegetated land (shrubland, grassland and mangroves) with a total area of 142km^2 (62.8%) and a waterbody with a total area of 13km^2 (32.5%). However, the built-up area increased to 153km^2 in 2020, representing 146.8% increase, while the bare land completely diminished to 0km^2 representing -100% decrease. Similarly, vegetated land decreased to 62km^2 representing -56.3% decrease, while the land area under the waterbodies decreased to 11km^2 representing a -15.3% decrease (Table 4.1). The apparent decrease in other LULC classes can be attributed to the increase in the built-up area which is also the dominant class. For instance, the vegetated areas have been cleared, while some portions of waterbodies have been backfilled for infrastructural development.

Table 4.1: LULC classes, their coverages, and changes over time



LULC classes	1991		2001		2011		2020		Total (km^2)
	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	
Built area	62	14.6	93	21.9	116	27.4	153	36.1	424
Bareland	9	90	1	10	0	0	0	0	10
shrubland	88	49.2	48	26.8	28	15.6	15	8.3	179
Grassland	23	17.5	43	32.3	42	31.5	25	18.7	133
Mangroves	31	26.4	34	28.8	31	26.2	22	18.6	118
Waterbodies	13	32.5	7	17.5	9	22.5	11	27.5	40

Source: Research statistics, (2023)

Notably, the current study's findings concur with the findings of a geospatial analysis by Liu & Weng, (2013) conducted in Indianapolis, Indiana, USA, which found an increase in size of the urbanized area and a decrease in size of other land use land cover types including; agricultural land and forest. However, the current study's finding on the decrease in size of grassland contradicts, Liu & Weng, (2013) finding that showed an increase in size and connectedness of grassland. This increase in size and connectedness could be attributed to the urban planning policies in the USA requiring city developers to replant grass upon completion of a development project. The current study's findings also concur with Mundhe and Jaybhaye (2014) findings from a study conducted in Pune City, India which showed an increase in size of urbanized areas at the expense of other land use land cover types such as agricultural land, fallow land, vegetation, and water bodies, which tremendously decreased in size. Although the current study did not include agricultural land in the LULC classes, its findings concur with the findings of a geospatial analysis by Sajjad & Iqbal (2012) conducted in Dudhganga watershed, India, which showed a significant decrease of in agricultural land, and a dramatic increase in built-up area between 1991 and 2010.

4.2 The relationship between LULC and LST

The study analysed the LST for the various LULC classes by classifying the LST distributions into appropriate ranges and color-codes and generating a thermal pattern distribution map of the study area, where it was determined that; different LULC classes had different LST values (Figure 4.2).

Evidently, the mean LST values were higher in built-up areas and bare land, while the LSTS values were considerably low in vegetated areas (shrubland, grassland and mangroves) and waterbodies.

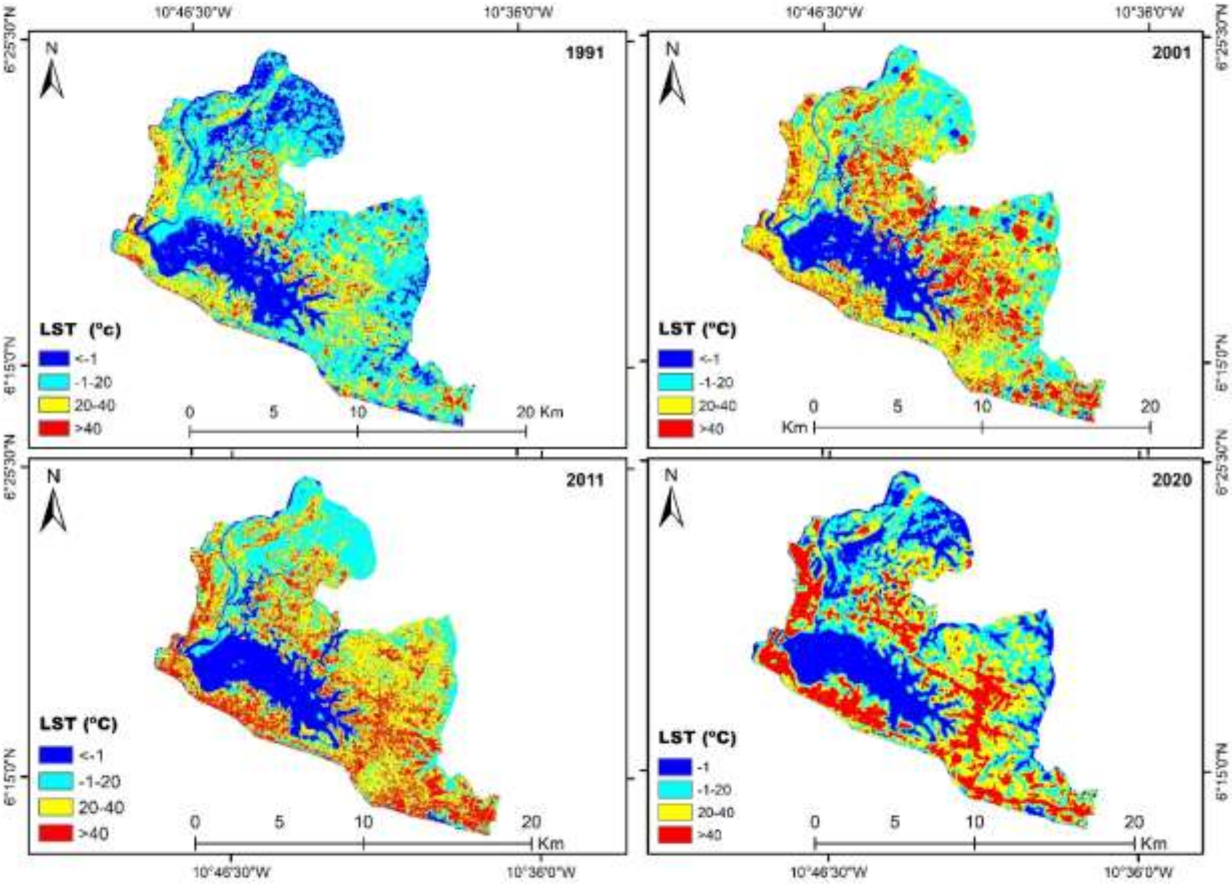


Figure 4.2: Land Surface Temperature maps of Greater Monrovia District for different

The LST analysis was based on an LST classification system including; very low (<-1^{0}C), low (-1^{0}C-20^{0}C), high (20^{0}C- 40^{0}C), and very high (>40^{0}C). Generally mean LST increased significantly from (29.3^{0}C) in 1991 to (36^{0}C) in 2020. For the year 1991, the result of the LST analysis showed that the built-up areas had a mean LST of 36^{0}C, while the bare land had a mean LST of (32^{0}C). However, the mean LST for the built-up area and bare land were very high in 2020 recording up to 42^{0}C and 38^{0}C respectively. Notably, the other classes of LULC including; shrubland, grassland, mangroves and waterbodies recorded high mean LST (34.8^{0}C) for the 1991, and (33^{0}C) for the year 2011, with high mean LST in the range of (30^{0}C- 37^{0}C) being recorded in 2020. The high mean LSTs recorded for bare land, shrubland, grassland, mangroves and waterbodies between 1991 and 2011 could be attributed to increase in economic growth and associated infrastructural development. Noteworthy, Liberia began reconstruction and rehabilitation of the post-war destruction around 2010, hence the increase in built-up areas and the associated LSTs in 2011. The high LSTs recorded between 1991 and 2011 could also be attributed changes in climate which might led to increase in temperature hence high LSTs. Table 4.2 shows the mean LST for the LULC classes for the period 1991 – 2020.

Table 4.2: Mean LST for the LULC classes for the period 1991-2020

LULC classes	**1991**			**2001**			**2011**			**2020**		
	Min (⁰C)	Max (⁰C)	Mean (⁰C)	Min (⁰C)	Max (⁰C)	Mean (⁰C)	Min (⁰C)	Max (⁰C)	Mean (⁰C)	Min (⁰C)	Max (⁰C)	Mean (⁰C)
Built-up area	27	45	36	19	30	25	32	44	38	39	44	42
Bareland	27	36	32	30	38	39	31	39	35	37	39	38
Shrubland	35	42	39	29	38	34	31	37	34	36	37	37
Grassland	34	42	38	36	39	38	23	36	30	34	35	35
Mangroves	24	37	31	26	38	32	32	34	33	32	34	33
Waterbodies	28	34	31	22	33	28	34	33	34	27	32	30
Overall mean			**29.3**			**32.7**			**34**			**36**

Source: Research statistics, (2023)

This study's findings concur with the findings of a previous study by Dhar *et al.* (2019) conducted in Rajarhat Block, West Bengal, which assessed the link between LULC changes and LST, and found out that; there was an increase in LST due to loss of vegetation. Notably, the conversion of vegetated land to bare land led to an increase in LST as was observed in the current study where bare land recorded high mean LST values as compared to vegetated lands. The findings also concur with Le-Xiang *et al.* (2006) findings from a geospatial assessment conducted in Zhujiang Delta, that evaluated the impact of LULC change on LST, and found out that; LST had increased in the newly built-up parts of Zhujiang Delta due to a strong and unbalanced urban development. Noteworthy, the current study also found high LST values in built-up areas.

4.3 Urban Heat Island Analysis

The study assessed the consequences of the relationship between LULC and LST on UHI by generating UHI maps, and determined that, different LULC classes along with their LST values exhibited different UHI. That is, built-up areas and bare land with high LST showed high UHI (1) as compared to vegetated areas (shrubland, grassland, and mangroves) and waterbodies with low LST, which showed relatively low UHI (0) (Figure 4.3). Interestingly, this result shows that UHI exist in Greater Monrovia District.

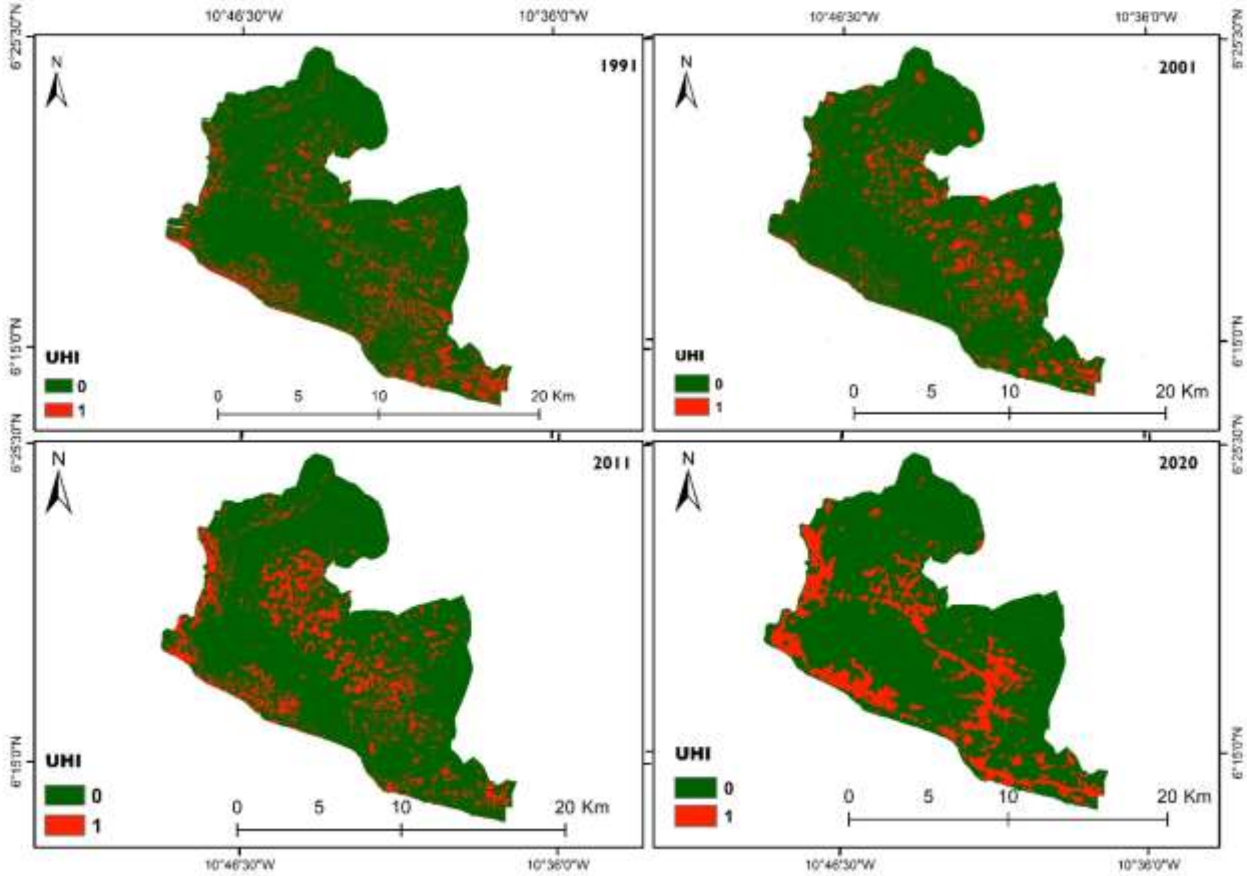


Figure 4.3: Urban Heat Island maps of Greater Monrovia District for different years

The study further generated NDBI and NDVI maps of the study area to illustrate the link between built-up areas and LST and vegetated areas and LST respectively, and how that correlation is contributing to UHI. Evidently, the built-up areas showed high NDBI in the range of (-1 – 0.48) while the vegetated areas showed high NDVI in the range of (-0.07 – 0.80). Figure 4.4 and 4.5 show the NDBI and NDVI maps respectively.

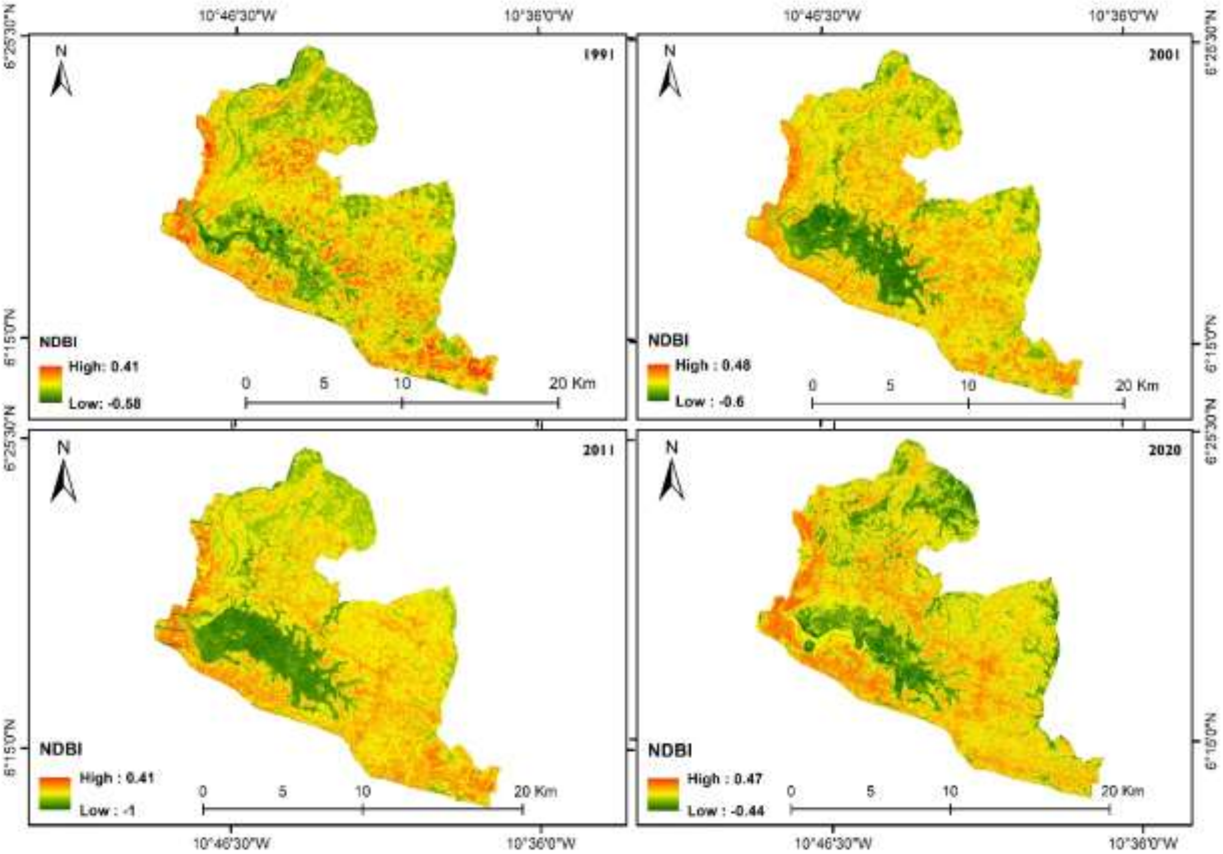


Figure 4.4: NDBI maps of Greater Monrovia District for different years

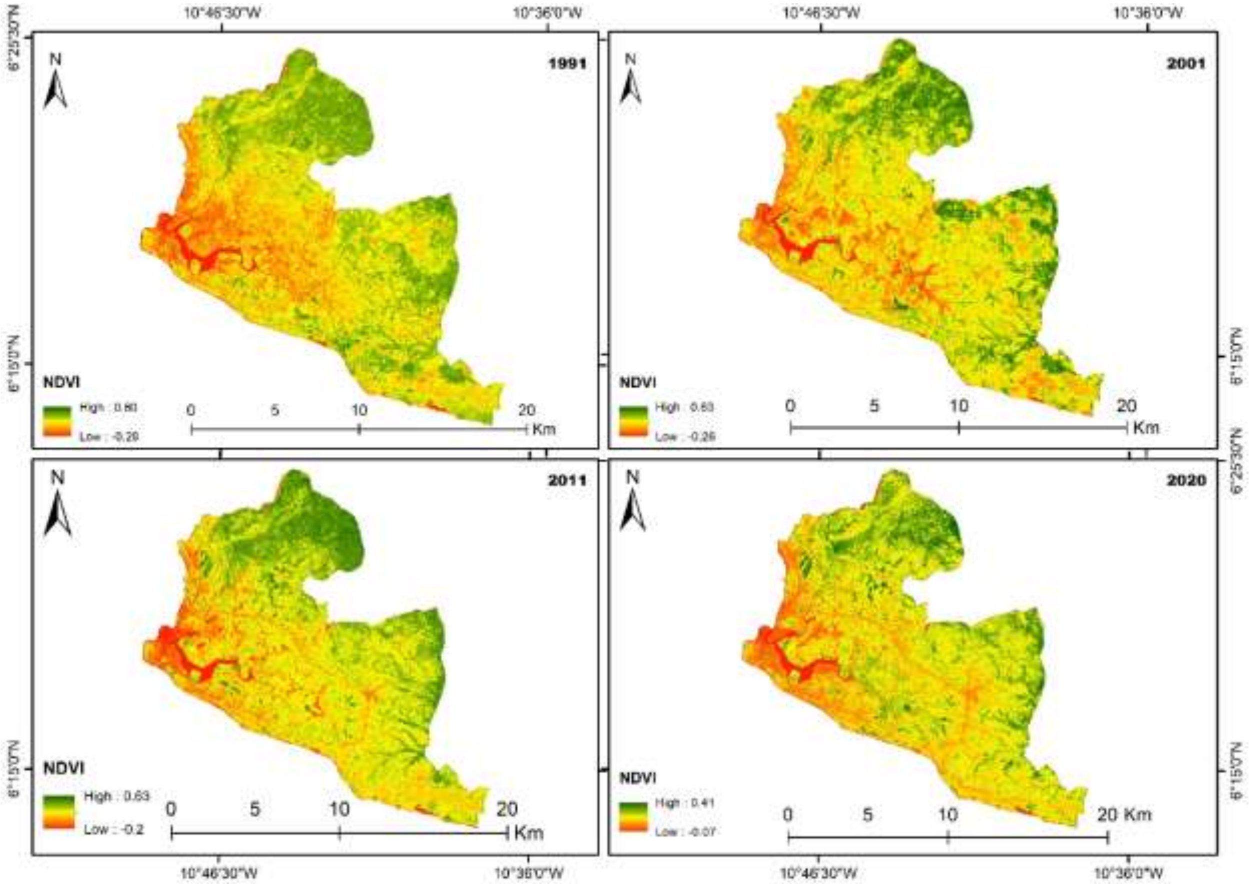


Figure 4.5: NDVI maps of Greater Monrovia District for different years

Moreover, Pearson's correlation coefficient was used to show the correlation between NDBI and LST and the correlation between NDVI and LST. Notably, the scatter plots revealed a positive correlation between LST and NDBI for all years (Figure 4.6). This implies that the higher the NDBI, the higher the LST values. The positive correlation found between LST and NDBI shows that built-up area is producing much LST variations and is the main contributor to UHI effect (Figure 4.3). The scatter plots also revealed a negative correlation between LST and NDVI in all the years (Figure 4.7). This significant negative correlation validates the role that UGI play in mitigating UHI effect. That is the higher the NDVI, the lower the LST, thus the relationship between LST and NDVI in urban Green space can effectively reduce the UHI effect. Essentially, the evapotranspiration of plants plays a physiological role in reducing ambient temperature, eventually alleviating surface temperature and thus reducing the UHI effect.

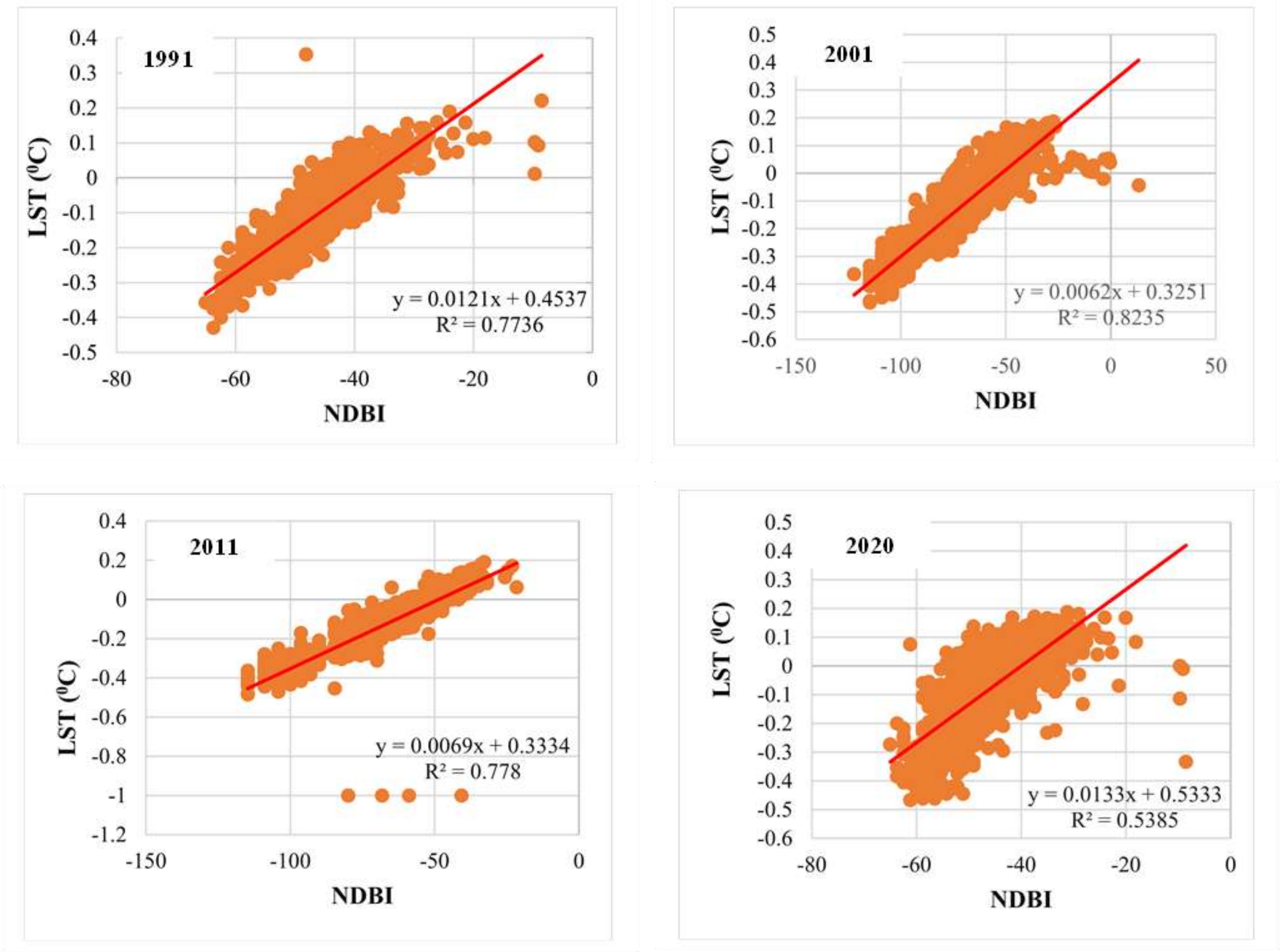


Figure 4.6: LST as a function of NDBI during different years

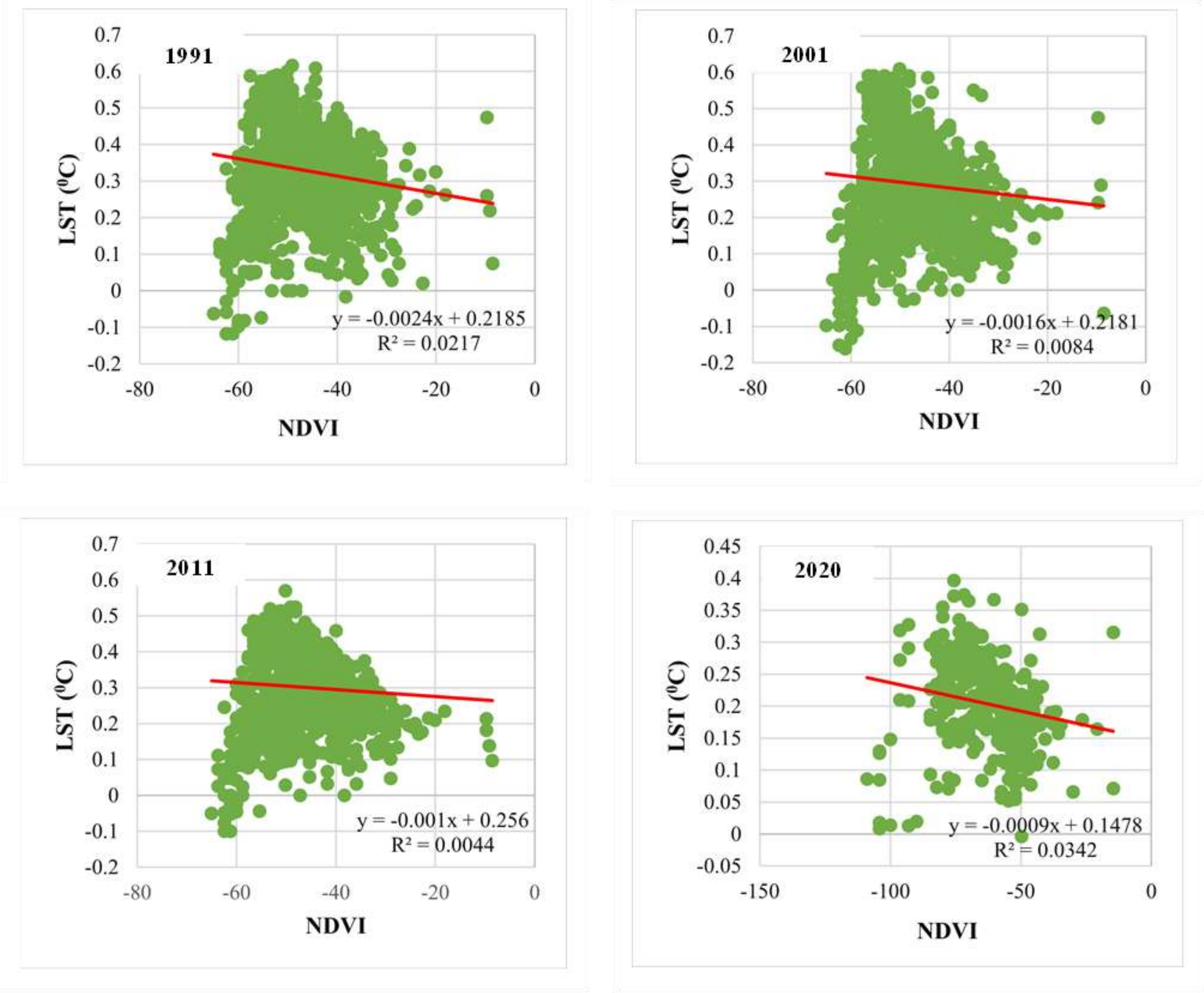


Figure 4.7: LST as a function of NDVI during different years

The study further correlated NDBI and NDVI for all the years, and found a negative correlation between NDBI and NDVI for all the years. That is, the higher the NDBI the lower the NDVI (Figure 4.8). This demonstrates how urbanization leads to loss of urban green spaces by converting them into impervious or built-up areas.

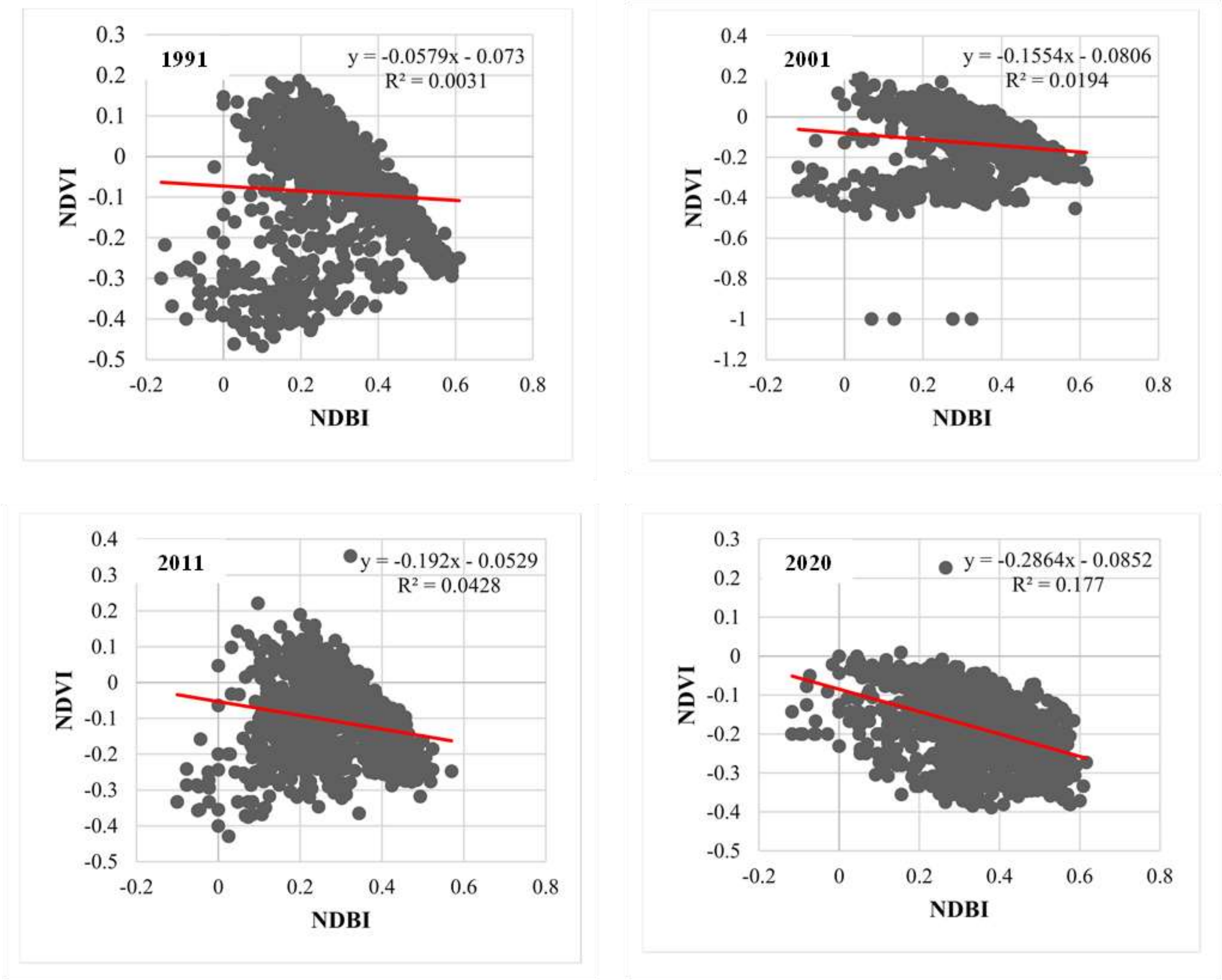


Figure 4.8: Correlation between NDBI and NDVI for different years

The current study’s finding on the positive correlation between NBDI (built-up areas) and LST, concur with the findings of a study by Uddin *et al.* (2022) which assessed UHI effects brought about by changes in urban areas in Dhaka City, Bangladesh, from 2001-2017, and found out that; increase in size of the built-up area of the city led to a significant increase LST by about 3°C, hence could potentially contribute to UHI unless measures are put in place to mitigate it. The current study’s finding on the potential of urban green spaces (NDVI) to mitigate UHI by regulating LST also concurs with Abdulateef & Al-Alwan, (2022) finding from a study conducted in Risafa municipality, Baghdad city, that used ENVI-met to assess the how Surface Urban Heat Island (SUHI) can effectively be reduced using urban green infrastructure, and that indicated that; urban green infrastructure had an apparent role in reducing surface temperature.

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In view of the geospatial analysis, the study concludes that;

There are visible trends in LULC change with built-up area showing a significant increase in size as compared to bare land, land areas under vegetation (shrubland, grassland and mangroves) and waterbodies which showed a significant decrease over the study period. This simply implies that the expansion of Greater Monrovia District, especially infrastructural development, has led to the loss of green spaces, backfilling of water areas as well as encroachment of mangrove forests.

The increase in size of built-up areas and a decrease in size of bare land, land areas under vegetation (shrubland, grassland and mangroves) and waterbodies has resulted in increase of LST with built-up areas recording high mean LST. This demonstrates that built-up areas such as buildings, roads and other impervious surfaces, absorb and retain more heat from shortwave radiation as compared to other LULC types, hence the high mean LST in built-up areas.

The relationship between LULC and LST have contributed to the development of UHI phenomenon. For instance, built-up areas where natural and semi-natural landscapes are converted into impervious surfaces have led to the development of UHI by raising LST. Built-up areas absorb and retain heat during the day and slowly release it during the nighttime thereby contributing to UHI. Additionally, NDBI negatively correlated with NDVI implying that increasing built-up areas have led to loss of urban green spaces which could potentially contribute to the development of UHI effect, while NDBI positively correlated with LST implying that the higher the built-up index the higher the LST, hence the formation of UHI phenomenon. In contrast, the land areas under vegetation and waterbodies showed relatively low LST which underscores the potential contribution of urban green spaces/infrastructure in mitigating UHI. Evidently, NDVI negatively correlated with LST implying that; the higher the vegetation index the lower the LST.

5.2 Recommendations

On the basis of the research findings, the study makes following recommendations;

- **i.** Environmental Protection Agency (EPA) of Liberia should convene a national roundtable on Urban Green Infrastructure and its role in mitigating UHI, to draw the attention of experts, donors, policymakers; UN, and private sector to the issue of UHI and the need for Urban Green Infrastructure.
- **ii.** Environmental Protection Agency (EPA) of Liberia should create awareness among city dwellers on the UHI and the benefits of having UGI such lawns, trees, and green roofs to help increase the coverage of vegetation.
- **iii.** Environmental Protection Agency (EPA) of Liberia should support urban planning policies requiring development projects to include UGI.
- **iv.** UNDP and World Bank should fund projects on the development of Urban Green Infrastructures within greater Monrovia District to help address the UHI effect.
- **v.** Liberia Land Authority and Monrovia City Corporation should designate land areas within Greater Monrovia District for funding and development into Urban Green Infrastructure to help regulate LST.
- **vi.** Environmental Protection Agency (EPA) of Liberia should liaise with Forest Development Authority (FDA) and Public Works to implement the urban green infrastructure development projects along the roads by planting roadside vegetation.
- **vii.** Environmental Protection Agency (EPA) of Liberia should ensure that the mangroves forests area adequately monitored and protected as they have shown a great reduction in LST in Greater Monrovia District.
- **viii.** Environmental Protection Agency (EPA) of Liberia should ensure that the backfilling of wetlands for infrastructural development is halted as the waterbodies showed a great cooling effect potential which could mitigate the UHI effect.

5.3 Areas for further research

Based on the research findings, the study recommends further research on; the relationship between LULC change and Air temperature and how that has contributed to UHI, the impacts of encroachment on mangroves forest on the mangrove ecosystem, and the urban expansion patterns and how it affects LULC, LST and UHI.

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