



**WALLAGA UNIVERSITY
SCHOOL OF GRADUATE STUDIES**

**ASSESSING URBAN SPRAWL AND ITS IMPACTS ON
URBAN THERMAL ENVIRONMENT BY USING
GEOSPATIAL TECHNOLOGY IN ADDIS ABABA AND
SHAGGAR CITIES, ETHIOPIA**

**BY:
YONAS NAME WODAJO**

**FEBRUARY , 2026
NEKEMTE, ETHIOPIA**



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**A THESIS SUBMITTED TO THE COLLEGE OF ENGINEERING AND
TECHNOLOGY IN PARTIAL FULFILLMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN GEOMATICS ENGINEERING**

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APPROVAL SHEET FOR SUBMITTING FINAL THESIS

As members of the Broad of Examining of the final M.Sc. thesis open defense, we certify that we have read and evaluated the thesis prepared by Yonas Name Wodajounder the title "Assessing Urban Sprawl And Its Impacts On Urban Thermal Environment By Using Geospatial Technology In Addis Ababa And ShaggarCitiesEthiopia" and recommend that the thesis be accepted as fulfilling the thesis requirement for the Master of Degree in (MSc) Science In Geomatics Engineering

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I hereby certify that all the correction and recommendation suggested by the broad of examiners are incorporated into the final thesis "Assessing Urban Sprawl And Its Impacts On Urban Thermal Environment By Using Geospatial Technology In Addis Ababa And Shaggar City, Ethiopia" by Yonas Name Wodajo

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DECLARATION

This is to certify that this thesis entitle title/

Assessing Urban Sprawl And Its Impacts On Urban Thermal Environment By Using Geospatial Technology In Addis Ababa And Shaggar City, Ethiopia” in the partial fulfillment of the requirement for the award of the degree of masters of Geomatics Engineering. by the school of graduated studies, Wallaga University through the College Of Engineering And Technologydone by Yonas Name Wodajo, This thesis has not been submitted earlier for the award of any degree or diploma. The assistance and help received during the course of this examination have been dully acknowledged. Therefore, I recommended that it can be accepted as fulfillment the research thesis requirement of (MSc) Science InGeomatics Engineering

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November 24, 2025

Name of Advisor

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STATEMENT OF THE AUTHOR

I **Mr/Miss/Mrs. Yonas Name Wodajo** hereby declare and affirm that the thesis entitled **“Assessing Urban Sprawl And Its Impacts On Urban Thermal Environment By Using Geospatial Technology In Addis Ababa and ShaggarCities , Ethiopia”** is my own work conducted under the supervision of **DessalegnObsiGemed (PhD)**. I have followed all the ethical principles of scholarship in the preparation, data collection, data analysis and completion of this thesis. All scholarly matter that is included in the thesis has been given recognition through citation. I have adequately cited and referenced all the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and I have not misrepresented, fabricated, or falsified any idea / data / fact / source in my submission. This thesis is submitted in partial fulfillment of the requirement for a degree from the Post Graduate Studies at Wallaga University. I further declare that this thesis has not been submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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ACRONYMS

ERDAS	:	Earth Resources Data Analysis System
GIS	:	Geographic Information system
GPS	:	Geographic Positioning System
LST	:	Land Surface Temperature
LULC	:	Land-use/land-cover
MODIS	:	Moderate resolution Imaging Spectroradiometer
NDVI	:	Normalized Difference Vegetation Index
UGC	:	Urban Green Cover
UHI	:	Urban Heat Island
USGS	:	United States Geological Survey

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ABSTRACT

Uncontrolled urban land use land cover change (LULC) is a major driver of urban sprawl in developing countries. Unplanned urbanization negatively affects the urban microclimate due to the degradation of urban green spaces. This study aimed to analyze urban sprawl and its impacts on the urban thermal environment, particularly land surface temperature (LST) and the urban heat island (UHI) effect, in Addis Ababa and Shaggar cities from 1995 to 2025. Multispectral and thermal bands of Landsat TM of 1995, ETM+ of 2010 and OLI/TIRS of 2025 were used. Supervised classification method with maximum likelihood algorithm and monowindow algorithm were used for LULC classification and LST calculation respectively, over the study period. In addition, UHI of the study area was generated from the LST from 1995 to 2025. The results show that urban areas expanded significantly by 518.3 km², while agricultural land and forest land decreased by 886.7 km² and 103.3 km², respectively, between 1995 and 2025. This trend indicates rapid urban expansion and conversion of agricultural land driven by population growth and increasing food demand. As a consequence of built-up area expansion, the mean LST increased by 7.9 °C, and the maximum UHI intensity increased by 9.9 °C over the study period. Linear correlation analysis revealed a strong negative relationship between LST and the Normalized Difference Vegetation Index (NDVI) ($R^2 = 0.953$) and a strong positive relationship between LST and the Normalized Difference Built-up Index (NDBI) ($R^2 = 0.935$) in 2025. These findings suggest that future studies should focus on assessing the long-term impacts of climate change on urban thermal comfort in relation to socio-economic activities.

Key Words: Correlation, LULC; LST; NDBI; UHI; NDVI

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

Urban sprawl is a widespread global phenomenon characterized by the unplanned and uncontrolled expansion of urban areas into surrounding rural landscapes (Sinha, 2023). This spatial pattern of urban growth has profound implications for land use and land cover (LULC) dynamics, often resulting in environmental degradation, particularly in relation to urban thermal conditions (Viana et al., 2019). In developing countries, rapid population growth, intensified rural to urban migration, and inadequate urban planning frameworks have accelerated the outward expansion of cities beyond their traditional boundaries, leading to the large scale conversion of agricultural and natural lands into built areas. In Sub-Saharan Africa, where urban populations are projected to triple in the coming decades, the magnitude and pace of urban expansion are especially pronounced (Kassa, 2014).

In Ethiopia, rapid urbanization and population growth have been identified as primary drivers of declining urban green spaces, particularly in Addis Ababa (Moisa and Gemed, 2021; Moisa et al., 2022). The loss of vegetated surfaces associated with urban sprawl has significant implications for the urban thermal environment. Extensive expansion of impervious surfaces, coupled with reductions in vegetation cover, intensifies the urban heat island (UHI) effect and contributes to elevated land surface temperatures (LST) within urban areas compared to their rural surroundings (Vani and Prasad, 2020). Land surface temperature is governed by the balance between incoming solar radiation and outgoing terrestrial energy, a process that is strongly influenced by surface materials, vegetation density, and land cover characteristics (Olamitomet al., 2023).

Global climate change further exacerbates urban thermal stress. Since the pre-industrial era, the Earth's atmosphere has experienced a sustained warming trend, with both observed and projected increases in global mean surface temperature posing significant risks to urban systems (Chauhan et al., 2022). Among the most pressing environmental challenges of the twenty-first century is the urban heat island effect, which has emerged as a critical consequence of rapid urbanization (Hoffmann et al., 2012). Urbanization alters local

energy balances and ecological processes, resulting in persistent warming of urban environments relative to adjacent rural areas a phenomenon widely recognized as the UHI effect (Feyisa *et al.*, 2016). A key mechanism underlying UHI formation is the absorption and storage of solar radiation by urban construction materials. Empirical evidence indicates that roofs, roads, and pavements constitute more than 60% of urban surfaces, and dark materials may absorb up to 80–90% of incoming solar radiation (Wang and Akbari, 2014).

The UHI effect amplifies exposure to biophysical and climatic hazards in urban areas, including heat stress, deteriorating air quality, and increased energy demand (Paulina *et al.*, 2015). Elevated urban temperatures adversely affect environmental quality, public health, and overall urban livability (Gaitani, 2011). Numerous studies have demonstrated that urban areas exhibit consistently higher LST values than their rural counterparts, with densely populated cities showing stronger thermal anomalies (Wicki *et al.*, 2018). These temperature differentials are particularly pronounced during nighttime hours due to the gradual release of stored heat from impervious urban surfaces (Heisler and Brazel, 2010). Consequently, research on the environmental, climatic, and energy related impacts of UHIs, as well as on mitigation and adaptation strategies, has gained increasing prominence within sustainability and climate resilience initiatives (Wang and Akbari, 2014). These efforts are closely aligned with Sustainable Development Goal 3, which emphasizes the promotion of healthy lives and well-being for all age groups (Howden *et al.*, 2017).

Cities in developing regions, particularly in Sub-Saharan Africa, are disproportionately vulnerable to the impacts of climate change due to rapid, unplanned urban expansion and increasing anthropogenic emissions (Li *et al.*, 2017; Mwangi and Mutua, 2015). Despite this vulnerability, empirical research on urban thermal environments in secondary and emerging cities remains limited. In Ethiopia, existing UHI studies have predominantly focused on Addis Ababa, where accelerated urban growth has resulted in substantial LULC transformations and significant modifications to urban microclimatic conditions (Feyisa *et al.*, 2016).

Conventional UHI assessments rely on air temperature measurements obtained from networks of urban and rural meteorological stations. However, the limited availability and uneven spatial distribution of such stations constrain the comprehensive analysis of urban thermal patterns, particularly in rapidly growing cities (Konstantinov *et al.*, 2015). In response to these limitations, satellite-based remote sensing has emerged as a robust and widely applied approach for evaluating urban thermal environments. Satellite derived LST data provide spatially continuous and temporally consistent information, enabling detailed analysis of surface urban heat islands in data-scarce regions (Huang *et al.*, 2017). Monitoring LST is essential for understanding vegetation dynamics, land atmosphere interactions, and the influence of LULC changes on surface energy balance (Ramzan *et al.*, 2022).

In Ethiopia, increasing concern has emerged regarding LST variability and UHI development in rapidly expanding urban centers such as Addis Ababa and Shaggar City. Urban heat islands in these cities are primarily driven by anthropogenic activities and land use patterns, as natural and vegetated surfaces are progressively replaced by impervious materials that absorb and retain heat. These thermal alterations have far reaching implications for public health, energy consumption, and sustainable urban development. Although satellite-based remote sensing enables accurate estimation of surface thermal characteristics (García-Santos *et al.*, 2022), the majority of existing studies emphasize large metropolitan areas, particularly Addis Ababa, while rapidly growing cities such as Shaggar City have received limited scholarly attention. Shaggar City has experienced accelerated urban expansion, marked by increasing impervious surface coverage and declining green spaces, which are key drivers of rising LST and intensified UHI effects.

Geospatial technologies, including remote sensing, geographic information systems (GIS), and spatial analysis, play a critical role in assessing urban sprawl and its thermal impacts. These technologies facilitate systematic monitoring of LULC changes, LST variation, and UHI intensity, thereby providing scientifically robust evidence to support sustainable urban planning and climate-sensitive policy formulation. Accordingly, this study seeks to address existing research gaps by assessing urban sprawl and its impacts on the thermal environment of Addis Ababa and Shaggar City, with particular emphasis on LST dynamics and the UHI phenomenon using geospatial techniques.

The findings are expected to contribute to evidencebased urban management strategies and sustainable development planning in Ethiopia.

Key research gaps regarding urban sprawl, thermal environments, and urban heat islands (UHIs) in Ethiopia, particularly in Addis Ababa and Shaggar Cities, include a limited focus on secondary cities, which leaves a lack of understanding of UHI effects in smaller urban centers; insufficient empirical data on land surface temperature (LST) and UHI dynamics in these emerging areas; and under explored relationships between urban sprawl and inadequate planning frameworks, which could provide insights for sustainable urban management. Additional gaps include the need for research on how the loss of vegetation impacts LST and urban climate, along with limited studies on the health implications of rising LST, which are essential for improving public health strategies. Comparative analyses of different urban areas could enhance our understanding of how various land use patterns influence thermal conditions, while there exists an opportunity to leverage geospatial technologies to more effectively analyze land use and LST variations. Finally, limited research on long-term trends and adaptation strategies to mitigate urbanization's thermal effects highlights the need for comprehensive studies. Addressing these gaps could improve our understanding of urban thermal dynamics in Ethiopia, inform better urban planning, and contribute to the Sustainable Development Goals aimed at promoting health and well-being in urban areas.

1.2. Statements of The Problem

Rapid urbanization has become a major driver of environmental change, leading to significant challenges in urban areas. Among these, the Urban Heat Island (UHI) effect and alterations in Land Use and Land Cover (LULC) patterns stand out as critical concerns (Feinzizadeh&Blaschke, 2013).

The transformation of vegetative and agricultural lands into impervious surfaces such as concrete, asphalt, and built-up infrastructure disrupts natural land-atmosphere interactions (Singh & Kumar, 2012). This shift intensifies land surface temperatures (LST), alters humidity levels, and modifies the radiative and thermodynamic balance of urban environments (Li *et al.*, 2011). One of the primary contributors to increased LST and UHI formation is the expansion of impervious surfaces, which absorb and retain more heat compared to natural landscapes (Buyantuyev& Wu, 2010). Such transformations result in urban microclimates characterized by significantly higher temperatures than surrounding rural areas. The implications of this phenomenon are far reaching, particularly for public health, as extreme heat conditions disproportionately affect vulnerable populations, including the elderly (Tuminiet *al.*, 2016; Vianaet *al.*, 2019; Ambergeret *al.*, 2016).

The intensity and distribution of the UHI effect depend on various factors such as urban morphology, traffic congestion, population density, industrial activity, and climatic variability (Zhou *et al.*, 2017). While extensive research has been conducted globally to investigate these dynamics, studies examining UHI effects in developing countries, especially in the African context, remain scarce. This is particularly true in Ethiopia, where limited attention has been given to understanding the link between urbanization-induced LULC changes and climate-related impacts such as UHI (Dibaba, 2023). Addis Ababa and Shaggar Cities are among the rapidly urbanizing cities with close geographic and functional relationship, and marked by dynamic urban landscape where changes in LULC significantly affect local climatic conditions, particularly in terms of LST and UHI effect. They have been experiencing noticeable warming trends over recent decades. Projections indicate that, under the A2 emissions scenario, mean annual temperatures in Ethiopia will increase by 0.7°C to 2.3°C in the near term, and up to 2.9°C by 2050 (Conway *et al.*, 2011).

These increasing temperatures, coupled with rapid urbanization and infrastructure growth in cities such as Addis Ababa and Shaggar, underscore the urgency of assessing the urban thermal environment. Although some studies have investigated the impacts of urban expansion on LST in Addis Ababa and Shaggar between 1994 and 2024 (Moisa *et al.*, 2025), they have not adequately explored the role of LULC changes in shaping UHI effects. Given this gap, there is a pressing need for comprehensive assessments that utilize geospatial technologies to quantify and analyze urban thermal dynamics. Therefore, this study aims to assess urban sprawl and its impacts on the urban thermal environment, specifically focusing on LST and UHI effects, using geospatial techniques in Addis Ababa and Shaggar Cities, Ethiopia.

1.3. Objectives of the Study

1.3.1. General objectives of the Study

The general objective of this study is to assess the extent of urban sprawl and its impact on the urban thermal environment in Addis Ababa and Shaggar Cities, Ethiopia.

1.3.2. Specific objectives of the Study

The specific objectives of this study are;

- To evaluate spatio-temporal of land use land cover change from 1995 to 2025 in the study area,
- To explore the land surface temperature variation of Addis Ababa city and Shaggar city over the study period,
- To examine correlation between LST and NDVI, NDBI and LULC types of the study area
- To investigate spatio-temporal variations UHI of Addis Ababa and Shaggar city

1.4. Research Questions

1. How much LULC types were changed from 1995 to 2025 in Addis Ababa and Shaggar city ?
2. How do LST vary in Addis Ababa and Shaggar city from 1995 to 2025?
3. What is the correlation between land surface temperature (LST) and normalized difference vegetation index (NDVI), NDBI and LULC types of the study area?
4. Is there UHI varies spatially and temporally in Addis Ababa and Shaggar city?

1.5. Scope of the Study

The UHI issue is the concern of every country in the world as a whole because, even though the geography is far apart; the atmosphere and the climate impact is common to all over the world. Geographically, This study was done in the local microclimate of Addis Ababa and Shaggar city. Methodologically, the study was conducted on Landsat images based analysis of the UHI of Addis Ababa and Shaggar city. The relationship between LST and NDVI and NDBI as well as LULC change was examined in order to calculate LST of the area as a function of LULC type and investigate the UHI effect. Finally, the study will create recommendations regarding UHI. a mitigation plan to ensure better air quality in the designated city.

1.6. Significance of The Study

This finding was used for urban planning to control urban sprawl due to informal settlement after evaluating the previous and current land used land cover types classification. In addition, analysis of thermal environment particularly land surface temperature and urban heat island were used for decision makers to mitigate urban climate by conservation vegetation cover in and around of the study area. Moreover, conservation of urban green spaces was used for improving cooling efficiency of urban microclimate and sustainable urban development in the study area.

1.7. Organization of The paper

There are five chapters in this thesis. The introduction and study the background were covered in the first chapter, which also elaborated on the broad concept of the current study as a global study topic. It also includes a problem statement and a description of the issues with the study's title, ranging from general to specific. Additionally, chapter one comprised the general purpose, specific objective, research question, significance of the investigation, and scope of the study. The literature review and other significant subjects pertaining to the study's issue are covered in Chapter 2. The materials and methods covered in Chapter 3 include a description of the study area, a description of the data sources, and an explanation of the data analysis approach. LULC classification, accuracy evaluation, LULC change detection, LST computation, and Landsat indices including NDVI, NDBI, and UHI were listed and explained under data analysis. The results of LULC changes, LST, and UHI, as well as the link between LST and NDVI and NDBI, are presented and discussed in Chapter 4. Chapter 5 concludes with a conclusion and a recommendation. The conclusion is based on the study's findings and is suggested for decision-making by appropriate bodies.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Urbanization

The term urbanization has been defined differently by many researchers. Qiao et al (2024) described the process of population concentration as urbanization. Urbanization is defined by demographers as limited elements like population density and size. Numerous variations in the Earth's surface temperatures have been brought about via urbanization. The heat balance is changed as a result of the concretization of rural and suburban areas and the conversion of agricultural and vegetation cover into urban areas. Cities and towns now feature unique microclimates due to changes in surface temperature patterns brought about by increased concretization and related changes in land use and cover (Singh, Grover, and Zhan, 2014). When it comes to its ecological effects, urbanization is generally a disruptive type of land alteration, and as the population and material needs increase, so does its impact (Patel and Raval, 2024). By 2035, 61% of people would reside in cities, according to the same prediction.

2.1.1. The trends of Urbanization in Ethiopia

Urbanization in Ethiopia has accelerated markedly over recent decades, despite the country's historically low level of urban development compared to other Sub-Saharan African nations. This rapid urban growth is driven by population increase, rural urban migration, administrative reclassification of settlements, and government-led infrastructure and industrial expansion (Kassa, 2014; UN-Habitat, 2020). Major cities such as Addis Ababa have expanded rapidly, while secondary and emerging cities, including Shaggar, are increasingly experiencing significant spatial growth. However, the pace of urban expansion has often outstripped the capacity of urban planning and governance systems, resulting in predominantly horizontal and unplanned development into peri-urban and rural areas (Ministry of Urban Development and Construction [MoUDC], 2015). This trend has led to substantial land use and land cover changes, characterized by the conversion of agricultural and green spaces into impervious surfaces, contributing to environmental degradation, rising

land surface temperatures, and the intensification of urban heat island effects in Ethiopian cities (Feyisa *et al.*, 2016; Moisa & Gemed, 2021; Vani & Prasad, 2020).

2.2. LULC changes in urban areas

Depending on Jianguo's analysis (2014), There is no single definition for the term "urban"; instead, many definitions place emphasis on various aspects of urban systems. High human densities, large impermeable surfaces, an abundance of built-up structures, and changed ecosystem services and functions are all characteristics that urban regions generally have in common. The term "land use change" describes how the dynamics of land use have changed over time. The characteristics that make up an urban area are characterized by urban land areas. These could include raw terrain, impermeable concrete or surfaces, green vegetation areas, built-up areas, and bodies of water. Prior research has unequivocally shown that rapid urban growth has the effect of reducing vegetated areas while increasing surface temperatures and altering the urban microclimate (Foietta, 2025).

Urban land-use and land-cover changes alter terrestrial, biological, physical, and climate. Changes in LULC, including the structure of populated areas, water bodies, and vegetation covers, correspond to the intensity of UHI. Urban processes, resulting in serious ecological and environmental issues (Gaur and Singh, 2023). The intensity of urban heat islands (UHI) is associated with changes in land use and land cover, including the types of developed areas, the presence of water bodies, and the extent of vegetation (Chen *et al.*, 2006). Research examining the connection between changes in land use and land cover and the urban heat island effect contributes to effective land use planning. Currently, approximately half of the global population resides in urban areas, a figure projected to increase to 70 percent by the year 2050. Cities and other urban areas are significant sources of greenhouse gas emissions. Up to 80% of the world's energy production is consumed in cities, which also contribute around the same amount of greenhouse gas emissions (World Bank, 2010).

2.3. Land Surface Temperature and Algorithms

The surface temperature that we can observe right away is called the LST. Unbalanced environmental conditions, such as ice melting, unexpected rainfall, and vegetation stress, are brought on by rising LST (Li *et al.*, 2023). An area's brightness temperature and land surface emissivity, which are computed using a Split Window Algorithm, can be used to determine its land surface temperature (Rajeshwari *et al.*, 2014).

The amount of vegetation present is a crucial feature for assessing LST, which is the foundation for employing vegetation indices like the NDVI. Research on the link between LST and NDVI revealed a significant positive association between them (Li *et al.*, 2023). Several factors, including the length of the day, season, wind, ocean currents, clouds, topography, location, rural surrounds, land use, building material, and city geometry, affect an urban area's surface temperature. However, replacing soil, water, and vegetation in metropolitan areas with impermeable concrete, metal, or asphalt has negative effects on the environment, such as decreased evapotranspiration, increased runoff, and elevated surface temperatures that result in UHI (Deng *et al.*, 2013).

The surface temperature of various land uses and covers varies seasonally (Li *et al.*, 2013). Seasonal variations in ground cover, weather, and solar intensity all affect the size of surface UHIs. Surface UHIs are usually highest in the summer due to this variance (Charabi and Bakhit, 2011) and High UHI in the winter has also been shown in several studies. LST which is defined as the skin temperature of the surface, is a measurement of how hot the land is at a specific location (Li *et al.*, 2023).

Furthermore, it operates from the spatially corrected Landsat Thermal Infrared (TIR) band 6 and Landsat 8 thermal infrared (TIR) bands 10, which are located in the thermal infrared region (Yu *et al.*, 2014). For LST recovery using remote sensing images, land surface emissivity (LSE) is crucial (Li *et al.* 2013). Researchers use a range of techniques to compute the emissivity values, even though LST is an essential variable to understand the impacts of urbanization-induced LULC changes. The NDVI is one technique for increasing land surface emissivity (Fu and Weng, 2016), as a result of its ability to methodically describe the city-scale thermal environment at a particular time (Guo *et al.*, 2016).

2.3.1. Mono-Window Algorithm

To calculate LST, mono-window algorithms use bright measurements in a single infrared window channel and account for atmospheric factors (Susskind *et al.*, 1984). As a result, single-channel techniques can be employed for multi-channel thermal sensors as well as sensors with a single infrared channel. For instance, mono window algorithm use to retrieve LST from thermal band (band 6) Landsat 5 and landsat 7. Moreover, from thermal band of landsat 8 (band 10) LST was calculated by using monowindow algorithm (Sobrino *et al.*, 2004)

2.4. Remote Sensing Indices

2.4.1. Normalized Defference Vegetation Index (NDVI)

To distinguish between non- vegetated and vegetated areas, the NDVI, a one band creation, is computed as a ratio of the Red (R) and near infrared (NIR) standards. The value ranges from -1 to 1, and it is driven from NIR and read infrared (USG, 2014). A higher NDVI value indicates the density and vitality of the plants. Because a high NDVI value suggests a low LST due to the latent heat flow from the surface to atmosphere via evapotranspiration, the LST of a given region is determined by the growth conditions of the vegetation. Generally speaking, regions with high NDVI have lower LSTs. (Li *et al.*, 2015). Several studies showed a negative correlation between the NDVI value and LST. According to research, green spaces or urban vegetation cover are necessary to preserve the urban climate, reduce the impact of urban heat islands (UHIs), and support the urban ecology (Al-Saad *et al.*, 2020).

2.4.2. Normalized Difference Built-up Index (NDBI)

By mapping the built-up changes, remote sensing time-series data will assist us in illustrating the evolution of urban growth over time (Fu *et al.*, 2019). The NDBI technique can be used to extract information on built-up land, and a value of (1) shows that built-up areas have a positive value. (Fu *et al.*, 2019 and Zhou *et al.*, 2014). The built-up area may be automatically extracted using the technique. Plant noise is frequently combined with the NDBI. As a result, blare is eliminated using NDVI.

2.4.3. Urban LST Characteristics

The built-up area may be automatically extracted using the technique. Plant noise is frequently combined with the NDBI. As a result, noise is eliminated using NDVI (Hu and Jia, 2010). The larger urban area, the greater the magnitude of climate change. LST quantities are influenced by different types of land cover.

The lowermost surface temperatures are found in water and vegetation, whereas the highest surface temperatures are found in urban areas like airports, neighborhoods, and factories (Feizizadeh and Blaschke, 2013 and Mallick *et al.*, 2013).

2.5. The Impact of Urban Heat Islands

The phenomenon known as an UHI happens when the air and surface temperatures in urban areas are noticeably higher than those in neighboring rural areas (Tony, 2012 and Sobrino *et al.*, 2012). The difference between the air temperature inside the city and the surrounding air temperature can also be used to identify Urban Heat Island (UHI) (Sobrino *et al.*, 2012). Due to urbanization, this phenomena is characterized by greater air temperatures in urban environments as opposed to nearby rural areas. It is caused by higher atmospheric and surface temperatures in metropolitan areas (Meng and Liu., 2013).

According to (Najah, F. T.,)The significant conversion of green spaces to built-up surfaces is one of the potential causes of UHI. By trapping incoming solar radiation during the day and reradiating it at night, the conversion of natural land cover, especially vegetated areas, to constructed surfaces enhances the LST and explains the UHI effect (Walsh *et al.*, 2011 and Sitiet *et al.*, 2013). Instead of releasing heat directly into the city, buildings, and infrastructure, anthropogenic sources including air conditioning, central heating systems, transportation, and industrial operations create surface unevenness, which contain lower wind speeds, convective heat loss, and evapotranspiration (Walsh *et al.*, 2011).

Irfeeyet *et al.*, (2023), Instead of releasing heat directly into the city, buildings, and infrastructure, anthropogenic sources including air conditioning, central heating systems, transportation, and industrial operations create surface roughness, which can lower wind speeds, convective heat loss, and evapotranspiration. change of land surfaces, with more

built-up surfaces and decreasing green and open spaces. In particular, impermeable surfaces and structures with dark colors (roads, parking lots, walls and roofs of buildings, and commercial and industrial spaces) are responsible for absorption of solar radiation (Radhiet *al.*, 2014).

When the air and surface temperatures in metropolitan areas are sophisticated than those in neighboring rural areas, this is an environmental condition (Shahmohamadiet *al.*, 2011). Cities around the world have seen this heat island phenomena. The climate, air quality, and land and land use types of Urban Heat island (UHI) affected cities are distinct from those of the surrounding natural and agricultural areas (Feyisa, 2013).

Anthropogenic activities that produce heat from various sources, including traffic, residential structures, industry, and densely populated mass buildings, exacerbate the UHI impact. As a result, the growing trend of UHI and its impact on various urban climatologies are highlighted studies (Yuan and Bauer, 2007). Land surface temperature and temperature of the air are also impacted by this temperature differential. Several research suggest that vegetation can help lessen the effects of UHI. The cooling effect of tree planting in urban areas is very strong; a study on the effectiveness of parks in reducing the impact of urban heat islands in Addis Abeba (Feyisaet *al.*, 2014) illustrated how a high tree canopy cover intensity has a greater cooling effect on the temperature of the daytime air.

2.6. Types of UHI

On the basis of its impacts, the UHI effect can be of two types: Surface UHI and Atmospheric UHI.

2.6.1. Surface-Urban Heat Islands

These conditions are brought on by the urban setup's open and dry surfaces absorbing heat from the sun. Therefore, the brightness of radiation from the sun, which varies seasonally and during the day, determines its magnitude. This explains why summertime, particularly during the day, has the highest levels of surface UHI. Summertime has high Surface UHI for another reason: because clear skies are more common during this time of year, solar radiation is not distributed.

Additionally, there are calm days with little wind, which reduces air mixing. more temporal and spatial variation, greater in intensity in the day, and present throughout daytime and nighttime. Daytime: 10–15°C; evening: 5–10°C Another common identifying technique is remote sensing, or indirect measurement.

2.6.2. Atmospheric Urban Heat Islands (UHI)

These phenomena occur when the air temperatures in rural and urban areas fluctuate. Most serious at night, but may be minimal or nonexistent during the day. Reduced variability Daytime temperatures range from 1 to 3°C; night time temperatures range from 7 to 12°C. Mobile traverses or stationary weather stations are used for identification.

2.7. Application of GIS and Remote Sensing for UHI

Geographic information System (GIS) and Remote sensing Technology are widely used in analyzing LST, classifying green spaces, determining the extent of green cover and processing of meteorological data to generate valuable information required for effective decision making (Balet *et al.*, 2004). The technique of determining and monitoring the physical attributes of an object, location, or event by analyzing data collected by a device without coming into touch with the object being explored and geographic data is known as remote sensing. system is a computer-based instrument used for gathering, organizing, managing, visualizing, analyzing, and interpreting data. It also aids in the comprehension of trends, patterns, and connections among various kinds of referenced data (Omiaet *et al.*, 2023). One of the most common remotely-sensed LST datasets for SUHI research is the Moderate-resolution Imaging Spectroradiometer (MODIS) global LST product (Peng, S.*et al.*, 2012).

CHAPTER THREE

3. MATERIALS AND METHODOLOGIES

3.1. Study area description

Addis Ababa and Shaggar Cities are located in the central part of Ethiopia, sharing a common region and administrative boundary, with Shaggar City encircling Addis Ababa. They are roughly located in between 8°37'00" N to 9°16'30" N and 38°30'00" E to 38°62'70" E (Figur 1). Addis Ababa, the capital city of Ethiopia, serves as the political, economic, and cultural hub of the nation. It is characterized by rapid urban growth, high population density, and extensive infrastructure development.

Surrounding Addis Ababa on all sides is Shaggar. Shaggar functions as a metropolitan administrative zone under the Oromia Regional State, and it encompasses various urban, peri-urban, and rural settlements. The cities have elevation that ranges from 1978 to 3380 meters above sea level and thus experiences a subtropical highland climate with relatively moderate temperatures throughout the year. Their population is 8817500 according to CSA projection (2024).

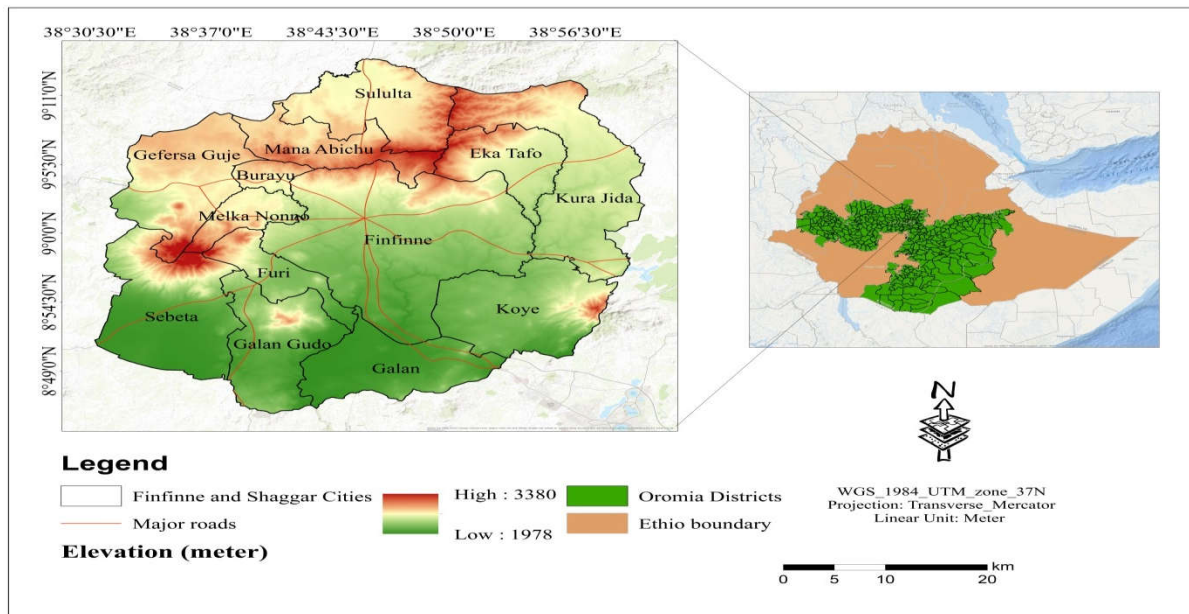


Figure 1: Locational Map of Addis Ababa and Shaggar Cities' with elevation variation (Etho-GIS, Oromia Spatial Planning Team, 2022).

Research Design

The study of urban LULC and change happening in Addis Ababa's and Shaggar's UHI use a variety of methodologies, including statistical methods and remote sensing, to describe the relationship between external temperatures and various land-use land cover (LULC) types and landsat indicators (Moisaet *al.*, 2025).

Quantitative method was employed to investigate the variation in LST and land use land cover change. With regard to the variance of LST in the city, zonal statistical data and other descriptive analysis techniques was used to conduct a thorough urban heat variation analysis utilizing both descriptive and numerical analysis methods.

3.2. Methodology

3.2.1. Data Source

For the study Landsat image of Thematic Mapper (TM); Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager/Thermal Infrared sensor (OLI/TIRS) of which obtained free of charge from USGS (<http://earthexplorer.usgs.gov/>) was used. All the images were taken with little cloud cover (<10%) in order to decide the seasonal susceptibility. Google Earth 1995,2010,2025 respectively was utilized to provide ground truth points (training sites) for LULC mapping in addition to field observations regarding urban land use categories.

A. Primary Data Sources

To define the types of land use and land cover and to take pictures of the research region, routine field observations were conducted.

B. Secondary Data Sources

The necessary information, such as NASA Landsat pictures from three separate years, was taken from secondary data sources, such as publications and STRM DEM. Additionally, nearly all of the research period was devoted to reviewing various pertinent published and unpublished literatures of relevant documents and associated studies of various areas. The table below provides a summary of all the data used in the study.

Table 1:Details of acquired and used satellite images

Satellite	Sensor	Acquisition year	Path and row	Spatial resolution
Landsat5	TM	January, 1995	168/54	30m/120m
Landsat7	ETM+	February, 2010	168/54	30m/60m
Landsat8-9	OLI/TIRS	January, 2025	168/54	30m/100m

3.2.2. Software used

For the achievement of this study purpose.different software required are stated below in Table 2 with their purpose.

Table 2:Software used for the study

No	Software's	Purpose
1	ArcGIS 10.3	Analyzing and visualization of spatial data
2	ERDAS 2015	For image classification and accuracy assessment
4	Google earth pro	Use as a base map in visual image interpretation, and generate coordinate points for each image for LULC accuracy assessment

3.3. Method of Data Analysis

The study employed three main analytical approaches to assess urban sprawl and its thermal impacts. First, Land Surface Temperature (LST) estimation in this study was performed using Landsat satellite imagery, which provides thermal and reflective spectral bands suitable for analyzing urban thermal patterns. For Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+), Band 6 (10.4–12.5 μm) was used to extract thermal radiance. For Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS), Band 10 (10.6–11.19 μm) was used due to its improved calibration and reliability for thermal analysis.. Second, land use and land cover (LULC) classification was performed to evaluate urban expansion and associated land cover changes. Third, zonal statistical analysis was applied to examine the relationships between LST, the Normalized

Difference Vegetation Index (NDVI), and the Normalized Difference Built-up Index (NDBI). Finally, the urban heat island (UHI) effect was assessed by comparing LST variations across land cover types and urban rural zones, with the overall analytical workflow summarized in the schematic flowchart (Figure 2).

3.3.1. Image Pre Processing

Image preprocessing which comprises, image enhancement, band combination and false color combination was applied to the images. Thermal band (Band 6 for TM and ETM+ sensor and Band 10 for OLI/TIRS sensor) was allocated to obtain LST.

Layer stacking: A common use of Layer Stacking is combining different band groups from a Landsat data into one file. The input and output bands will be extracted to the study area.

3.4.2. Image Classification

The process of obtaining multiband information classes raster image or information based on an object's reflectance is known as image classification in remote sensing. This process serves a specific purpose, which is to turn image data into thematic data. It is feasible to organize similar pixels into classes that correspond to the informational categories that users of remotely sensed (RS) data are interested in. These classes create areas on a picture or map (You *et al.*, 2022; Moisa *et al.*, 2023).

Based on the spectral characteristics of features in the images, six LULC classes were identified: Agriculture land, Bare Land, Built Up area, Forest Land, Grassland, Water body. These LULC kinds were chosen based on the local thermal parameters. Using the maximum likelihood technique, sample data from Google Earth was created, along with a visual representation of the classification of the chosen land use/land cover category. ArcGIS 10.3 was used to create land use/land cover polygons in order to extract and reclassify the urban land use and land cover types of the region. ERDAS Imagine version 2015 software is used for classification.

3.4.3. Accuracy Assessment

One of the most important last steps in the classification process is accuracy assessment. Accuracy assessment aims to quantitatively evaluate how well the pixels are sampled into the

proper land cover groups (Sophia *et al.*, 2017). In essence, accuracy is a measure of the proportion of correctly categorized ground truth pixels. When examining the land cover map, it's critical to keep in mind that no map accurately depicts the world. It is crucial to remember that the map was most accurate when looking at geographic trends across broader regions. Based on the average of the accuracies for each class on the map, the accuracy assessment's outcome gives the map's overall accuracy (Lyons *et al.*, 2018). A total of 120 Ground Control Points (GCPs) were collected for the six LULC classes to ensure sufficient and representative samples for supervised classification and accuracy assessment. This provides an average of 20 points per class, which is within the recommended range (15–30 samples per class) to improve classification reliability, reduce bias, and enhance statistical confidence in the result

$$(OA\%) = \frac{SCC}{TS} \times 100 \text{Eq (1)}$$

Where: **OA** is overall accuracy,

SCC is sum of correctly classified, and **TS** is total sample.

The accuracy of classification was carried out by means of overlaying of the classified maps and the test samples.

$$UAC = \frac{X_{ii}}{X_{+i}} \times 100 \text{.....Eq (2)}$$

$$PAC = \frac{X_{ii}}{X_{i+}} \times 100 \text{.....Eq (3)}$$

Where: UAC is user accuracy, PAC is producer accuracy, X_{ij} is the diagonal values, X_{i+} is the column total, and X_{+i} is row total, r is the number of categories,

3.4.4.LULC Change Detection

To determine the quantitative characteristics of land use and land cover (LULC) changes between 1995 and 2025, cross-tabulation was employed to compare classified image pairs from different time periods. This method produced a change matrix, from which quantitative area statistics were derived, including the total changes in each LULC category as well as the increases and decreases over the study period, following the approach of Pal and Ziaul (2017). Additionally, the trend of change (Hailuet *al.*, 2020) and the percentage of

conversion (Abate, 2011) were calculated to quantify the magnitude of transitions among different land cover classes, using Equations (4) and (5), respectively.

$$\text{Trend of change} = X - Y \dots\dots\dots \text{Eq (4)}$$

$$\text{Rate of change (km}^2\text{/year)} = \left(\frac{X-Y}{Z}\right) \dots\dots\dots \text{Eq (5)}$$

where, X is an area of LULC (km²) in time 2, is an area of LULC (km²) in time 1 Z is time interval between X and Y in years

3.4.5. Landsat 5, 7, and 8 (TM, ETM+, and OLI/TIRS) image estimation for LST

Due to low rates of evapotranspiration, high levels of near-surface energy output, and solar radiation absorption by ground objects, the UHI effect shows that the air and Land Surface Temperature (LST) in urban areas are greater than those in the neighboring rural regions (Irfeey *et al.*, 2023). The Land Surface Temperature values were computed using the Landsat thermal images band 6 for Landsat 5 TM and 7 ETM+ and band 10 for Landsat 8 OLI/TIRS Satellites in order to investigate the UHI influence of the research area (Zhao *et al.*, 2020).

The conversion of digital numbers into radiance is the first step; the brightness temperature is calculated in the second step; the +NDVI is calculated in the third step; the land surface emissivity is estimated from the NDVI values obtained in the fourth step; and the corrected surface temperature is calculated in the fifth step after the emissivity is estimated. The corrected surface temperature is then converted into the urban heat island in the sixth step, as recommended by (Isaya *et al.*, 2016).

I. Conversion of Digital Numbers (DN) to Radiance

Digital Numbers (DN) are used to record the thermal data from Landsat sensors in satellite photography. Pixels that have not yet been calibrated are represented by digital digits. They serve as a representation of the raster image's various brightness levels. Converting digital numbers into radiance was the initial step after acquiring the satellite photos. The formula used to translate DN into the spectrum radiance of the Landsat 5, 7, and 8 image TM/TIRS sensor is displayed in equation (6).

$$L\lambda = ML \times Qcal + A - Oi \dots\dots\dots Eq (6)$$

Where: $L\lambda$ is the spectral radiance in $W/(m^2 \times sr \times \mu m)$ at the top of the atmosphere, **ML** is the band-specific multiplicative rescaling factor from the metadata (radiance mult band 6 and 10), **Qcal** is the quantized and calibrated standard product pixel values (DN), **AL** is the band specific additive rescaling factor from the metadata (radiance add band 6 and 10), **Oi** is the corrections published by USGS for calibration of the TM/TIRS bands.

II. Computation of Brightness Temperature (BT)

Thermal infrared data can be converted from atmosphere reflectance ($L\lambda$) to effective sensor brightness temperature (TB) using thermal constants provided in the Meta data file. Remote sensing data (Landsat imagery) thermal band that is band 6 on thematic mapper and enhanced thematic mapper plus and OLI/TIRS band 10 needs to be converted from at sensor spectral radiance to effectiveat sensor brightness temperature. $L\lambda$ (spectral radiance) covert to brightness temperature (TB) based on the following equation(Li *et al.*, 2023).The brightness temperature is calculated by Equation (7)

$$BT = \frac{K2}{\ln(K1|L\lambda + 1)} \dots\dots\dots Eq (7)$$

Where: BT is the brightness temperature in (K), $L\lambda$ is the spectral radiance at the top of the atmosphere, K1 and K2 is a specific constant for conversion into the thermal band.

III. Calculation of NDVI

The NDVI is used to differentiate between vegetated and non-vegetated areas based on the difference between reflectance measurements in the near-infrared (NIR) and red portions of the spectrum (USGS, 2014). The NDVI value ranges from -1 to 1, where a negative value indicates the absence of green vegetation in a particular area and a positive value indicates the vegetated surface reflectance of the area. The higher NDVI value is caused by a relatively higher reflectance value in the NIR and lower in the red band (Tomaret *al.*, 2013). As a potential basis function. The Normalized Difference Vegetation Index (NDVI) is given by Equation (8).

$$\text{NDVI} = \left(\frac{\text{NIR} - \text{R}}{\text{NIR} + \text{R}} \right) \dots\dots\dots \text{Eq (8)}$$

Where: NDVI is the Normalized Difference Vegetation Index, NIR is the near infrared band and R is the red band.

IV. Determination of Land Surface Emissivity (LSE)

The normalized difference vegetation index is used to estimate emissivity using the Land Surface Emissivity (LSE) technique (Rozenstein, 2014). Since, land-surface emissivity is estimated from the NDVI values, the proportion of vegetation (PV) was calculated by using the NDVI method Equation (9).

$$\text{Pv} = \left\{ \frac{\text{NDVI} - \text{NDVI}_{\min}}{\text{NDVI}_{\max} - \text{NDVI}_{\min}} \right\} 2 \dots\dots\dots \text{Eq (9)}$$

where: Pv is represents the amount of vegetation, $\text{NDVI}_{\min}$ is represents the minimum values of the NDVI, and $\text{NDVI}_{\max}$ represents the maximum value of the NDVI. Land surface emissivity (ϵ) is computed by using Equation (10).

$$= 0.004 \text{ Pv} + 0.986 \dots\dots\dots \text{Eq (10)}$$

where; ϵ is emissivity and pv is vegetation proportion

V. Correction of Land Surface Temperature

Brightness temperature correction was carried out following the estimation of the soil surface emissivity. Planck's function was applied for this. Planck's function is displayed in equation (11) (Sinha, 2014). This function adjusts a surface's emissivity relative to a black body.

$$\text{LST}(\text{°C}) = \frac{\text{BT}}{\left\{ 1 + \left(\frac{\lambda \times \text{BT}}{\rho} \right) \ln \epsilon \right\}} \quad 273.15 \dots\dots\dots \text{Eq. (11)}$$

Where: LST is the surface temperature (K), BT is the brightness temperature (K), λ is the wavelength of the emitted radiation, ρ is $(h \times c \div \sigma) = 1.438 \times 10^2 \text{ mK}$: h is Planck's constant ($6.26 \times 10^{-34} \text{ Js}$), c is the velocity of light ($2.998 \times 10^8 \text{ m/s}$) and σ is Stefan Boltzmann's constant ($1.38 \times 10^{-23} \text{ J-K}^{-1}$) and ϵ is the surface emissivity.

Le is the vegetation emissivity from (Eq.7) (Jeevalakshmi *et al.* 2017). Lastly, the computed LST values (Kelvin) is changed to degrees Celsius ($^{\circ}\text{C}$).

VI. Transformation of LST into the UHI

It is inappropriate to compare several data images from different years because to seasonal change and variable atmospheric conditions within the same period among years. Thus, the following equation was used as a normalization method to compare UHI from various dates. Equation (12) as suggested by (Abutaleb *et al.*, 2015):

$$\text{UHI} = \frac{\text{Ts} - \text{Tm}}{\text{SD}} \dots \text{Eq. (12)}$$

Where: **Ts** is the land surface temperature, **Tm** is the mean of the land surface temperature of the study area, and **SD** is the standard deviation.

3.4.6. Normalized Difference Builtup Index (NDBI)

By mapping the built-up changes over time, remote sensing time-sensitive data will enable us to demonstrate urban development (Fu *et al.*, 2019). According to Zhou *et al.* (2014), the built-up land information can be recovered using the NDBI technique, and the built-up areas have a positive value of 1. An automated method for extracting the built-up area is the algorithm. The employed formula Equation (13) (Fu *et al.*, 2019) is:

$$\text{NDBI} = L\lambda \left(\frac{\text{MIR} - \text{NIR}}{\text{MIR} + \text{NIR}} \right) \dots \text{Eq. (13)}$$

Where: NDBI is Normalized Difference Built-up Index, MIR is refers is Mid-Infrared and NIR is refers to Near-Infrared.

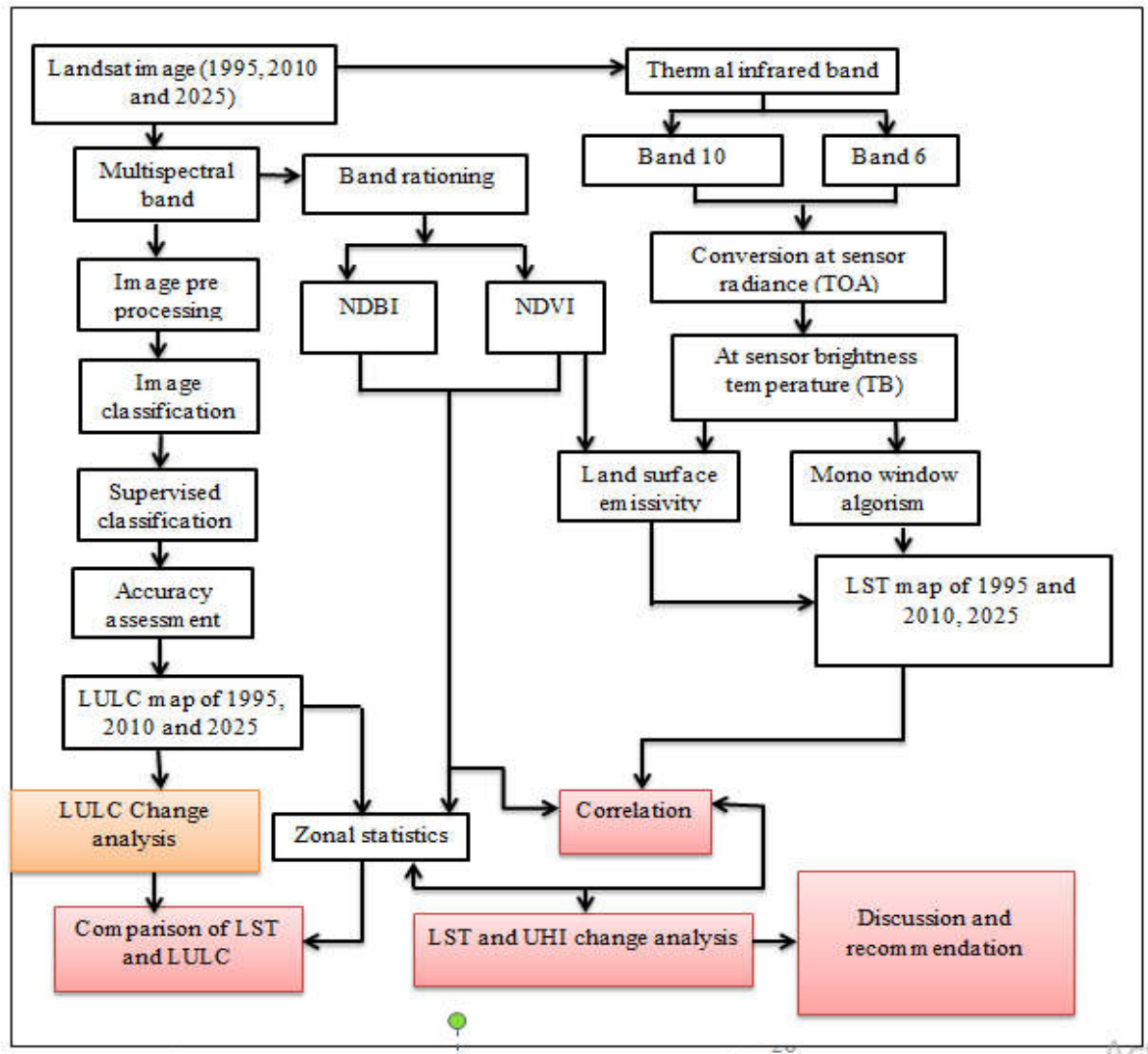


Figure 2: Methodological flow diagram

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Evaluation of Land Use Land Cover Change of Addis Ababa and Shaggar cities

4.1.1. Derivation of the LULC Classes

The Land Use/Land Cover (LULC) classes of the study area were derived by analyzing spatial datasets from the years 1995, 2010, and a projected scenario for 2025. The categorization includes six distinct LULC types: agricultural land, bare land, built-up area, forest land, grassland, and water body (table 3 and Figure 3).

Table 3: LULC types from 1995 to 2025

LULC Types	1995		2010		2025	
	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)
Agricultural land	1561.3	76.6	1494.3	73.3	674.6	33.1
Bare land	58.0	2.8	62.3	3.1	115.0	5.6
Built up area	97.1	4.8	105.6	5.2	615.4	30.2
Forest land	201.5	9.9	178.3	8.7	98.2	4.8
Grassland	115.2	5.7	193.5	9.5	530.1	26.0
Water body	5.4	0.3	4.5	0.2	5.2	0.3
Total	2038.5	100.0	2038.5	100.0	2038.5	100.0

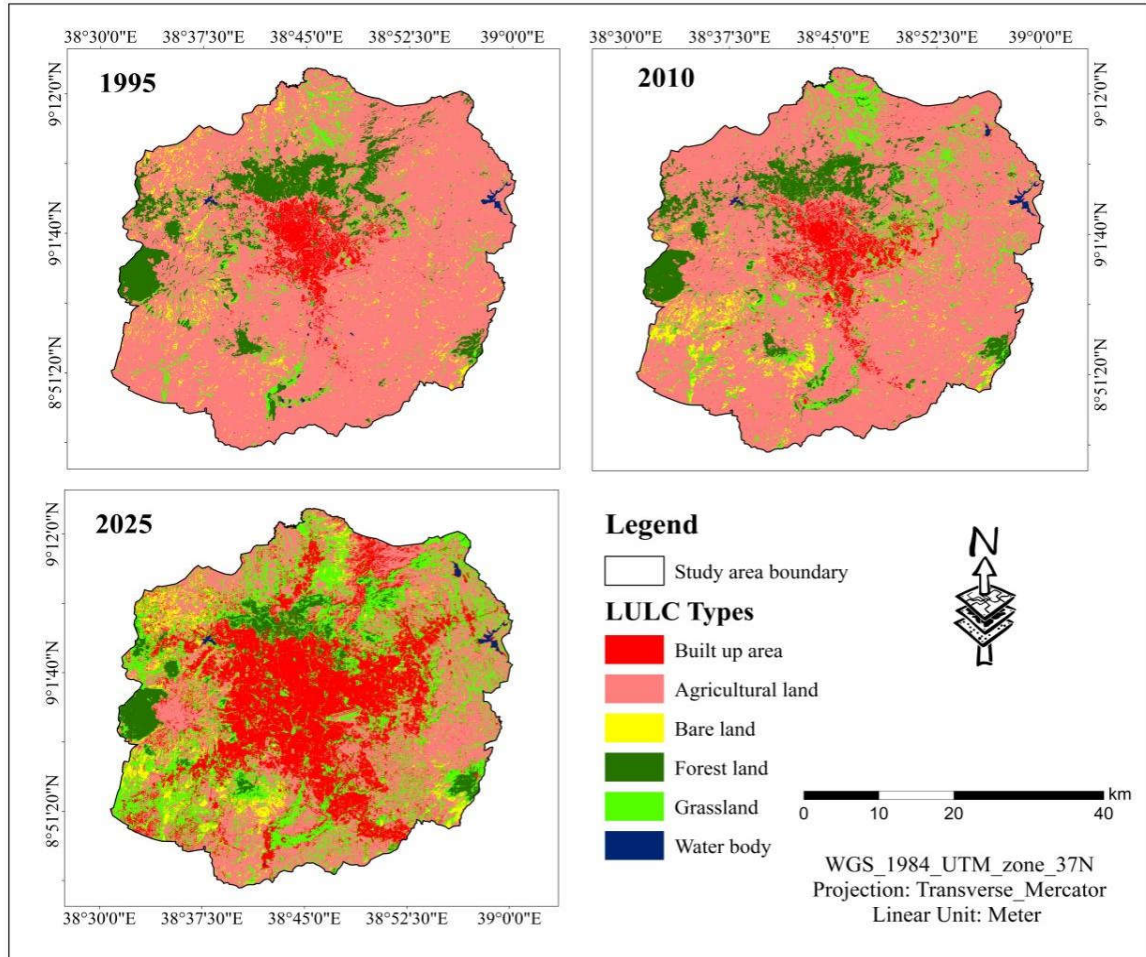


Figure 3:LU/LC types of the study area

4.1.2. Accuracy Assessment

The land use land - cover (LULC) classification accuracy assessment of 1995, 2010 and 2025 of Addis Ababa and Shaggar city was assessed. Overall accuracy and kappa coefficient were calculated to confirming the reliability of the classification process. The result revealed that, the overall accuracy of 1995, 2010 and 2025 were 97.3%, 95.8% and 96.7% respectively indicating that the classification methods employed are robust and effective in distinguishing between different land cover types over time. In addition, kappa coefficient result of the study area was 0.95, 0.94 and 0.95 in 1995, 2010 and 2025, respectively (Table 3). Similarly, the Kappa coefficient, which measures the agreement between classified and reference data beyond chance, remains high across all years, fluctuating slightly between 0.94 and 0.95. This strong agreement further underscores the reliability of the classification (Vermaet *al.*, 2020).

Table 4: Accuracy Assessment

Year	1995	2010	2025
Overall accuracy (%)	97.3	95.8	96.7
Kappa Coefficient	0.95	0.94	0.95

4.1.3. Magnitude of LULC change

The LULC change analysis of the study area was evaluated from 1995 to 2025. The results revealed that, the built up area was 97.1km² (4.8%) in 1995, 105.6km²(5.2%) in 2010 and 615.4km²(30.2%) in 2025 in Addis Ababa city and Shaggar city. The findings indicate that rapid population expansion in the research area caused an increase in built-up area over the study period. However, agricultural land was dramatically decreased from 1561.3km² (76.6%) in 1995 1494.3km² (73.3%) in 2010 and 674.6km² (33.1%) in 2025. The indicated that, built up area was expanded on agricultural land from 1995 to 2025. In addition, forest land was decreased by 5.1% over the study period due to expansion of impervious surface in the study area (Table 4; Figure 3).The expansion of bare land in Addis Ababa and Shagar City represents transitional cleared surfaces created by rapid urban sprawl, infrastructure development, and farmland conversion prior to permanent construction. The result of this study was inline with Moisa and Gemed (2021) conducted in Addis Ababa city and built up area was increased with 15.8%, however, agricultural land was decreased with 15.3% from 1990 to 2020. The findings concluded that, agricultural land was shrinked because Addis Ababa's built-up area increased between 1990 and 2020.

4.1.4. Trends of LULC change

Between 1995 and 2025, the study area experienced substantial land use and land cover (LULC) transformations, primarily driven by rapid urbanization, agricultural land conversion, and infrastructural expansion. Built-up areas increased by 518.3 km², reflecting accelerated urban growth at both regional and global scales (Figure 4). Similar patterns have been documented in major Ethiopian cities such as Addis Ababa, Jimma, and Bahir Dar, where urban sprawl is closely linked to population growth and economic expansion (Amareet *et al.*, 2023). Concurrently, agricultural land declined by 886.7 km², largely due to its conversion into urban and peri-urban land uses. Although the rate of agricultural land loss

slowed in the later years of the study period, this may indicate land saturation or a gradual transition toward more regulated and sustainable urban development (Assefa *et al.*, 2022).

Forest cover also declined sharply as urban expansion intensified, leading to significant environmental degradation. The loss of forest land has severe ecological consequences, including biodiversity decline, rising land surface temperatures (LST), and increased carbon emissions. In addition, grasslands and wetlands were substantially reduced, mainly due to their conversion into built-up and bare land classes. Wetland loss is particularly critical, as previous studies have linked it to ecosystem degradation, reduced water regulation capacity, and increased flood risks (Woldeet *et al.*, 2023). Similar land conversion trends have been observed in Ethiopia, where agricultural and wetland ecosystems have increasingly been replaced by urban land uses (Haile *et al.*, 2023).

These findings emphasize the urgent need for sustainable land management strategies to reduce the adverse impacts of uncontrolled urban expansion and ecosystem degradation. Integrated land-use planning, reforestation programs, and environmentally sustainable urban development are essential for restoring ecological balance and strengthening long-term environmental resilience. Liniger *et al.* (2021) stress that coordinated land-use policies are fundamental for maintaining ecosystem services while supporting socio-economic development.

The results of this study are consistent with findings from regions with similar ecological and climatic conditions, such as the highlands of Kenya and northern Tanzania, where rapid LULC changes have caused significant vegetation loss and increased surface temperatures (Maina *et al.*, 2020). While urbanization and agricultural land conversion remain the primary drivers of LULC change and rising LST, this study advances existing research by integrating long-term NDVI and LST trends with spatially detailed land-use patterns, offering a more comprehensive interpretation of ecological degradation processes.

The study also contributes to global sustainability frameworks, particularly the Sustainable Development Goals (SDGs), including SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action). By identifying areas undergoing critical environmental change, the findings provide a scientific basis for evidence-based planning, climate adaptation

strategies, and sustainable land management initiatives (UN, 2015). Moreover, LULC dynamics directly influence several SDGs: while the expansion of built-up areas at the expense of vegetation negatively affects local climate regulation and biodiversity, reforestation and sustainable agricultural practices can enhance ecosystem health and climate mitigation. As noted by Halder et al. (2024), LULC change plays a significant role in determining progress toward climate and sustainability targets.

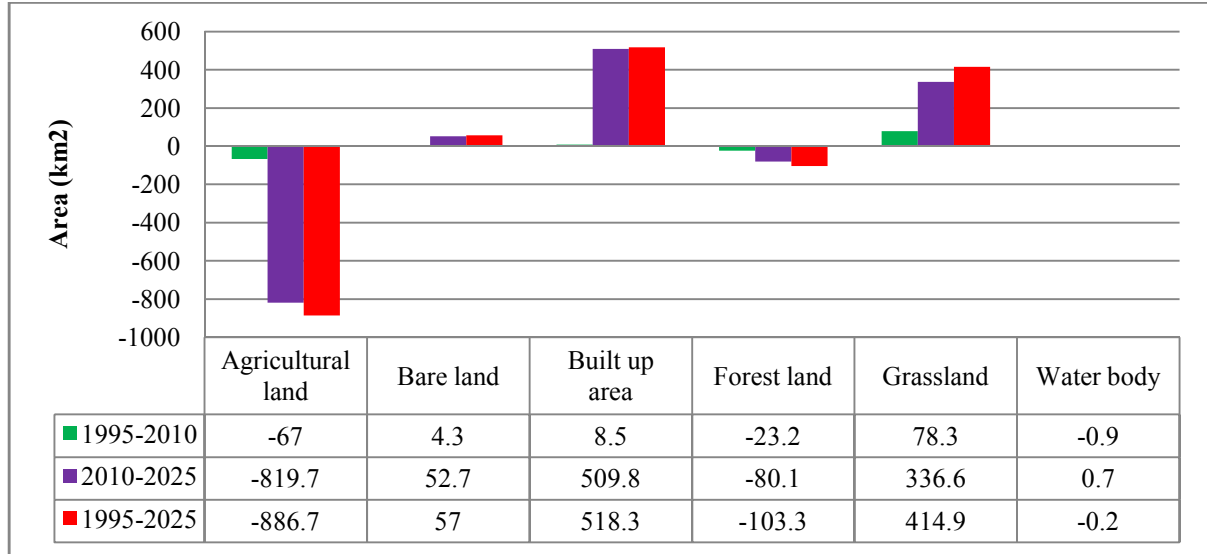


Figure 4: Trends of LULC change

4.1.5. Rate of LULC change

The analysis of the rate of LULC changes from 1995 to 2025 reveals significant transformations in land cover dynamics. Bare land increased steadily at a rate of 1.9 km²/year across all periods, suggesting gradual land degradation or conversion, in line with broader environmental change patterns (Turner *et al.*, 2013). Built up areas expanded notably, with the rate accelerating from 0.57 km²/year between 1995 and 2010 to 33.99 km²/year from 2010 to 2025, and, resulting in an overall increase of 17.28 km²/year. This reflects a global trend of accelerating urban expansion as cities grow (Seto *et al.*, 2012; Huang *et al.*, 2015). Agricultural land saw a significant decrease, with rates ranging from 4.47 km²/year (1995-2010) to 54.65 km²/year (2010-2025), and averaging 29.56 km²/year (1995-2025). This decline is consistent with urbanization driven by rising built up area (Foley *et al.*, 2011; Lambinet *et al.*, 2014). In contrast, forest land decreased from 1.55 km²/year between 1995 and

2010 to 5.34 km²/year from 2010 to 2025, and with an overall average decrease of -3.44 km²/year, highlighting significant deforestation linked to urban expansion (Achard *et al.*, 2014). Grasslands increased significantly, with rates of 5.22 km²/year (1995-2010) and 22.44 km²/year (2010-2025), and resulting in an average rate of 13.83 km²/year, reflecting initiative of Ethiopian corridor construction in the study area (Table 6).

Table 5: Rate of LULC change

LULC Types	1995-2010	2010-2025	1995-2025
	km ² /year	km ² /year	km ² /year
Agricultural land	-4.47	-54.65	-29.56
Bare land	0.29	3.51	1.90
Built up area	0.57	33.99	17.28
Forest land	-1.55	-5.34	-3.44
Grassland	5.22	22.44	13.83
Water body	-0.06	0.05	-0.01

4.1.6. LULC conversion Matrix

The LU/LC transition analysis between 1995 and 2025 highlights significant shifts across various land types. The results show that, agricultural land was changed to built up area with 450.4km². In addition, forest Land and grassland were converted to built up area with 32.6km² and 24.5km² from 1995 to 2025, respectively. This change underscoring the growing pressure of urbanization on agricultural and natural ecosystems. Agricultural land has also shows a notable decline, largely absorbed by impervious surface over the study period (Table 6; Figure 5).

These transitions align with findings from other studies on LULC changes, especially in rapidly urbanizing regions like Ethiopia. Studies by (Belayneh *et al.*, 2021) and (Ma *et al.*, 2020) indicates a similar patterns, by which sprawl leads to the conversion of grasslands and forests into residential and infrastructural developments. The decline in forest land and wetlands is of particular concern, as these ecosystems provide vital services for biodiversity conservation and carbon sequestration (Shiferew *et al.*, 2023) highlighted that significant loss of forest lands due to deforestation and land degradation for urban expansion. The study

reflects broader trends of urban expansion, and ecosystem degradation, challenges that are prevalent in many developing regions. These results emphasize the need for sustainable land management policies to mitigate the adverse effects of LULC changes, such as deforestation, land degradation, and the loss of wetlands. Sustainable planning and conservation efforts can help balance the demand for urban growth while preserving vital ecosystems.

Table 6: LULC conversion matrix from 1995 to 2025

		2025						
LULC Types (km2)	Agricultur al land	Bare land	Built up area	Forest land	Grassla nd	Water body	Total	
1995	Agricultural land	641.9	82.9	450.4	9.7	383.1	1.4	1569.4
	Bare land	17.5	17.1	14.3	0.0	10.0	0.0	59.0
	Built up area	0.0	0.0	85.0	0.0	2.5	0.0	87.5
	Forest land	10.4	2.1	32.6	89.5	68.5	0.0	203.2
	Grassland	13.5	11.7	24.5	2.8	61.5	0.0	113.9
	Water body	0.3	0.0	0.6	0.0	0.8	4.0	5.6
	Total	683.5	113.9	607.4	102.1	526.3	5.4	2038.5

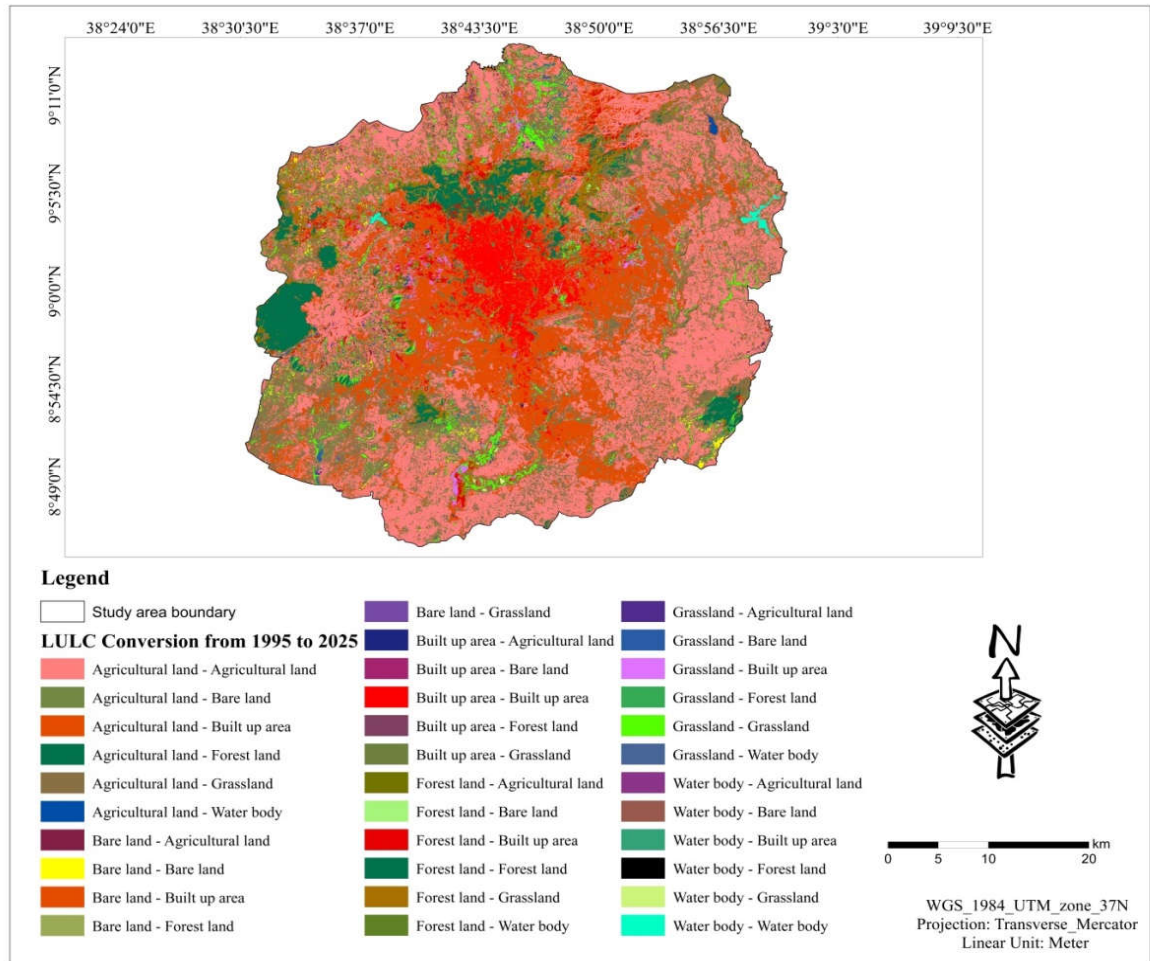


Figure 5:LU/LC conversion of the study area

4.1.7. Urban Expansion of Addis Ababa and Shaggar Cities from 1995 to 2025

Urban expansion of The research area was assessed using LULC types of the study area from 1995 to 2025. The result revealed that, built up area in the 1995 was dominated in central particularly Finfinne city and expanded to all Shaggar sub cities like Burayu, GefersaGuje, ManaAbichu, EkaTafo, Koye, Sebeta, MelkaNonno, Furi, Galan, Sululta and Kura Jida in 2025 (Figure 6).

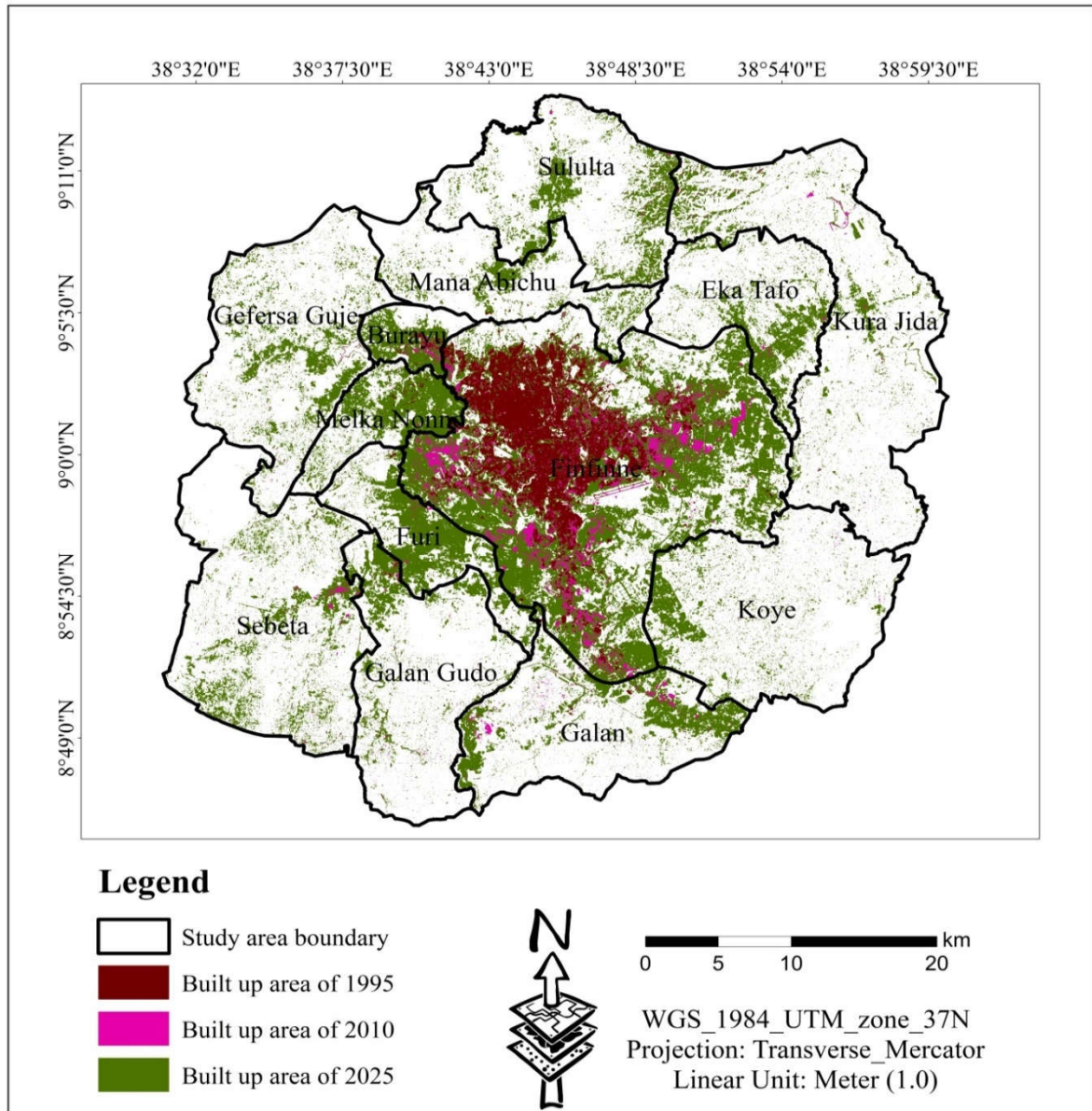


Figure 6:Urban expansion from 1995 to 2025

4.2. LST variation of Addis Ababa and Shaggar city city

The LST from 1995 to 2025 demonstrates a significant warming trend. The concentrated LST has increased from 33.5°C in 1995 to 43.6°C in 2025, indicating an increment by 10.1°C over the past 30-years. Similarly, the mean LST has risen from 26°C in 1995 to 33.9°C in 2025, indicating an overall warming of 7.9°C. The minimum LST has also shown an upward trend, moving from 18.4°C in 1995 to 24.2°C in 2025, reflecting a 5.8°C increase (Table 7; Figure 7). These changes suggest a significant shift in the climate, with increasing

surface temperatures likely linked to global climate change, urbanization, and other environmental factors. Ecosystems, agriculture, water supplies, and human health are all negatively impacted by these rising temperatures, making adaptive measures necessary to lessen possible effects.

Furthermore, the seasonal variations in LST reveals notable differences between dry and wet seasons, which are closely associated with seasonal precipitation patterns and ambient temperature fluctuations. During the dry season, LST values tend to rise significantly due to low soil moisture, reduced vegetative cover, and minimal evapotranspiration, leading to greater absorption of solar radiation by bare land and impervious surfaces (Li *et al.*, 2013; Zhou *et al.*, 2016). In contrast, the wet season typically shows lower LST values, as increased rainfall enhances soil moisture and vegetation density, thereby promoting evapotranspiration and providing a cooling effect (Zhang *et al.*, 2019).

Vegetation plays a buffering role, particularly in forested areas where canopy cover moderates surface temperatures throughout the year, while urban and agricultural areas display greater LST variability due to reduced natural cover and altered surface properties. These seasonal dynamics underscore the impact of climatic reasons on surface temperature and highlight the importance of vegetation in mitigating heat extremes. Understanding the interaction between LST, seasonal climate patterns, and land cover is essential for developing adaptive land-use strategies and managing climate-induced thermal stress (Sobrino *et al.*, 2012).

Table 7: LST from 1995 to 2025

LST (°C)	1995	2010	2025
Maximum	33.5	36.7	43.6
Mean	26	28.5	33.9
Minimum	18.4	20.4	24.2

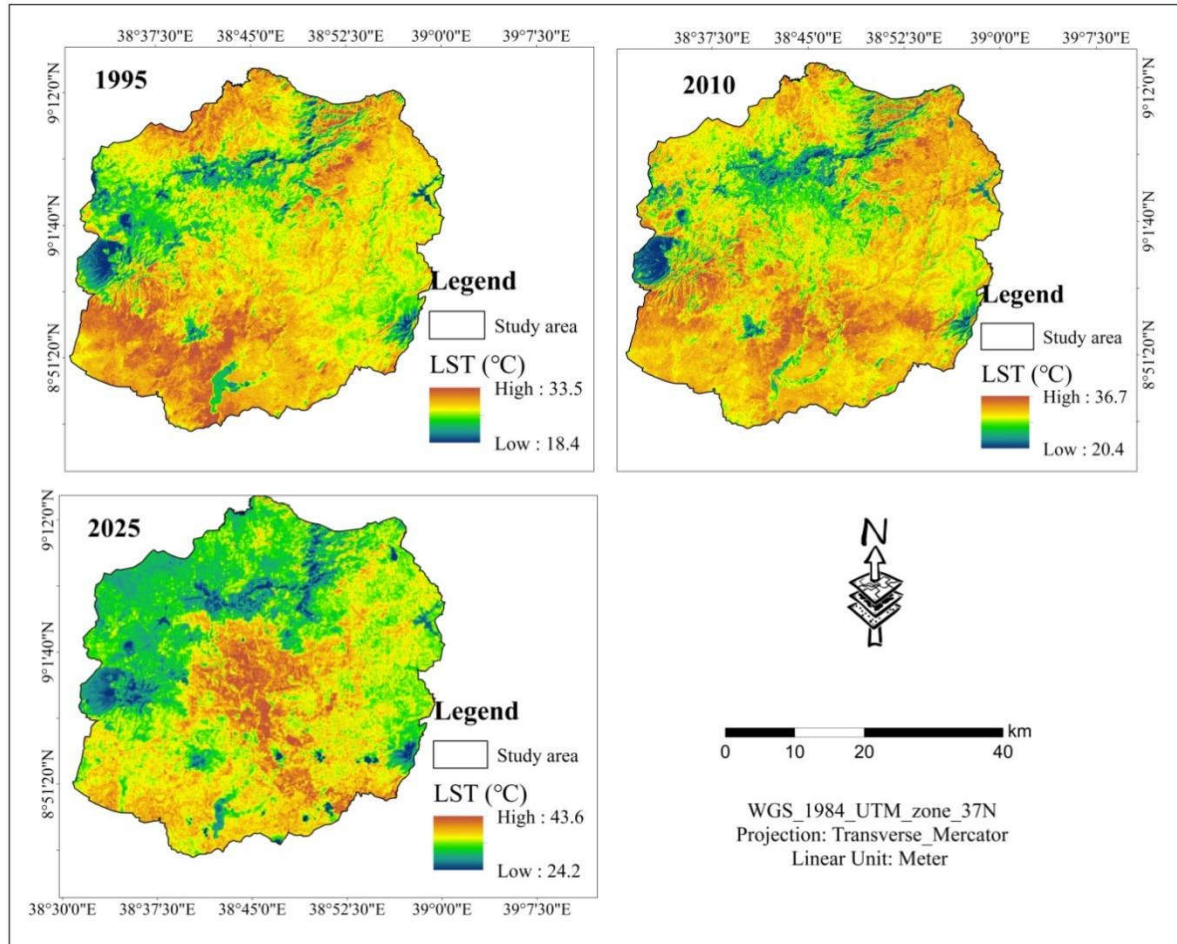


Figure 7: LST of the study area

4.3. Analyze the relationship between LST and the research area's NDVI, NDBI, and LULC types.

4.3.1. Normalized difference vegetation index

Normalized difference vegetation index (NDVI) was used to measure vegetation cover abundance in the study area. Changes in LULC are significant drivers of climate change in general, and LST in particular (Moisa and Gemed, 2022). The results show that NDVI values in Addis Ababa City decreased from 0.69 in 1995 to 0.58 in 2010, and further to 0.54 in 2025. Significant areas of vegetation were replaced by built-up areas due to high demand for housing construction in Addis Ababa and Shaggar city. Spatially, central parts of the study area shows low vegetation cover due to dominated by built up area. However, western and northern parts of the study area captured with high vegetation cover and low built up density (Figure 8). As the result, an area covered with little vegetation cover has high land

surface temperature and high urban heat island, whereas, area dominated with high vegetation cover has low LST and low urban heat island and comfortable in the study area.

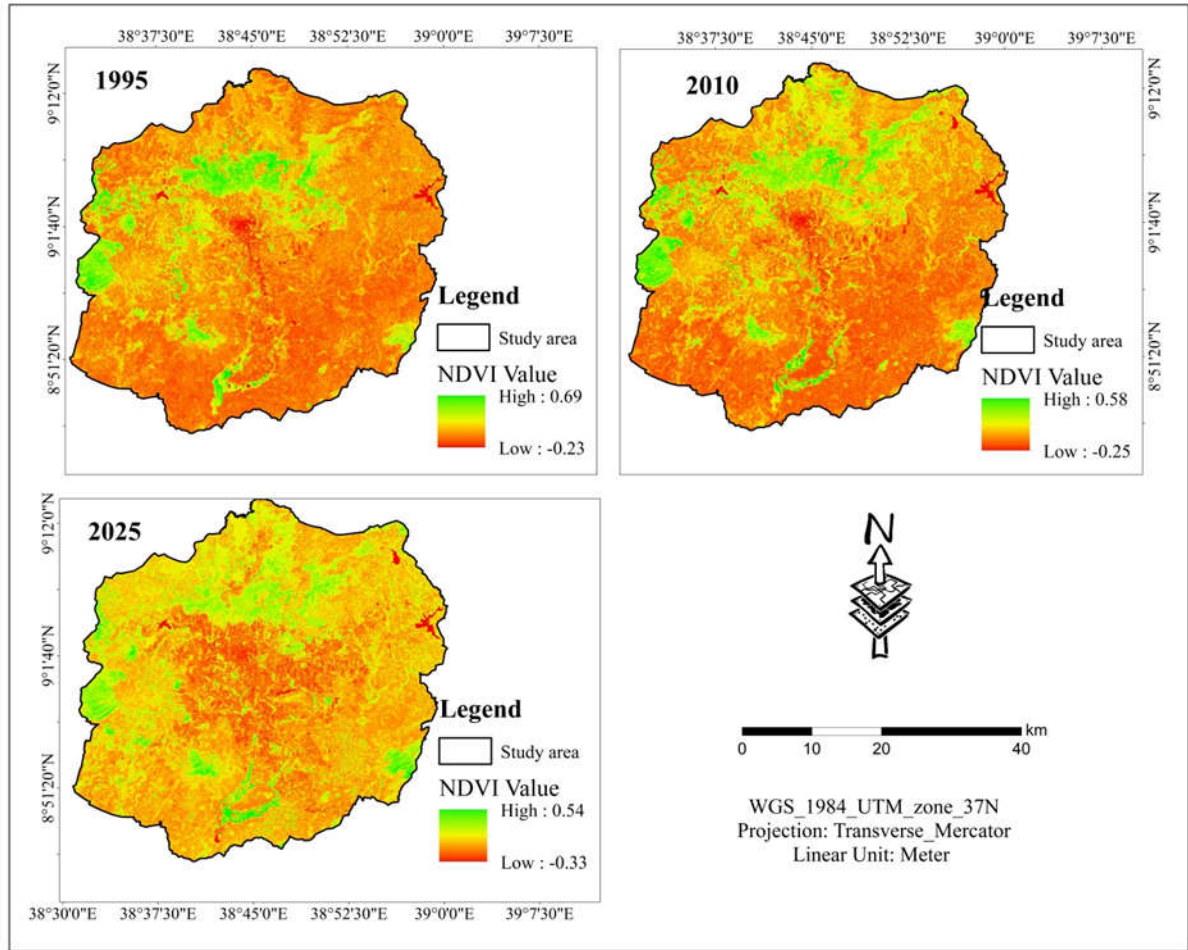


Figure 8:NDVI map of the study area between 1995 and 2025

4.3.2. Normalized difference built up index

The analysis of the NDBI for Addis Ababa and shaggar cities reveals notable trends in The effects of urbanization on LST. The NDBI values increased from 0.38 in 1995 to 0.51 in 2010, and further to 0.65 in 2025 (Figure 9). This progression reflects a substantial rise in built-up areas over time, indicating significant urban growth (He *et al.*, 2018). Geographically, the central parts of the study area dominated by high built up area with high LST and high urba heat island and the peripheral parts of the study area captured with low built up area with low LST and how urban heat island.

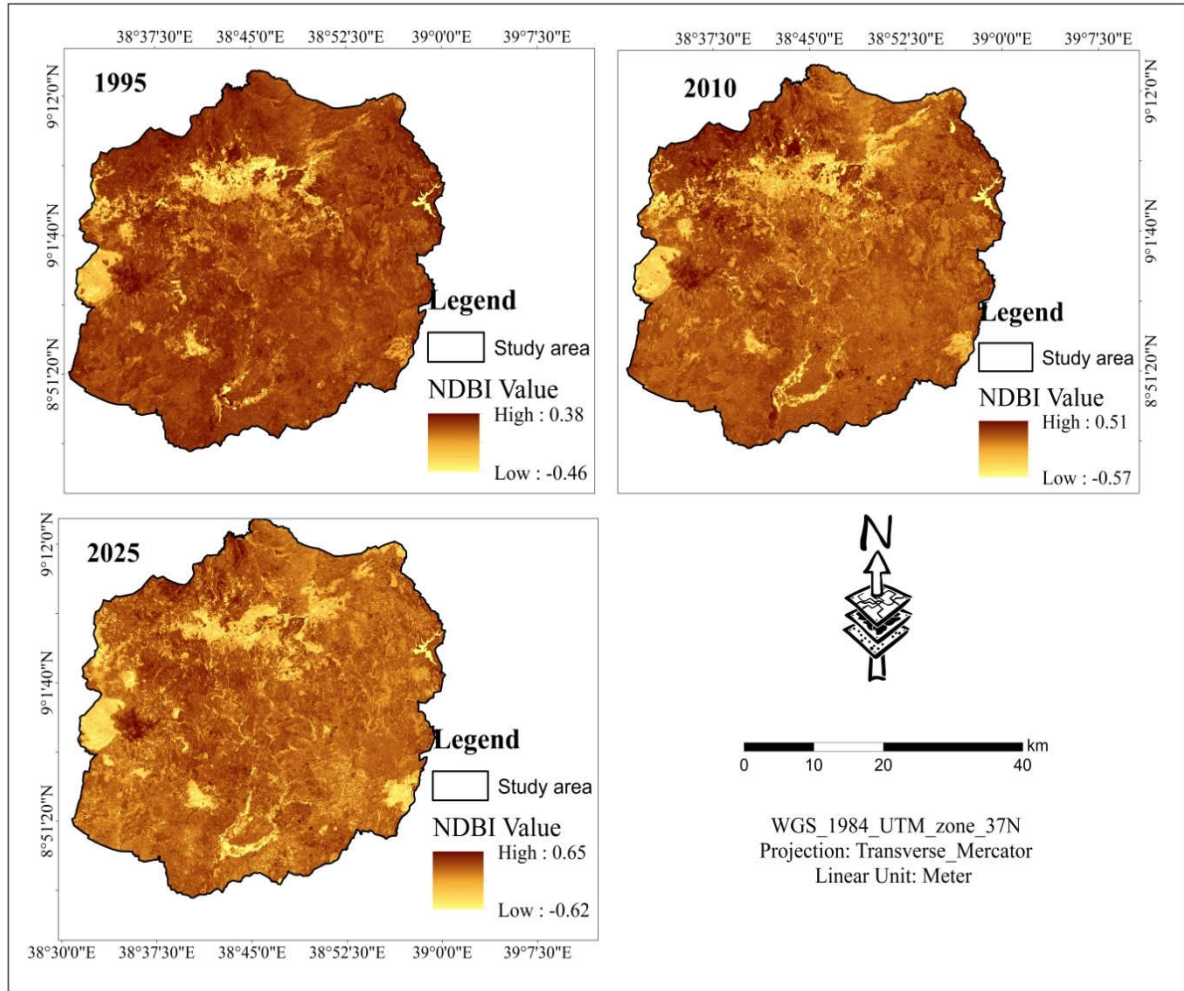


Figure 9:NDBI map of the study area from 1995 to 2025

4.3.3. Relationship of LULC types with Land Surface Temperature (LS)

The relationship between LULC and LST between 1995 and 2025 is shown in Table 9. This result reveals significant trends in the rising temperatures across various land cover types, which can be attributed to several environmental and anthropogenic factors. Bare land consistently exhibits higher LST values in the 1995. In 1995, the LST of bare land was 23.7°C, which rose steadily to 27.7°C by 2025. The warming trend in bare land is notable, with an increase of 4°C over the 30-year period. This trend is likely due to the lack of vegetation and soil exposure to direct sunlight, which can heat the surface more quickly, especially in areas with limited shade or soil moisture. Built-up areas, which include urbanized land, also show a substantial rise in LST during that time. In 1995, the LST in built-up areas was 23.4°C, which increased to 30.5°C by 2025.

The rise of 7.1°C underscores the urban heat island effect, where densely populated areas, with extensive concrete and asphalt surfaces, absorb and retain heat more efficiently than natural land covers. Urbanization intensifies this effect as buildings, roads, and other infrastructure increase the LST over time. an increase of 6.2°C. The significant warming of agricultural land can be attributed to intensive agricultural practices, land clearance for farming, and reduced vegetation cover, all of which contribute to higher surface temperatures. The increase in temperature can affect soil moisture, crop growth, and overall agricultural productivity.

Forest land has the lowest LST values among the different land types, although it still exhibits a gradual increase over the years. In 1995, the LST was 15.4°C, and by 2025, it increased to 19.4°C. The rise of 4°C reflects the general warming trend observed globally but still maintains lower temperatures compared to other land types due to the cooling effects of tree canopy cover, which provides shade and promotes evapotranspiration. However, deforestation and forest degradation may contribute to higher temperatures in forested regions, diminishing their cooling benefits. Grassland areas follow a similar warming trend to bare land and built-up areas, with LST rising from 21.5°C in 1995 to 24.7°C in 2025, reflecting an increase of 3.2°C.

The rise in temperature in grasslands can be attributed to changes in land use, and climate factors that reduce the natural vegetation cover (Table 9). These changes, combined with the lack of trees, contribute to higher surface temperatures, which can exacerbate soil erosion and desertification. Water bodies exhibit the lowest temperatures across all years, showing a gradual increase from 13.2°C in 1995 to 16.3°C in 2025. While water bodies naturally have a cooling effect due to their high specific heat capacity and the ability to regulate temperature through evaporation, the rise in temperature, albeit gradual, may be linked to reduced water levels, changes in water quality, and the overall warming climate. Still, water bodies remain cooler than land-based LULC types, offering an essential contrast to the more heat-absorbing land surfaces. Its implication is that, the increasing LST across various LULC types points to the broader impacts of land use and climate change. The sharp rise in LST in cultivated and built-up areas suggests a growing risk of urban heat island effects, which can exacerbate the health risks in urban populations. The significant temperature rise in cultivated lands may

affect agriculture by reducing crop yields, altering soil conditions, and increasing irrigation needs. The rise in temperature in forested and grassland areas highlights the vulnerability of natural ecosystems to changing climatic conditions and land use practices.

Moreover, the correlation analysis between LST and land use types reveals significant differences in temperatures across various land cover types. The specific causal factors behind these variations often are attributed to land cover type, such as forests maintaining lower temperatures due to shading and evapotranspiration, and water bodies keeping cool due to their high heat capacity, the influence of human activities. Urbanization, agricultural expansion, and deforestation all contribute to the rising LST, particularly in built-up and cultivated areas, where changes in surface properties (e.g., increased impervious surfaces, loss of vegetation) significantly alter thermal dynamics. According to Iftakhar et al. (2024), the study highlights the intricate relationship between population dynamics, urbanization, land-use changes, and LST, offering valuable insights for sustainable resource management.

Table 8:Relationship of LULC with LST from 1995 to 2025

LULC Types	1995	2010	2025
	LST mean (°C)	LST mean (°C)	LST mean (°C)
Agricultural land	22.3	24.4	28.5
Bare land	23.7	24.1	27.7
Built up area	23.4	25.5	30.5
Forest land	15.4	18.4	19.2
Grassland	21.5	23.3	24.7
Water body	13.2	15.8	16.3

4.3.4. Correlation analysis LST with NDVI and NDBI

Correlation analysis was conducted to evaluate the relationship of LST with NDVI and normalized difference built up index NDBI by using Landsat OLI/TIRS of 2025 in the study area. The result revealed a strong negative correlation between LST and NDVI (Figure 10A). This indicates that high LST values are associated with low vegetation cover, while lower LST values correspond to areas with more abundant vegetation cover. The observed negative correlation highlights the significant impact of vegetation cover on LST. As vegetation cover decreases, leading to advanced surface temperatures. This finding is reliable with the broader

understanding that vegetation plays a critical role in moderating surface temperatures through processes such as shading, evapotranspiration, and cooling (Tafesse and Suryabhagavan, 2019). However, LST and NDBI had significant beneficial correlations in the research area.. Higher LST values indicates highly dominated with built up area (Figure 10B). In addition, negative strong correlation between NDVI and NDBI due decline of vegetation cover and expansion of impervious surface in the study area (Figure 10C)

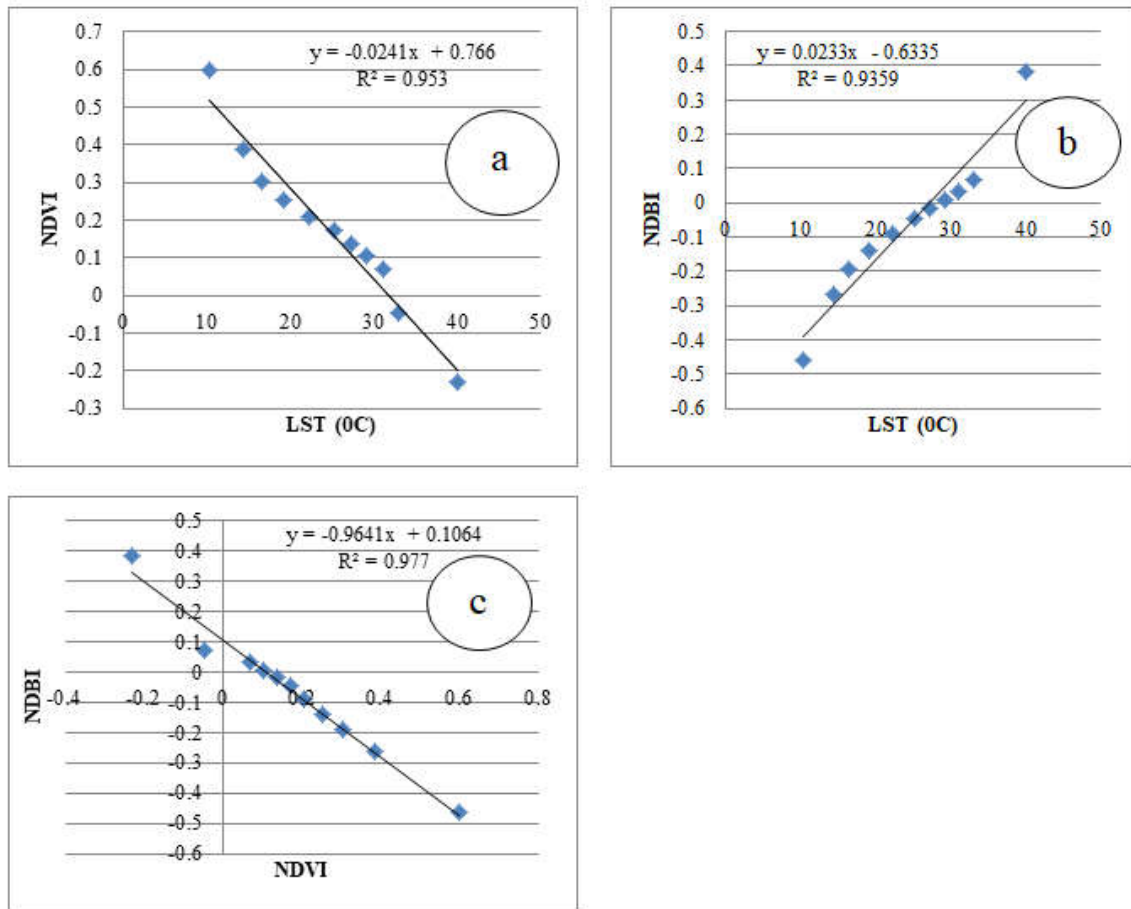


Figure 10:Correlation of LST vs NDVI (A), LST vs NDBI (B) and NDVI vs NDBI (C) map of the study area

4.4. Investigation of spatio-temporal variations UHI of Addis Ababa and Shaggarcities

According to Peng et al (2018), Urban heat island states to that when LST of the urban center higher than their surrounding rural area. The changes of temperature is mainly caused by antropogenic activities and the way cities are built. Urban heat island of the study area was

evaluated from 1995 to 2025 from LST of the study area. . The results revealed that, the maximum UHI of the study area was 30.4°C, 34.2°C and 40.3°C in 1995, 2010 and 2025 respectively. Geographically, the central parts of the study area was dominated higher UHI over the study period (Figure 11). The previous study (Moisa *et al.*, 2022) confirmed that, UHI effect was high in the central parts which covered by impervious surface and low vegetation cover in Jimma city. In addition, This finding shows that, higher UHI values was not comfortable for human life. According to Yin *et al* (2023) UHI has negative impacts on thermal comfort in New York city and not suitable for human life.

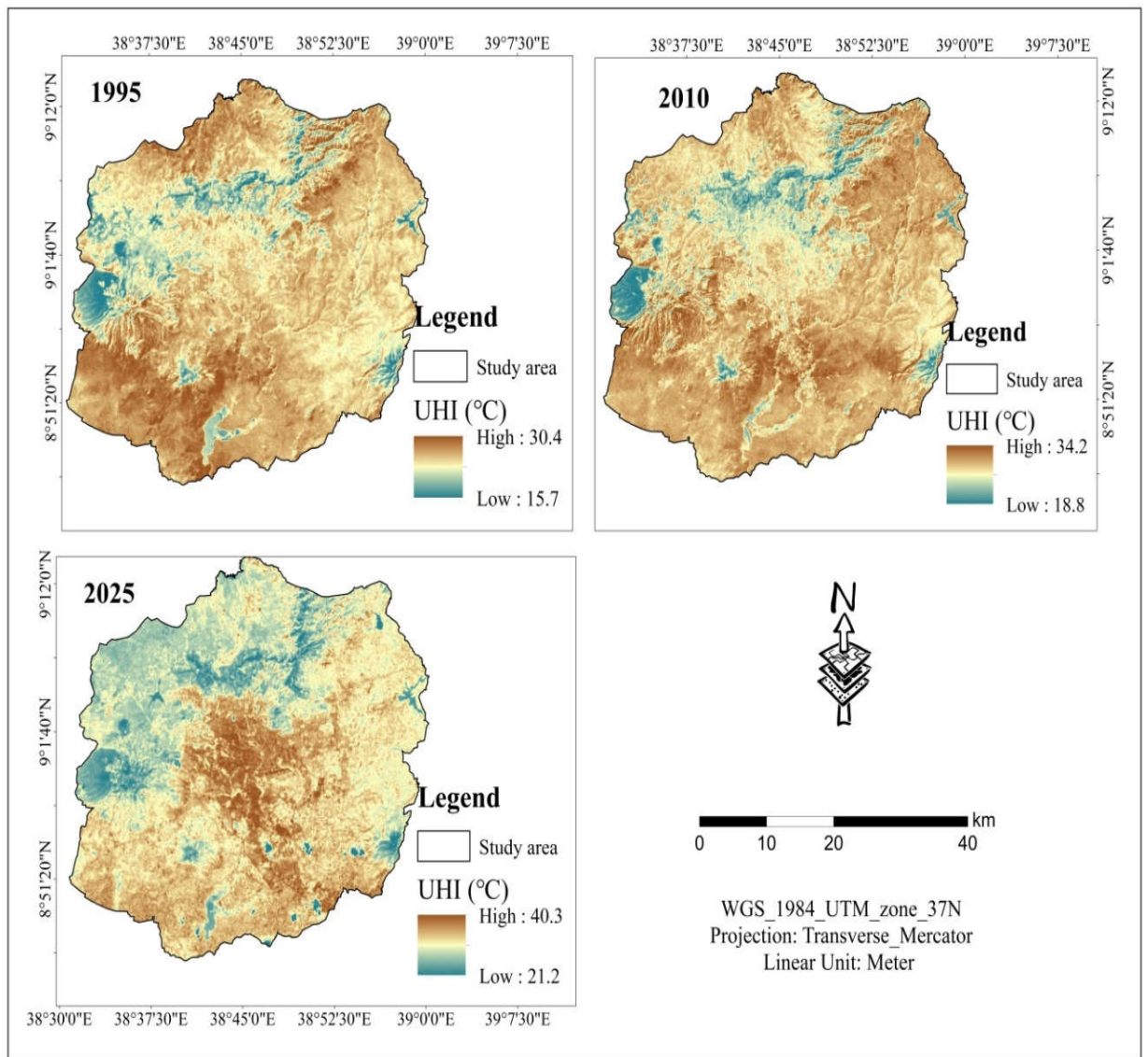


Figure 11:UHI of the study area from 1995 to 2025

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The assessment of urban sprawl and its effects on the urban thermal environment particularly land surface temperature (LST) and the urban heat island (UHI) effect between 1995 and 2025 reveals substantial and alarming changes within the study area. The results indicate a dramatic increase in built-up land, which expanded from 97.1 km² to 615.4 km² during the study period. Conversely, cultivated land and forest cover declined by 886.7 km² and 103.3 km², respectively. These changes reflect rapid urban expansion and the widespread conversion of agricultural and natural landscapes into urban land uses, driven by population growth and socio-economic development.

The rate-of-change analysis demonstrates an accelerating trend in urban growth accompanied by a pronounced decline in agricultural and forest lands, thereby intensifying environmental pressure. Furthermore, the NDVI results reveal a continuous decline in vegetation health, with maximum NDVI values decreasing and minimum values becoming increasingly negative over time. This pattern signifies substantial vegetation loss and progressive land degradation, largely attributed to unregulated urban development and weak land management practices. As a consequence of reduced vegetation cover and increased impervious surfaces, the study area experienced a marked rise in thermal conditions. Land surface temperature and UHI intensity increased by 10.1 °C and 9.9 °C, respectively, between 1995 and 2025. These findings confirm the strong relationship between land cover change and urban thermal stress.

The study therefore underscores the urgent need for integrated and sustainable land management strategies to mitigate the adverse effects of urbanization. Policy interventions such as land-use zoning, reforestation programs, urban greening, and environmental regulation must be strengthened. In addition, the incorporation of green infrastructure, promotion of agroforestry, and adoption of sustainable agricultural practices are essential to enhance ecological resilience and ensure balanced development. Public participation and institutional coordination are also vital to achieving long-term environmental sustainability in the region.

5.2. Recommendations

Based on the findings of this study, it is recommended that urban planning authorities in Addis Ababa and Shaggar City enforce compact and controlled urban development to reduce the thermal impacts of urban sprawl.

- ✓ Urban green infrastructure should be expanded and integrated into land-use plans to mitigate increasing land surface temperatures.
- ✓ Future research should concentrate on evaluating the long-term effects of climate change on urban thermal comfort levels with socio-ecological activity.
- ✓ future research should also prioritize the use of high-resolution satellite imagery to provide more detailed and accurate insights into land surface temperature dynamics and LULC change.
- ✓ Building regulations should incorporate climate responsive design standards. In addition, the institutional use of GIS and remote sensing for monitoring urban growth and thermal conditions is recommended to support informed policy decisions. These measures will assist policymakers in addressing urban heat challenges while promoting sustainable urban development.

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