

**THE ROLE OF URBAN FOREST IN REGULATING THE URBAN HEAT ISLAND  
EFFECT IN LUSAKA DISTRICT, ZAMBIA**

**BY**

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## ABSTRACT

The Urban Heat Island (UHI) effect is about significant temperature increase in the Central business district (CBD) in comparison to the outskirts. It has the potential to amplify heat waves and hot seasons because of their intensity. UHI causes not only thermal discomfort, but also decreases in life quality. This study investigated the role of urban Forest in regulating the urban heat island effect in Lusaka district, Zambia. The study conducted a longitudinal correlational study on ambient air temperature data. Data was collected from Lusaka CBD, Woodlands suburbs, and Forest No. 27 using Mengshen Digital Psychrometer and mobile phone weather application for a period of Eight months September 2022, January 2023 – July 2023. Data analysis was achieved using Pearson's correlation, k Within-Groups ANOVA and Trend Analyses in generalized linear models. A comprehensive review of the available literature was also done. The results showed that CBD recorded higher overall temperatures (12.4 – 26.3°C, average=24.9°C) compared to slightly vegetated Woodlands suburbs (11.4 – 24.5°C, average=23°C) and highly vegetated Forest No.27 (9.8 – 19.9°C, average=18.2°C). This indicates that, while UHI is a common phenomenon, green infrastructure in urban areas may, in some cases, mitigate its effects. Furthermore, the study found that the scope and impact of UHI are not uniform: depending on the peculiarities of urban morphologies, they pose different challenges linked to the microclimate peculiar to geographical locations in this case CBD, Woodlands residential and forest No.27, with the CBD experiencing higher temperatures. The study concluded that preserving and expanding urban green resources contributes to additional benefits that may reduce the effects of UHI directly or indirectly. The study also emphasizes the importance of urban forest in maintaining green areas in the CBD. The study also emphasizes the importance of city planners paying closer attention to potential UHI effects when starting new construction projects or modifying existing ones.

**Keywords:** *Green Infrastructure, Heat waves, microclimate, Psychrometer, urban heat island*

## **DEDICATION**

I dedicate this paper to my late mum, Ms Rose Lambi, who taught me that with hard work and determination, one can achieve anything and my late father-in-law, Mr Dixon Mazyopa who taught me about being transparent in life. May their souls continue resting in Peace.

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## LIST OF ABBREVIATIONS AND ACRONYMS

<b>AHR</b>	Anthropogenic Heat Release
<b>CBD</b>	Central Business District
<b>CO<sub>2</sub></b>	Carbon Dioxide
<b>DMS</b>	Degrees Minutes Seconds
<b>EIZ</b>	Engineering institute of Zambia
<b>EPA</b>	Environmental protection Agency
<b>FAO</b>	Food and Agriculture Organization
<b>HAM</b>	High Albedo material
<b>LULC</b>	Land use land cover
<b>MS</b>	Microsoft Software
<b>MSe</b>	Mean Square
<b>SFM</b>	Sustainable Forest Management
<b>TC</b>	Thermal Comfort
<b>TSG</b>	Trees, Shrubs and Grass
<b>UFAM</b>	Urban Future assessment Method
<b>UHI</b>	Urban Heat Island
<b>VEG</b>	Vegetation and green roof
<b>ZIA</b>	Zambia institute of architect
<b>ZIP</b>	Zambia institute of planners

## **CHAPTER ONE**

### **INTRODUCTION**

#### **1.0. Introduction**

This chapter discusses the background of the urban heat island (UHI). It discusses how UHI is accelerated by human activities such as urban expansion and how UHI affects the local climate. It also discusses how urban forest contributes to the sustainable management of the green environment in urban area and help reduce the negative effects of UHI.

#### **1.1 Background**

The Urban Heat Island (UHI) effect is a kind of heat accumulation within urban areas in comparison to the peri-urban. It is due to urban construction and human activities. It is recognized as the most evident characteristic of urban climate (Yang et al., 2016. 11-18). Structures such as buildings, roads, and other infrastructure absorb and re-emit the sun's insolation more than natural landscapes such as forests and water bodies (Borah et al., 2018). The UHI effect is a common environmental problem in metropolitan areas where the temperature is significantly higher than in the suburbs. The heat island forms because urban surfaces such as roadways and rooftops absorb and emit heat to a greater extent than most natural surfaces (Rosenzweig et al., 2005). Urban areas, where these structures are highly concentrated, have limited green spaces and become "islands" of higher temperatures relative to outlying areas. These pockets of heat are referred to as "heat islands." Heat islands can form under a variety of conditions, including during the day or night, in small or large cities, in suburban areas, in northern or southern climates, and in any season (Fargallah and Ragheb, 2022).

With the advent of anthropogenic ally induced climate change, the UHI effect has increasingly become a global problem of late. The UHI effect is accelerated due to human activities such as deforestation which is also a driver of climate change (Ahmed, 2018). The growing urban population creates pressure on the environment as more land needs to be cleared for settlements. Technology is also another contributing factor to the UHI effect. The materials used in the building contribute to UHI effect. Dark surfaces used in construction absorbs far more solar heat and radiation, which is why roads, pavement and roofs of building in urban areas witness a spike in high temperature as compared to their counter parts in rural areas

(Rosenzweig et al., 2005). UHI effect could be a risk to human health as growing urban population exacerbates the heating effect of cities and the built environment due to the continued replacement of forests with concrete and paved surfaces. Hence this study, investigated the possibility of curbing the UHI with urban forest.

Urban forest can be achieved by the process of urban revegetation. Urban revegetation is basically the process of planting trees in an urban area. Urban revegetation is the human-induced restoration and conversion of land that has not had plants to vegetated land through planting, seeding or the human-induced promotion of natural seed sources (Bredemeier and Dohrenbusch, 2009). In this sense planting, sowing and spontaneous regeneration represents the mechanisms of engaging in revegetation. Urban forest usually will increase carbon capturing. In many governmental lands, non-governmental organizations directly engage in programs of revegetation to create forests, increase carbon capture and carbon sequestration and help to anthropogenically improve biodiversity (Borah et al., 2018). Planting of trees and forests in urban areas are a means of soil conservation, preventing landslides in fragile ecosystems with steep terrain, little vegetation and harsh seasonal rains, and thus protecting people's lives and homes (Kuchelmeister, 2000). Unused and degraded land and terminated landfill sites are increasingly being reclaimed through urban revegetation and converted to parks. Where land is contaminated, particularly with heavy metals, some trees are capable of absorbing the pollutants. Through repeated felling and removal of the timber, the level of contamination can gradually be reduced (Punshon et al., 1996).

Urban revegetation creates urban forests which are an economic asset. When they are properly designed and managed, their overall benefits are such that they are increasingly regarded as a vital component of the urban infrastructure essential in maintaining a liveable and sustainable environment (Kuchelmeister, 2000). Urban forest should be implemented within the context of Sustainable Forest Management (SFM) which extends beyond the simple planting of trees to encapsulating the planting of the right trees in the right places. Given the nature of urban forest as a major change in land use, the activity impacts greatly on the site and its surroundings. It also has wider implications in relation to, for example, the protection of river catchments, landscape management and the provision of an adequate regional infrastructure. Forests contribute significantly to the urban environment, with benefits including increased air quality, landscape improvement, enhanced opportunities for recreation and environmental education, and the promotion of public health. In an increasingly urbanized world, it is appropriate that any SFM includes forests in urban areas (Food and Agriculture Organization [FAO], 2002).

Reduction in vegetation and crop field as a result of urbanization increases the effect of the UHI (van Heerwaarden and de Arellano, 2008). With decreased vegetated spaces cities also lose the shade and evaporation cooling effect of trees (Schneider dos Santos et al., 2017). This is because trees are natural air conditions. Decreased vegetation in cities has been through cutting down of trees, grass as well as decreased green spaces. Generally, very few households in urban areas have appreciable space for lawns. Most households have resorted to paving their yards or just clearing it and leaving it bare. Maintaining green spaces could be beneficial to the environment through air purification, as well as trapping dust and dirt hence improving air quality. Vegetation also serves as a carbon sink thereby removing excess carbon greenhouse gas from the atmosphere, significantly contributing to temperature reduction as excess carbon in the atmosphere is one of the drivers of global warming. Green spaces further reduce temperatures by absorbing heat and dispersing it at night (Faragallah and Ragheb, 2022).

The UHI can alter the local wind pattern, the humidity and the rate of precipitation. The extra heat provided by UHI leads to greater upward motion which can induce additional shower and thunderstorm activities. Warmer climates create an atmosphere that can collect, return and unleash more water, changing weather patterns in such a way that wet areas become wetter and dry areas drier. In addition, the UHI creates a local low-pressure zone during the day where relatively moist air from its rural surroundings converges, possibly leading to more favourable conditions for clouds formation (van Heerwaarden and de Arellano, 2008). The UHI decreases air quality by increasing the production of pollutants such as ozone (Perera and Sanford, 2011). Heat islands contribute to higher day time temperature, reduces night time cooling and higher air pollution levels. As earlier alluded to, UHI effect could be a risk to human health as growing urban population exacerbates the heating effect. These in turn contribute to heat related deaths and heat related illness such as general discomfort, the respiratory difficulties, heat stress, heat cramps, heat exhaustion and non-fatal heat stroke (Santamouris, 2020).

Lusaka dominates Zambia's urban system and accounts for 32 percent of the total urban population in the country. It is a growing urban city in which formal green spaces lie outside the urban area, with a clear separation between high impervious surfaces in the city centre and green spaces in the peripheries (Simwanda et al., 2019). Unplanned and uncontrolled urbanization worsens this situation and exacerbates UHI effects. The uncontrolled and unplanned urbanization has put Lusaka under constant ecological and environmental threat. One of the critical ecological impacts of urbanization likely to adversely affect Lusaka urban dwellers is the UHI effect (Acioly Jr., 2010). The rapid urbanization, unplanned and

uncontrolled informal settlements in the city of Lusaka has resulted in increased temperatures, which makes the city to be susceptible to the UHI effect and a good case for this study.

## **1.2 Problem Statement**

The UHI effect occurs in cities where the air temperature is significantly higher than the suburban areas. The UHI effect can mainly be attributed to high density infrastructure, which not only limit air flow but also emit heat stored from solar energy. The reduction of vegetation and wetlands increases the heat releasing capacity of cities. The need and urgency to mitigate the UHI effect is because it is a huge threat to the environment and human health. High temperature lead to increased energy demands for cooling resulting in higher energy costs. As a result, power plants have to supply the needed extra energy, and since they rely on fossil fuel for energy production, there is an increase in greenhouse gas emissions and air pollutants. The main greenhouse gases and pollutants include carbon dioxide, (CO<sub>2</sub>), and sulphur dioxide. Therefore, this study looks at the need to revegetate the city because Plants and trees are supposed to cool the air through evapotranspiration as they also absorb carbon. However growing cities such as Lusaka are dominated by paved surfaces with little room for green spaces. Lesser trees mean less cooling efficiency, causing the creation of the UHI effect.

## **1.3 Study Objectives**

### **1.3.1 Main objective**

The aim of the study was to investigate the role of urban forest in mitigating the urban heat island effect experienced in Lusaka, Zambia.

### **1.3.2 Specific objectives**

- i. To investigate the occurrence of the UHI effect in Lusaka urban.
- ii. To assess the severity of the UHI in Lusaka CBD in comparison to woodlands residential and forest No.27
- iii. To assess the role of urban Forest in mitigating the UHI effects in Lusaka urban.

## **1.4 Research Questions**

- i. What is the occurrence of the UHI effect in Lusaka urban?
- ii. How severe (intense) is the UHI effect in Lusaka Urban in comparison with the residential area Woodlands and Forest No. 27?

iii. What is the role of urban forest in mitigating UHI effects in Lusaka urban?

### **1.5 Research Hypothesis**

Urban forest can significantly reduce the UHI effect experienced in Lusaka urban.

### **1.6 Study Rationale**

The research brought into focus the role and importance of urban forest as a solution to UHI effect. It aided the promotion of revegetation in urban environments and possibly in peri-urban environments in the near future. Urban revegetation should be viewed within the context of SFM and it extends beyond the simple planting of trees to encapsulate the planting of the right trees in the right places. Given the nature of urban forest, it also has wider implications in relation to, for example, landscape management and the provision of an adequate regional infrastructure. The study findings therefore may have an impact on the sustainable management of forest resources in the country which includes putting in place appropriate revisions to policies, legislation and regulations to govern forest management, investment, research and development, among others as governed by the Forest Act No. 4 of 2015 and the National Forestry Policy of 2014. This study offers crucial insights into the UHI effect in Zambia, elucidating its intricate relationship with urban morphology, demographic trends, and the overarching challenges posed by climate change. The comparative analysis of the Lusaka CBD, Woodlands Residential Area, and Forest No. 27 emphasizes the critical importance of effective spatial planning and urban design as strategies for mitigating the UHI effect and fostering sustainable urban development. By prioritizing these approaches, urban planners and policymakers can work towards enhancing urban resilience and improving the quality of life for all city inhabitants.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.0 Introduction**

This chapter reviewed research works on urban afforestation and UHI effects globally, regionally and locally. The chapter consists of the conceptual framework of the UHI effect, the causes of the UHI effect, the severity of UHI, the effects of UHI in urban areas and the role that urban forest through afforestation plays in mitigating UHI effects. Finally, the gaps in literature were highlighted.

#### **2.1 Conceptual frame work - of the urban heat island effect**

The urban expansion experienced by cities, is associated with numerous environmental problems, one of these is the UHI. Defined as the temperature difference between the urban area and its surroundings, it is the result of two different but related processes; the first and most important, changes in land cover as a result of the urbanization process that transforms materials with impervious surfaces such as asphalt and concrete. The second refers to activities in the city mainly transport and industry due to thermal emissions that contribute to urban heating (Oke, 2002). The issue is increasingly important because of the global trend toward urbanization and sprawl of cities, also because the UHI has direct implications for air quality, public health, energy management and urban planning. The UHI effect has become one of the major environmental challenges because of its relation to the urbanization process, and exacerbate the problems are mentioned above (Villanueva-Solis, 2017).

The urbanization of the natural land scape such as roads, bridges, dams, houses, and high-rises has dramatically altered its waters, soils, and vegetation. In fact, the most stereotypical "urban" characteristics of cities are also those which can cause temperatures to rise. By replacing vegetation and soil with concrete and asphalt, there is a reduction in the landscape's ability to lower daytime temperatures through evapotranspiration and lose the obvious benefits of shade. By using dark-coloured materials on roads, buildings, and other surfaces, we create entire cities that absorb, rather than reflect, incoming solar energy (Adinna et al., 2009).

The combination of reduced reflectivity called "albedo" and reduced vegetation has resulted in a temperature difference between urban and rural areas that is most clear in late afternoon and early evening, when roads, sidewalks, and walls begin to release the heat they have stored

throughout the day. The difference is most extreme in densely developed areas. In fact, heat islands are broken up partially by parks and other vegetated areas, even within the downtown area. But throughout the last century, increasing rates of urbanization and industrialization have exacerbated the heat island effect. Peak temperatures in Los Angeles, for instance, have risen by 5°F (15°C) in the last fifty years (Akbari, 2009). While the nature and effects of UHI are still being studied, the causes are well established. Denuded landscapes, impermeable surfaces, massive buildings, heat-generating cars and machines, and pollutants all help to make urban areas hotter. The replacement of vegetation or soil by concrete or asphalt reduces an urban landscape's ability to lower daytime temperatures through evaporation and plant transpiration (Mobaraki, 2012). In a rural or irrigated landscape, a large amount of daytime solar energy is actually spent on evaporating water, not on raising air temperatures. Trees and other vegetation perform this function through the process of "evapotranspiration." In this process, the plant draws moisture from the ground, utilizes what it needs for growth and moderating its own temperature, transpires the excess, and cools the surrounding air (Bousse, 2009).

When a natural vegetative cover is replaced by asphalt or concrete, it loses its ability to moderate temperatures. Instead, the solar energy normally delegated to the evaporation process is left to raise surface temperatures. Urban areas get hotter than rural settings not only because their ability to cool evaporative is reduced, but also because they reflect less incoming solar energy. This reflective capacity is called 'albedo'. Asphalt, in particular, has low albedo; it absorbs almost all the solar energy falling on it. This, combined with asphalt's inability to evaporate water, means that streets and parking lots paved with this material often reach blistering temperatures on sunny summer afternoons (Akbari, 2009).

Buildings also contribute to the UHI in a number of ways. Like pavement and sidewalks, buildings do not have the capacity to moderate heat through evaporation. Instead, they absorb and store the day's heat, and then radiate it back to the urban atmosphere at night. You can feel this heat if you stand close to a brick building early on a summer evening. In downtown areas, the densely clustered, tall office buildings create "urban canyons" that take hours to cool off every night. In addition, buildings and other architectural structures obstruct the natural flow of breezes, making wind speeds noticeably lower in the cities. This obstruction prevents winds from carrying heat build-up away from the city and from assisting in the reduction of the heat island (Akbari et al., 2001).

Urban pollution also affects the heat island, depending on the time of day and season of the year. During daylight hours, pollution lowers heat build-up slightly, because it blocks incoming solar energy. At night, however, pollution prevents heat from escaping by covering the city like a blanket, and thereby increasing the heat island effect. Finally, heat and pollution from cars, machines, and other mechanical systems contribute to winter heat islands. During the summer, however, solar energy is so intense that it overwhelms the heat output from these human activities. Consequently, the severity of the summer heat island is determined largely by the interplay of the urban landscape and solar radiation (Wang and Akbari, 2016). In the urban areas, especially in the city centres, air pollution is eminent. Exhaust gases from vehicles and industrial pollutants released in the environment, trap solar radiation (Bousse, 2009). Thus, the temperature rises and the microclimate effect becomes stronger. A summary of conceptual frame work is shown in Figure 1.

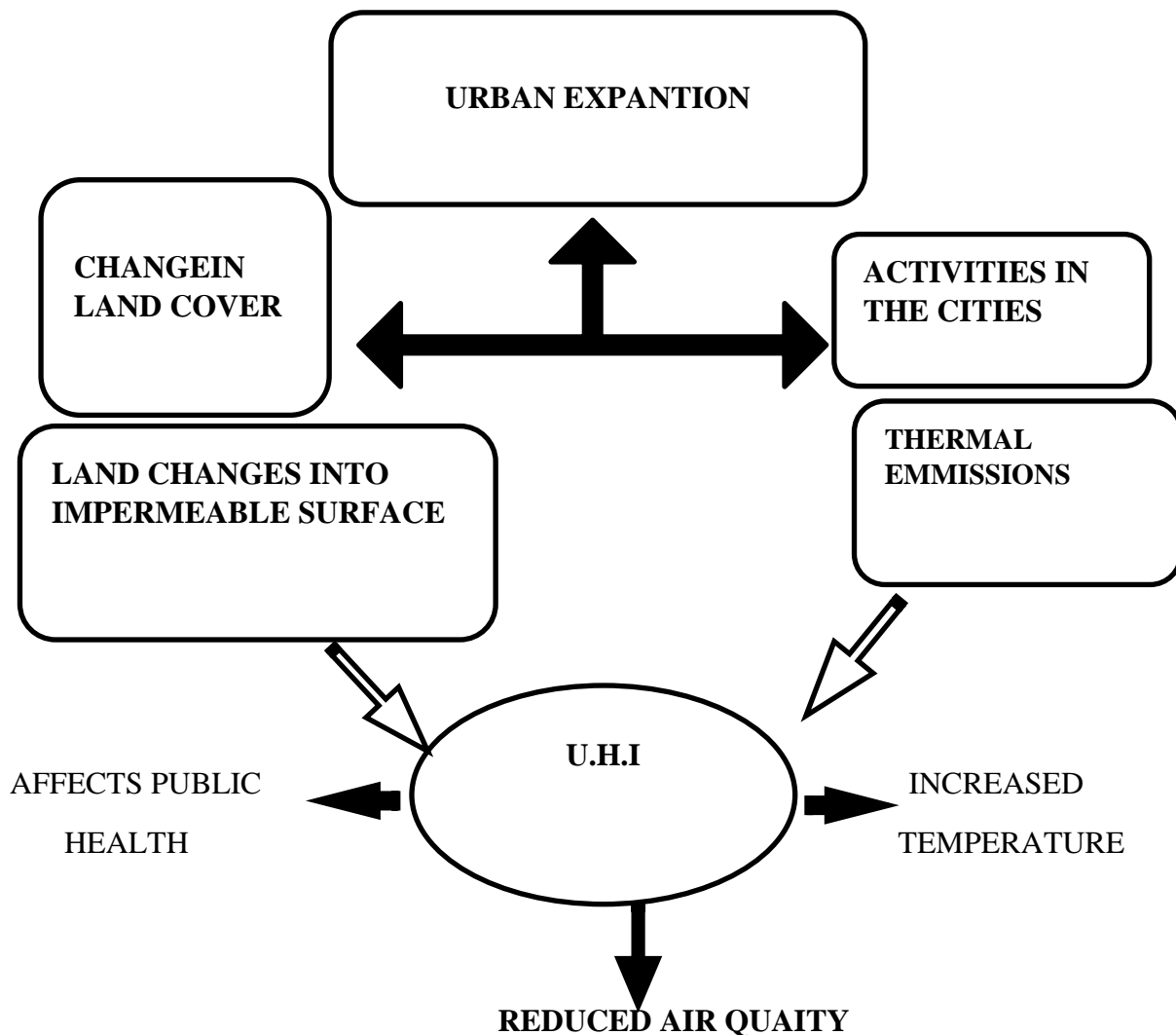


Figure 1. Conceptual framework of the UHI

## **2.2 Causes of the urban heat Island effect**

The UHI is caused by low amount of evapotranspiration because of less vegetation; absorption of solar radiation due to low albedo; hindrance to the flow of air because of higher rugosity; high amount of anthropogenic heat release (AHR) (Santamouris, 2020; Akbari et al., 2001; Oke, 2002). However, there are other factors which contribute to the formation of the UHI, among them, increased use of air conditioners; destruction of trees, and wind blocking.

### **2.2.1 Low amount of evapotranspiration**

With fewer plants, urban ecosystems experience less evapotranspiration. When there is less vegetation and/or trees in an urban area it means that there are fewer of them adding moisture to the atmosphere. Lesser trees mean less cooling efficiency. This limited hydration is what causes city air to heat up in the first place and increases plants' vulnerability to drought (Oke, 2002).

Evapotranspiration is lower in urban areas due to plenty of impervious surfaces. The availability of water for evaporation is lower in urban areas where rainwater is gauged effectively away by sewers. Evapotranspiration cools down the surfaces and air, because the change of water from liquid state to vapour state requires energy. In other words, energy is transferred to latent heat instead of sensible heat. In cities where less evapotranspiration takes place, less energy is used in evaporation and more energy is available in the form of sensible heat, thus raising surface and air temperatures (Akbari, 2009).

### **2.2.2 Absorption of solar radiation due to low albedo**

According to Bouyer et al. (2011), albedo is evaluated by the ratio of the reflected solar energy to the incident solar energy. It depends on the arrangement of surfaces, materials, pavements, and coatings. Albedo has a direct impact on the formation of the microclimate. The albedo of a city varies according to various factors like surface arrangement that is, orientation, heterogeneity; materials for roofs, pavements etc. (Bouyer et al., 2011). If the albedo of the urban surface is low, it will store more solar energy and the effect will be an increase in urban temperature and creation of the urban microclimate.

### 2.2.3 Hindrance to the flow of air because of higher rugosity

This refers to the use of impermeable paving such as asphalt and concrete, effectively sealing the soil and this limits evaporative cooling in urban areas. This results in the warming of the air above the urban surface, by convection and radiation. The conditions of high rugosity are dominated by surface building materials and the shape of the urban environment, referred to as urban roughness. An increasing degree of urban roughness can have a marked effect on air currents and their turbulent flow and an effect on mixing cooler air with the urban hotter air (Akbari, 2009).

### 2.2.4 High amount of anthropogenic heat release

Anthropogenic Heat Release (AHR) is produced by human activities and spreads to the surrounding atmosphere. AHR is generated from many kinds of sources, with major sources from human metabolism Figure 2, industries, vehicles (traffic) Figure 3, and energy consumption in buildings including electricity and heating fuels. A large amount of anthropogenic heat flux provides additional energy in urban area and further alters urban thermal environment. Anthropogenic heat flux released to the near-surface atmosphere has led to changes in urban thermal environments and severe extreme temperature events (Rosenzweig et al., 2005).



Figure 2. Overcrowding in CBD contributes to high anthropogenic release



Figure 3. High anthropogenic heat release from vehicles in the CBD

### 2.2.5 Increased Use of Air Conditioner

To provide comfort to human beings during the hot season, air conditioners are highly used with a rising trend. Air conditioners keep a building cool inside, but release the heat absorbing from inside to the atmosphere (Okwen et al., 2011). As a consequence, the outside environment is warmed leading to the increasing of atmospheric temperature.

### 2.2.6 Destruction of Trees

To meet the demand of various urban facilities, forests are wiped out in a massive scale. Lesser trees mean less cooling efficiency. Trees intercept the solar heat and also absorb carbon dioxide (CO<sub>2</sub>) for their own photosynthesis, making the environment cool (Akbari et al., 2001). With the destruction of plant life, the efficiency of cooling system goes radically reduced, causing creation of the UHI effect.

### **2.2.7 Wind blocking**

Due to the presence of densely situated buildings, wind velocity is reduced. As a result, the cooling effect by convection lessens. So, the heat trapped, cannot be blown out, resulting in intensification of the effect (Priyadarsini et al., 2008).

### **2.3 Severity of UHI effect**

UHI effect has close relationship with urban heat release, properties and structure of underlying surface, vegetation coverage, population density and weather conditions. Meanwhile, the scale and intensity of UHI effect will be increasingly serious with the on-going urbanization. The severity of UHI refers to the intensity of the differences in temperature between the sub-urban and the urban (Santamouris M. 2015). It is studied that China is experiencing severe UHI effect in many modern cities, especially the average temperature difference on the outskirts of Beijing reaches 3.3°C from 1961 to 2000, and UHI effect of Shanghai reaches 7.4°C (Li et al., 2012). Urban temperature, especially surface temperature, is the energy balance centre of urban surface and one of the most important factors affecting urban climate, regulating and controlling various ecological processes. However, the increasingly intensive urbanization has led to the constant increase of surface temperature, definitely resulting in the altering of urban resources and energy flow. More importantly, the structure and function of urban ecological system will also be changed, affecting urban residents' health (Li et al., 2012).

In many large cities, the temperature at the heart or the centre of the city is noted to be higher than its surroundings or the suburban area (Adinna et al., 2009). In other words, cities demonstrate greater temperature in its center than the surrounding rural areas (Yamamoto, 2006). According to Oke (2002), under proper conditions, UHI may be up to 10-15°C. As a consequence of the microclimate created by the UHI, the demand for energy to cool buildings increases (Adinna et al., 2009). One of the vital reasons for these effects of UHI is the large number of built-up surfaces like concrete, asphalt which has a high heat capacity (Akbari et al., 2001). Low albedo materials are further contributing to worsening the phenomenon. According to Taha (1997), when non reflective and water-resistant, impervious materials at the surface takes the place of natural vegetation, UHI is created. It is a process which varies with the built regions and geographical conditions of a metropolitan area (Grimmond and Oke, 1999). Another reason to exacerbate the UHI effect is improper planning of cities (Li et al., 2012). Taha (1997) says air pollutants from industrial processes, power plants, exhaust gases from the

vehicles and anthropogenic heat may add to the intensity of UHI effect. The severity of UHI can be assessed by using a combination of techniques such as remote sensing, urban canyon models, field measurements. In this research the severity of UHI was measured using field measurement of temperature differences between the CBD and forest 27 and the CBD and woodlands residential.

## **2.4 Effects of UHI in Urban areas**

### **2.4.1 Increased energy consumption**

Increased temperatures during summer in cities amplify energy demand for air conditioning. Studies reveal that electricity demand for air conditioning or cooling increases in the ranges of 1.5 to 2 percent for every 1°F (0.6°C) increase in air temperatures (ranges of 68 to 77°F (20 to 25°C), implying that the community requires about 5 to 10 percent more electricity demand to cater for the urban heat effect. This means the increased demands for cooling or air-conditioning during summer contributes to higher energy bills. Also, during exacerbated periods of UHI, the resulting demand for air conditioning can overload systems, which can lead to power outages and blackouts (Akbari, 2009).

### **2.4.2 Elevated greenhouse gas emissions and air pollution**

As explained earlier, UHI raises electricity demand during summer. As a result, power plants have to supply the needed extra energy, and since they rely on fossil fuel for energy production, there is an increase in greenhouse gas emissions and air pollutants. The main greenhouse gases and pollutants include carbon monoxide, (CO<sub>2</sub>), and sulphur dioxide, nitrogen oxides, particulate matter and Mercury. Increased greenhouse gases cause global warming and climate change, while the pollutants negatively impact human health as well as the decline of air quality. Sometimes the UHI can also lead to the formation of ground-level ozone and acid rain. Research shows that high UHI correlates with increased levels and accumulation of air pollutants at night, affecting the next day's air quality (Sodoudi et al., 2014).

### **2.4.3 Discomfort and danger to human health**

Higher air pollution reduced night time cooling, and increased temperatures as outcomes of UHI can adversely affect human health. Human health is negatively impacted because of increased general discomfort, exhaustion, heat-related mortality, respiratory problems, headaches, heat stroke and heat cramps. Because UHI can also worsen the impacts of heat

waves, abnormal weather periods can arise, which can seriously affect the health of sensitive and vulnerable populations such as older adults, children, and those with weather-responsive health conditions (Steeneveld et al., 2011).

Exacerbated heat events or sudden temperature increases can result in higher mortality rates. Research by the Centre for Disease Control and Prevention indicates that between 1997 and 2003, more than 8,000 premature deaths were registered in the United States owing to excessive exposure to heat (Akbari, 2009).

#### **2.4.4 Secondary impacts on weather and climate**

Besides the high-temperature increases, UHI can bring forth secondary effects on the local weather and climate. This includes changes in local wind patterns, the formation of fog and clouds, precipitation rates and humidity. The unusual heat caused by UHI contributes to a more intense upward wind movement that can stimulate thunderstorm and precipitation activity. Furthermore, UHI creates a local low-pressure area where cool air from its adjacent areas converges that induces the formation of clouds and rain. This increases the total rainfall rates within cities. These changes may impact growing seasons within cities, especially by prolonging the growth of plants and crops (Taha, 1997).

#### **2.5 The Role of urban forest in mitigating UHI effects**

Wang and Akbari (2016) in their study stated that the urban vegetation system plays a significant role for UHI mitigation and adaption. The fraction of the ground covered by trees and other vegetation is smaller and contains less biomass than in non-urban areas. The absence of vegetation impacts the UHI in several ways, since vegetation, and in particular trees, intercept solar energy, and their shade reduces the temperature of surfaces below while increasing the latent heat exchange for the evapotranspiration process. Trees affect climates and building-energy use in two ways. Direct benefits accrue from the shade that trees provide to buildings and surfaces. By blocking solar radiation, trees prevent structures and surfaces from heating up beyond the ambient air temperature. Indirectly, trees cool buildings by cooling the air surrounding them through evapotranspiration. In a process similar to sweating, trees use heat to evaporate water from a leaf before it can heat the air, thus cooling the air immediately around the leaf. The cumulative effect of many leaves and many trees can cool the air in a large area (Yamamoto, 2006).

Two of the most cost-effective methods of reducing heat islands are strategic landscaping and light-coloured surfacing. Strategic landscaping refers to planting trees and shrubs around buildings and throughout cities to provide maximum shade and wind benefits. Light-coloured surfacing means changing dark-coloured surfaces to ones which more effectively reflect, rather than absorb solar energy. The combined effects of planting more trees and incorporating more light-coloured surfaces can be astonishing. Preliminary research indicates that late afternoon air temperatures on a hot summer day can be reduced by 5 to 10°F, resulting in cooling energy savings of up to 50 percent, depending on location. Implementing these measures may be cheaper than implementing other efficiency programs. In addition to mitigating environmental concerns, planting trees and changing surface colours provide many other physical, functional, and psychological benefits to urban dwellers. Trees help reduce noise and particulate matter in the air, and provide habitat for wildlife. Both trees and light-coloured surfaces enhance the aesthetics of urban spaces, thereby contributing to the psychological well-being of their inhabitants (Akbari, 2009).

Previous studies support the role that urban forest plays in mitigating UHI effects in urban areas. For instance, Theeuwes et al. (2012) measured the impact of green vegetation and water surfaces in the urban areas on UHI effect. They found that each 10% vegetative cover can reduce the high temperatures and commented that trees can reduce the effect substantially. However, they concluded that the existence of water bodies does not decrease the temperature; rather it increases the effect. Li et al. (2012) performed a case study by analyzing the heat environment of Tsinghua University to establish an urban planning approach. They suggested that enough space in between buildings and plantation of trees will be efficient to decrease the intensity of heat island.

Adinna et al. (2009) assessed the impact of UHI effect in the Enugu city of Nigeria and suggested adaptive measures to keep the UHI effect under control in the city. Their study concluded that the use of high dense green vegetation, low absorptive roofing materials and lightening of pavement materials can reduce the effect in Enugu urban. Akbari et al. (2001) studied the effect of cool surfaces and shade trees on the UHI effect. They found that surfaces with high albedo materials and urban trees have a significant contribution to reversing the heat island. In their paper, the cost reduction due to the mitigating measures of UHI effect is also calculated. According to Akbari et al. (2001), for every 10°C increase of temperature, the electricity demand may rise by 2-4%. On the other hand, 20% energy can be saved which is used for air conditioning if mitigation measures are taken order to reduce the UHI effect.

Yamamoto (2006) described several mitigation measures for UHI effect and also gave a description about some mitigation projects in Japan and other countries including the wind paths in Freiburg in Germany. He recommended some key mitigation measures like energy saving buildings and traffic systems, restoring green areas in urban areas and improvement of urban airflow. Sodoudi et al. (2014) simulated three different strategies using ENVI-met to observe their usefulness to mitigate the UHI effect in Tehran. They considered the following three measures: (1) High Albedo Materials, (2) Vegetation and Green roofs, and (3) Combination of both of them (HYBRID). The results indicated that the HYBRID was the most effective mitigation measure as the result showed that it reduced the temperature of Tehran city at daytime.

Rosenzweig et al. (2005) used regional climate model combining meteorological data, satellite and GIS data to determine the influence of urban forestry, living roofs and light surfaces on UHI effect in the New York metropolitan area. They analyzed the New York City heat island effect model by taking six case study areas and tested the mitigation strategies. They found that vegetation helps to keep surfaces cool more effectively than increasing the albedo. But they suggested that in order to reduce the temperature in New York City, replacement of low albedo materials with high albedo light-coloured materials will work great as 64% of the surface area of the city can be replaced easily (Rosenzweig et al., 2005). Synnefa et al. (2008) studied the use of cool materials which are characterized by the high reflectivity to reveal the effect on UHI. A study was conducted using a mesoscale model over the city of Athens, Greece. They considered two scenarios: a moderate and a large-scale increase in albedo scenario. They concluded that use of high albedo materials in a massive scale can lower the temperature by 20°C (Synnefa et al., 2008).

Taha (1997) reviewed urban climate and UHI. He illustrated characteristics of urban climate as well as various features of heat island such as causes and effects. After studying numerous literatures which are based on numerical simulation and field measurements, he commented that increasing albedo and vegetation cover prove to be effective to reduce both surface and air temperature substantially. The UHI effect of the Shiraz city of Iran which is booming as well as rapidly urbanizing has been studied by Mobaraki (2012). He analyzed the Shiraz city based on selected four districts around it. In his concluding remarks, he mentioned that the city should have greenery and high albedo materials to mitigate the microclimate effect (Mobaraki, 2012).

A study by O'Malley et al. (2014) stated that the key issue preventing vegetation from gaining a higher rating is its vulnerability to removal as a result of land use change and issues related to maintenance. Therefore, the local council and developers should make this a priority if resilience is to be increased. Significantly the UFAM method identified the local context within this area of London as very strong. Such that it overrides planning policy and that the local council is unwilling to construct anything which does not align with it. Therefore, in terms of sustainable development the local context can have both a positive and negative effect. This outcome aligns with and further proves previous research stating that vegetation is effective for mitigating the UHI effect. Research also indicates that parks and green spaces help to mitigate the heat island effect and reduce energy consumption for cooling buildings in the summer, while also maintaining changes of temperature induced by building materials. Therefore, there are multiple benefits related to inclusion of TSG within a development and is therefore highly recommended as an UHI mitigation strategy (O'Malley et al., 2014).

A study by Simwanda et al. (2019) revealed that, although most African cities have relatively larger green space to impervious surface ratio with most green spaces located beyond the urban footprint, the UHI effect is still evident. It was recommended that urban planners and policy makers should consider mitigating the UHI effect by restoring the urban ecosystems in the remaining open spaces in the urban area and further incorporate strategic combinations of impervious surfaces and green spaces in future urban and landscape planning. Faragallah, & Ragheb, (2022) did a case study on Evaluation of thermal comfort and urban heat island. Another study was done in south Africa Johannesburg by Hardy C.H and Nel in 2015. This paper describes the remote sensing data sets and processing techniques employed to study the heat island effect within Johannesburg.

## **2.6 Gaps in Literature**

Based on the studies conducted, it has been noted that UHI effects can be addressed, however, UHI studies in African cities remain uncommon and not centred on exclusively the role that urban forest plays in mitigating UHI effects in urban areas. Therefore, this study attempts to investigate the role of urban forest in mitigating the UHI effect experienced in Lusaka by promoting urban revegetation.

Although UHI is a global phenomenon and occurs almost in every part of the world in Lusaka very few studies have been conducted on understanding the causes, effects and ways of

mitigating the increasing UHI effects in the city. Therefore, priority has to be taken into consideration in order to tackle the problem.

Another gap is the knowledge gap in terms of lack of public education on the causes, effects and mitigation of UHI and implementation measures and the lack of trustworthy information shared on social media. Bridging these gaps is of key importance to fostering public engagement and improving the effectiveness of UHI mitigation measures.

# CHAPTER THREE

## DESCRIPTION OF THE STUDY AREA

### 1.0.Introduction

This chapter describes the study area. It discusses the location and climate of the study area.

### 3.1 Location

Lusaka is the capital city of Zambia. It is one of the fastest-developing cities in southern Africa (Council.L.C. 2008). Lusaka is located between Latitudes 15°20'S and 15°40'S and longitudes 28°10'E and 28°40'E in the central part of Zambia. It covers an area of 21,896 km<sup>2</sup> and borders with Chilanga in the southern part, Chongwe on the eastern part, Chisamba on the northern part and Shibuyunji on the west Figure 4 and Figure 5 (author) gives as the location map for the study sites.

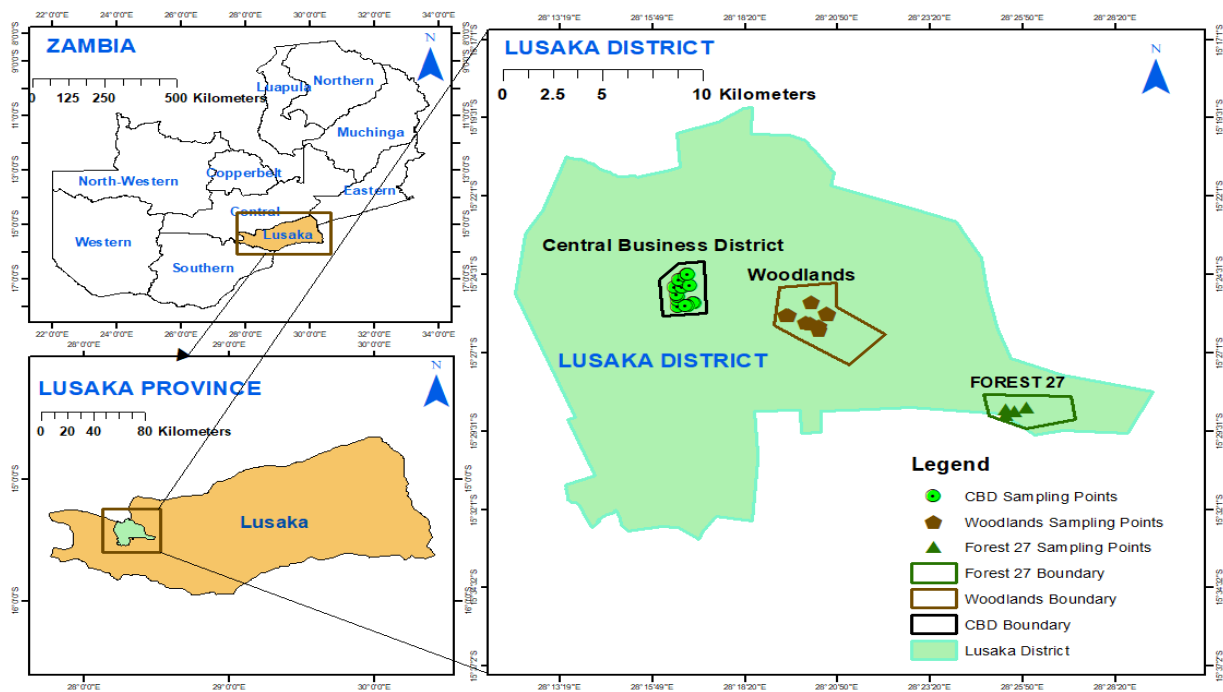


Figure 4. Geographical location of the study area



**Figure 5. Location map for the study sites**

### 3.2 Climate

Lusaka is in the southern part of the central plateau at an elevation of about 1,279 meters. Primarily due to its high altitude, Lusaka features a humid subtropical climate according to Köppen climate classification. Its coldest month, July, has a monthly mean temperature of 14.9°C. The hottest month is October, which sees daily average high temperatures at around 32°C. There are three main seasons: a hot and dry season (mid-August to mid-November), a wet rainy season (mid-November to April) and a cool dry season (May to mid-August) (Lusaka City Council 2008).

### 3.3 Description of the Study Sites

Lusaka CBD is located in the area around surrounding Cairo Road, to the west of the Zambia Railways line from Livingstone to the Copperbelt. This is the historical site where the original colonial town was founded in the early 20<sup>th</sup> century (Myers G.A.2006). Cairo Road, a north–south Multi lane highway roughly four kilometers, is the CBD's main artery, which features office buildings as well as shops, cafes and other retail businesses. . Altitude for CBD is 1280m

above sea level. The vegetation in Lusaka CBD is sparse with a good number of trees along Cairo Road which stretches 1.9km long. The dominating tree species are *Trichilia spp.* Mean temperature for CBD is 25<sup>0</sup>c.

Woodlands is a suburb in Zambia and has an elevation of 1,309 meters. Woodlands is situated northeast of Chilenje, and south of Kabulonga. Its coordinates are Latitude -15.4333300° or 15°25'60.0"S and Longitude 28.3333300° or 28°19'60.0"E. Woodlands Residential area has a higher vegetation coverage than the CBD and most of the vegetation is around the houses. The type of vegetation is miombo woodlands which is a broad-leafed deciduous trees. Its mean temperature is 23<sup>0</sup>c.

Forest No. 27 is important as it is the largest area of indigenous vegetation left on the outskirts of Lusaka City. It is also the headwaters of the Chalimbana River, which means it is an important recharge area. More recently the Forest 27 was degazetted for commercial and residential use leaving only a third of the original forest still gazetted. The forest reserve has shrunk to just 716 hectares (1,770 acres) from its original 1,750-hectare (4,320-acre) span to make way for housing and lifestyle developments. Lusaka East Forest Reserve Number 27 is a forest reserve (class L - Area) in Lusaka Province (Central), Zambia (Africa) with the region font code of Africa/Middle East. It is located at an elevation of 1,223 meters above sea level. Its coordinates are 15°25'60" S and 28°24'0" E in DMS or -15.4333 and 28.4 (in decimal degrees). Mean temperature for forest 27 is 18.2<sup>0</sup>c.

### **Selection of the study site.**

Lusaka district was purposely selected because it has areas which are urbanized at different levels. Lusaka central business district (CBD) is completely urbanized with only a small stretch of 1.9km along Cairo Road which has trees. Lusaka CBD has high density of built areas such as shopping malls, tall buildings housing a mix of offices, services and sometimes residential spaces. Most of the ground spaces have paved surfaces with less green spaces. Woodlands residential was picked because it one of the town ships which are partially urbanized. The area has a combination of both urban forest and buildings. Forest No.27 was selected because of the vast presence of trees.

## **CHAPTER FOUR**

### **RESEARCH METHODOLOGY**

#### **4.0 Introduction**

This chapter discusses the research methodology that was used. The chapter comprises of the philosophical considerations of the research, the research approach and the research design. Sampling, data collection and data analysis have also been discussed. It further explained the size of the sample, the tools that were used to collect data and tools of analysis respectively. Finally, the ethical considerations that the research employed were highlight.

#### **4.1 Philosophical Considerations**

The ontological position of the research was objectivism or positivism. This ontological position asserts that social phenomena and their meanings have an existence that is independent of social actors” (Park et al., 2020). Positivism believes that reality is independent of the researcher. This was achieved in this research by engaging other independent people to help collect data besides the researcher. The researcher’s focus was on measurable empirical data.

The epistemological position of the research was positivism because it adheres to the view that only “factual” knowledge gained through observation (the senses), including measurement is trust worthy (Comte & Bridges, 2015). This was done using Digital psychrometer and weather phone app. The weather app was downloaded from Google Play Store. The reason it was used was to help compare temperature reading of the weather app with the digital psychrometer. The role of the researcher was limited to data collection, which involved measurement and interpretation in an objective way. In other words, the researcher was an objective analyst and distanced herself from personal values in conducting the study. As a result, the research findings were observable and quantifiable. Positivism therefore depends on quantifiable observations that lead to statistical analyses (Park, et al., 2020). Hence, quantifiable and observable data, which contributed to statistical analysis, is what was done in this research.

The axiological position that the research took was value-free. In this research no person was interviewed. Hence, the research is free from people’s opinions. It is based on measurable evidence.

## 4.2 Research Approach

A quantitative research approach was selected for the study therefore, the researcher was guided by quantitative research methods and techniques. Quantitative research emphasizes objective measurements and the statistical, mathematical, or numerical analysis of data collected through questionnaires and surveys, or by manipulating pre-existing statistical data using computational techniques. Quantitative research focuses on gathering numerical data and generalizing it across groups of people or to explain a particular phenomenon (Hancock, 1998). The quantitative data was generated from the temperature readings that were collected in eight (8) months.

## 4.3 Research Design

A longitudinal research design was adopted to anchor this study. A longitudinal study is a type of correlational research study that involves looking at variables over an extended period of time (Gustafsson, 2010). A longitudinal study helped to identify trends in temperature changes during the different times of the year and other UHI-related factors. Data collection for this study took place over a period of eight months from September 2022, January 2023 to July 2023. For three days in a week, Thursday, Saturday and Sunday, ambient air temperature was collected in Lusaka CBD, Woodlands residential and forest No.27. Over this period, at three locations in order to compare the effects of surroundings on temperature changes that can be attributed to the UHI. Temperature collection in the three study sites was conducted between 12 hours and 14 hours during the three days of data collection weekly. The data was collected 1 meter from the ground. This was to help capture even the underground temperature. Coordinates from the study sites are listed in Table 1.

**Table 1: coordinates for the study sites**

Location	latitude	longitude
CBD	15.42992, 15.42532499 15.423562 15.409448600	28.34248, 28.2802969 28.2825156 28.279140899
Woodlands residential	15.429811, 15.43390, , 15,4612081	28.342876 28.33311452 28.3545318
Forest No. 27	15.4791125 15.4898 15.479361	28.4327656 28.43418 28.4246782

#### **4.4 Sampling**

Lusaka was purposively selected because of its rapid urbanization that has taken place and continues to take place, making the phenomenon of UHI more easily comprehensible and noticeable. The three study sites of interest; Lusaka CBD, Woodlands and Forest 27, were also purposively selected to provide comparisons. Lusaka CBD was selected because it has a high concentration and presence of buildings, which may affect wind movement as the velocity of wind is reduced, and it lessens the cooling effect by convection. So, the trapped heat intensifies the effect. In addition, human gathering is huge at the city centers owing to the availability of various facilities; the emissions of CO<sub>2</sub> are high in these areas. CO<sub>2</sub> is a greenhouse gas it enhances atmospheric temperature. The ultimate effect is that it assists in the formation of UHI to a great extent. Woodlands was selected because despite it being a residential area, there is a presence of vegetation (trees) in the urban area. While Forest No. 27 was selected because it has the largest area of indigenous vegetation left on the outskirts of the city with less human interference and settlements. Forest No.27 served as the control group, as the presence of the vegetation in the forest will provide the basis for comparison with the other two study sites that have undergone human encroachment and urbanization.

#### **4.5 Data Collection**

The data in this research was collected using primary data collection techniques.

##### **4.5.1 Primary data**

Primary data was the main source of information, and this is the information that was collected using a psychrometer and the mobile weather application to record daily ambient air temperatures for a period of Eight (8) months. The reason the weather phone application was used was to help compare the temperature reading of the weather phone app with the digital psychrometer. It was a way of checking consistency across devices, which confirmed reliability. If there were any discrepancies between the two instruments, it could have helped to check if the psychrometer was malfunctioning. It was a way of helping with data validation.

##### **4.5.2 Ambient air temperature data**

Ambient air temperature data was collected as follows: September 2022. January 2023 to July 2023. There was focus for a period of three months (May 2023 to July- 2023) in the three study areas. The focus was on the three months because they are the ones that experience reduced

temperature. The researcher wanted to ascertain if UHI is also experienced in the cold season. It is easy to discuss UHI in hot weather due to the high temperature experienced. The longitudinal study helped the researcher to ascertain if UHI is also experienced in the rainy and cold season. The instruments used in temperature data collection were the psychrometer and a weather phone application on the mobile phone. The temperatures were collected between 12 to 14 hours for three (3) days a week, once a day in all three locations and 12 times a month. A distance of 1 meter from the ground was used to measure the temperature. This is because we wanted to capture the effect of heat from the ground and the effects of pavements. 3 area coordinates points were used. The temperature readings were collected every Thursday, Saturday and Sunday, and the readings were recorded as shown in Appendix II. The three days were picked on grounds that Thursday is moderately busy day in the CBD, Saturday is very busy day because everyone want to rush out of the CBD Sunday is a quiet day in the CBD. There is less activities in terms of anthropogenic emissions. Google map was used to help appreciate the difference in forest cover for the study sites. This included the extent of impervious surface, vegetation covers and building densities in the three areas

#### **4.6 Data analysis**

Data was collected from the same spot in the study sites which was properly marked. The spot was secured with cement. The researcher would go with the instruments on the day and time for collecting the temperature readings. The collected Data sorted in Microsoft Office Software (MS) Excel Spreadsheet version 16, was applied as input to the Statistical Package for the Social Sciences (SPSS) Software version 27. The spss helped to prepare the data for inferential analysis. In this case Anova and linear regression. In this way, the researcher was able to identify patterns and extract useful insights in order to answer the set objectives. Trend comparative analysis was used as a technique for extracting an underlying pattern of temperature differences across the study site for the eight-month period. This was in order to investigate the occurrence of UHI in Lusaka CBD and assess how intense the UHI is in Lusaka CBD. ANOVA was used in order to test whether the mean temperature in the study sites differed significantly. It helped to understand the variations within groups. Pearson's correlation was used to measure the strength and direction of the linear relationship. It helped the researcher to measure how strong temperature and vegetation are related to each other. For all statistical tests, a p-value of less than 0.05 was considered to be statistically significant.

#### **4.7 Ethical Considerations**

Ethical clearance of this study was obtained from the Natural and Applied Sciences Research Ethics Committee at the University of Zambia. As the study was conducted on non-human, it did not violate the ethical principles of privacy, confidentiality and justice. However, the ambient data collected was kept in confidence and was used only for the purpose of this study, and was made accessible only to the researcher, supervisor, and statistician. The instruments used in collecting data were also environmentally friendly.

#### **4.8. Study Limitations**

There were some limitations to this paper. Due to the longitudinal research design, the people who helped in collecting data needed to be reminded time and again to send the data. Another limitation is that this study did not use LULC analysis of Landsat images it only concentrated on temporal variations in temperature. Another limitation is that nighttime temperature data was not collected due to safety reasons. However the trend is unlikely to be different since the levels of absorption and heat emission is determined by the existence of internal substance of the materials used to build towns, which still remain the same with the same absorption and emitting properties whether night or day. Despite its limitations, the study's novelty stems from the fact that it is an extensive review of the literature combined with an empirical analysis of data from three geographical regions of Lusaka. Furthermore, the work done here provides supporting evidence that cities are especially vulnerable to UHI, but not to the same extent.

## **CHAPTER FIVE**

### **PRESENTATION OF FINDINGS**

#### **5.0 Introduction**

Using the data collected in Chapter four, the analyses were conducted and are presented in this chapter. Firstly, the changes in ambient air temperatures were presented, followed by trends in temperature changes in the study setting; then the relationship between the temperature changes in the CBD, Woodlands residential area, and Forest No.27 was presented. Thereafter, field observations in relation to land cover and land use were done in order to ascertain the role of urban forest in mitigating the effects of UHI.

The findings were presented, interpreted and analysed according to the research questions.

- Responds to the occurrence of the UHI effect. What is the occurrence of the UHI effect in Lusaka urban?
- Investigates how intense the UHI effect is in Lusaka CBD. How severe is the UHI effect in Lusaka urban in comparison with the residential area, woodlands and forest No. 27?
- What is the role of urban forest in mitigating UHI effect in Lusaka urban?

#### **5.1.1 Temperature change for September 2022, January 2023 to April 2023**

Temperature for September 2022, January 2023, February 2023, March 2023 and April 2023 were collected to help observe the temperature trends at different times of the year. From the data, it shows that the ambient temperature readings in September were high while from January to April, temperatures were decreasing. Temperatures in the CBD were higher than in the woodland residential area and forest No. 27 (Table 2.) Forest 27, which had more vegetation, recorded the lowest temperatures (September: 25°C, January: 19°C, February: 21°C, March: 21°C, and April: 19°C).

**Table 2: Changes in ambient air temperatures for September 2022, January 2023 to April 2023\***

Places	Months				
	Sep-22	Jan-23	Feb-23	Mar-23	Apr-23
<i>CBD</i>	28 ( $\pm 0.7$ )	22 ( $\pm 0.6$ )	25 ( $\pm 0.4$ )	26 ( $\pm 0.4$ )	26 ( $\pm 0.7$ )
<i>Woodland Residential</i>	27 ( $\pm 0.5$ )	21 ( $\pm 0.4$ )	23 ( $\pm 0.6$ )	23 ( $\pm 0.5$ )	23 ( $\pm 0.5$ )
<i>Forest NO. 27</i>	25 ( $\pm 0.3$ )	19 ( $\pm 0.2$ )	21 ( $\pm 0.5$ )	21 ( $\pm 0.4$ )	19 ( $\pm 0.2$ )

\*Data presented as mean  $\pm$  SEM.

Temperature readings were used to identify and quantify the UHI effect in the three study sites. As shown in Table 3. The mean ambient air temperature shows the lowest temperature in forest NO.27 in all the months of data collection. From the above data, we can say indeed UHI occurs in Lusaka urban because it recorded the highest temperature reading than woodlands residential and forest NO. 27

### 5.1.2. Mean temperature for September.

The ANOVA (Table 3) below gives us a summary of the temperature means in the month of September.

**Table 3: ANOVA for September 2022**

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	38.11111	2	19.05556	12.42754	0.000656	3.68232
Within Groups	23	15	1.533333			
Total	61.11111	17				

Since the p-value is much smaller than 0.05. We reject the null hypothesis. This means during the month of September there was a statistically significant difference in mean temperature among the three locations.

### 5.1.3. Mean temperature for the month of January 2023

The ANOVA (Table 4) below gives us a summary of the mean temperatures during the month of January in the selected study sites.

**Table 4: Anova output for the month of January 2023**

Anova: Single Factor

#### SUMMARY

Groups	Count	Sum	Average	Variance
CBD	10	221	22.1	3.877778
WOODLANDS	10	208	20.8	1.288889
FOREST	10	194	19.4	0.266667

#### ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	36.46666667	2	18.23333	10.06748	0.000541	3.354131
Within Groups	48.9	27	1.811111			
Total	85.36666667	29				

The ANOVA results showed a statistically significant difference in means among the three locations.  $F=10.067$ ,  $p=0.0005$ . Since the p value is below the significant threshold (0.005) we reject the null hypothesis, this indicates that at least one location has a significantly different mean temperature.

### 5.1.4. Mean temperature for the month of February 2023

The ANOVA (Table 5) gives a summary of the mean temperatures during the month of February.

**Table 5: Anova output for the month of February 2023**

#### SUMMARY

Groups	Count	Sum	Average	Variance
CBD	11	273	24.81818	1.963636
WOODLANDS	11	258	23.45455	4.272727
FORESTS	11	230	20.90909	3.090909

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	86.60606	2	43.30303	13.92788	5.2677E-05	3.31583
Within Groups	93.27273	30	3.109091			
Total	179.8788	32				

The ANOVA results for February 2023 indicate a statistically significant difference in ambient air temperatures among the three locations. The F-value (13.92788) is much higher than the F-critical value (3.3158), and the p-value (0.000526) is way below the 0.05 threshold, confirming that temperature variations between locations are not due to chance. This suggests that location had a notable effect on temperature variations in February 2023.

**5.1.5 Ambient Air temperature for March 2023.**

The trend lines of the minimum temperature-time graph in the month of March 2023 showed varying rates of temperature change across the three locations: CBD, Woodlands, and Forest No.27. The results indicate a general decrease in temperature over the observed period as the days progressed. (CBD:  $r^2=.013$ ,  $p=0.737$ ; Woodlands residential area:  $r^2=0.195$ ,  $p=0.174$ ; Forest 27:  $r^2=0.062$ ,  $p=0.460$ ; respectively)The rate of change in temperature was higher in the Forest 27 ( $b= 0.038$ ) compared to Woodlands residential area ( $b= -0.081$ ) and CBD ( $b= 0.016$ ) (Figure 6).

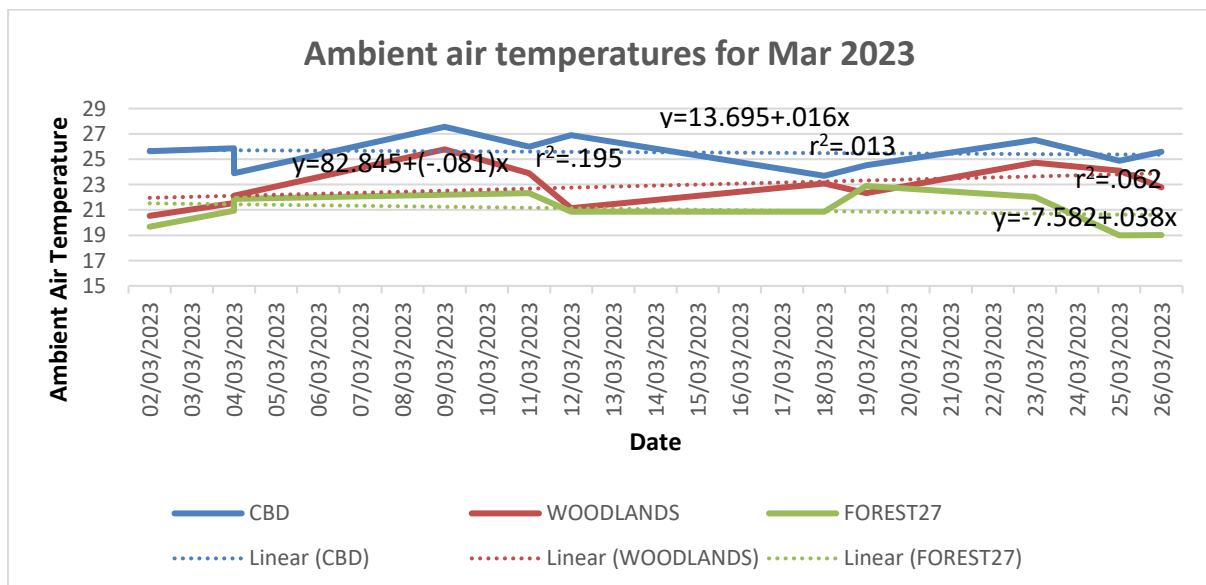


Figure 6. Mean temperature time graph for the month of March 2023

**Table 6: ANOVA output for March 2023**

Anova: Single Factor

**SUMMARY**

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
CBD	11	281.05	25.55	1.4786
WOODLANDS	11	252.03	22.91182	2.557256
FOREST	11	231.62	21.05636	1.837645

**ANOVA**

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	112.1834	2	56.09172	28.64989	1.1E-07	3.31583
Within Groups	58.73502	30	1.957834			
Total	170.9185	32				

The p value here suggests strong evidence against the null hypothesis. There are statistical differences in the temperature means among the three places (Table 6). This confirms the presence of UHI.

**5.1.6. Ambient Air temperature for the month of April 2023.**

The summary of the ambient air temperature is presented in the Anova Table 7.

**Table 7: Anova output for April 2023****SUMMARY**

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
CBD	6	170	28.33333	2.666667
woodlands	6	163	27.16667	1.366667
FOREST	6	149	24.83333	0.566667

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	38.11111	2	19.05556	12.42754	0.000656	3.68232
Within Groups	23	15	1.533333			
Total	61.11111	17				

From September 2022, January to April 2023 the anova results show a statistically significant difference in mean temperature among the three location. This is evident because the p values were all less than 0.005. The results suggest that the CBD has significantly higher temperatures in comparison to forest No. 27, whereas temperature in woodlands is closer to those in the CBD. This indicates that UHI effects may be influencing temperature variations across the locations. This is because the three areas differ in terms of heat absorbing material and vegetation cover. These results helps us respond to research questions number (i) and (II) that indeed UHI occurs in the CBD and that it is severe in comparisons to woodlands residential and forest No.27 .

**5.1.7 Temperature change for May to July 2023**

According to the ambient temperature distribution values for May, June, and July 2023, Lusaka CBD recorded higher overall temperatures (12.4 – 26.3°C, mean = 24.9°C) compared to slightly vegetated Woodlands residential area (11.4 – 24.5°C, mean = 23°C) and highly vegetated Forest No. 27 (9.8 – 19.9°C, mean = 18.2°C) (Table 8).

**Table 8: Change in ambient temperature from May to June**

<b>Variable</b>	<b>Month*</b>			<b>Mean</b>
	<b>May</b>	<b>June</b>	<b>July</b>	
Lusaka CBD ambient temperature				
<i>Minimum reading</i>	13.5 (±0.9)	12.7 (±2)	11.2 (±1.6)	12.4 (±1.8)
<i>Maximum reading</i>	28 (±0.8)	26.7 (±2.2)	24.4 (±2.8)	26.3 (±2.6)
<i>Average reading</i>	26.5 (±0.6)	25.4 (±2.3)	23.1 (±2.8)	24.9 (±2.6)
Woodlands residential area ambient temperature				

Variable	Month*			Mean
	May	June	July	
<i>Minimum reading</i>	12.8 (±0.7)	11.5 (±1.7)	10 (±1.2)	11.4 (±1.7)
<i>Maximum reading</i>	26 (±1)	24.8 (±2.3)	22.9 (±2.5)	24.5 (±2.4)
<i>Average reading</i>	24.7 (±1.3)	23.1 (±2.2)	21.4 (±2.3)	23 (±2.4)
Forest No.27 ambient temperature				
<i>Minimum reading</i>	11.6 (±0.8)	9.8 (±1.1)	8.4 (±1)	9.8 (±1.6)
<i>Maximum reading</i>	20.6 (±1.9)	21 (±1)	18.4 (±3.9)	19.9 (±2.8)
<i>Average reading</i>	18.7 (±2.2)	18.5 (±2.3)	17.5 (±2.1)	18.2 (±2.2)

\*All values are presented as means and standard deviations (±)

According to the above findings the higher temperature in the CBD in comparison to woodlands residential and forest No. 27 confirms the occurrence of UHI. The urban features in the CBD such as high building densities, paved surfaces and less green spaces are attributed to the cause in the high temperature indicated in the data above. The average temperature for CBD is 26.5<sup>0</sup>c in comparison to woodlands residential of 24.7<sup>0</sup>c while Forest No. 27 has 18.7<sup>0</sup>c in the month of May. This difference shows us how severe the UHI effect is in the CBD.

## 5.2.0 Trends in temperature changes over selected months in Lusaka CBD, Woodlands and Forest No. 27

The values of minimum temperature from the CBD, Woodlands residential area and Forest No.27 in Lusaka were recorded over a period of three months (May 2023 to July 2023) and were analyzed. Line graphs

### 5.2.1 Ambient air temperatures for May 2023

As shown in Figure , trend lines of minimum temperature-time graph showed no significant difference as minimum temperatures did not consistently rise or drop during the month of May as shown by low R<sup>2</sup> values (CBD: r<sup>2</sup>=0.0036, p=0.853; Woodlands residential area: r<sup>2</sup>=0.1089, p=0.295; Forest 27: r<sup>2</sup>=0.091, p= 0.341; respectively). Concerning the rate of change, Figure 7 indicates that there were negligible variations in minimum temperatures from the three locations in the month of May: with temperatures in Woodlands residential area showing a

higher positive rate of change ( $b=0.0297$ ) and temperatures in the CBD showed a lower negative rate of change ( $b= -0.0068$ ).

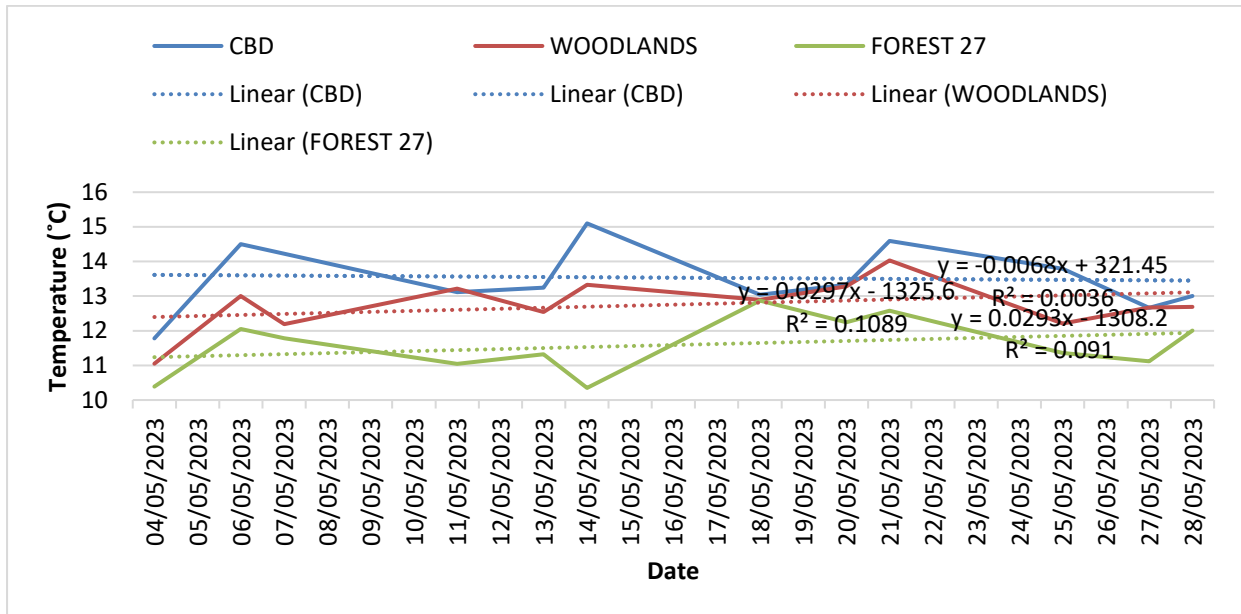


Figure 7. Minimum time graph for the month of May 2023

Trend lines of maximum temperature-time graph in the month of May for CBD and Woodlands residential area showed that there were no significant changes in maximum temperature over the month of May in CBD and woodlands residential. (CBD:  $r^2=0.0314$ ,  $p=0.582$ ; Woodlands residential area:  $r^2=0.0696$ ,  $p=0.407$ ; respectively): indicating that there was minimal increase in maximum temperatures from these locations in the month of May. However, the trend line for maximum temperatures in Forest No.27 showed a significant increase in maximum temperature over the course of the month ( $r^2=0.3975$ ,  $p=0.028$ ). The rate of change was higher in Forest 27 ( $b=0.1472$ ) compared to Woodlands residential area ( $b=0.0311$ ) and the CBD ( $b=0.0164$ ), Figure 8

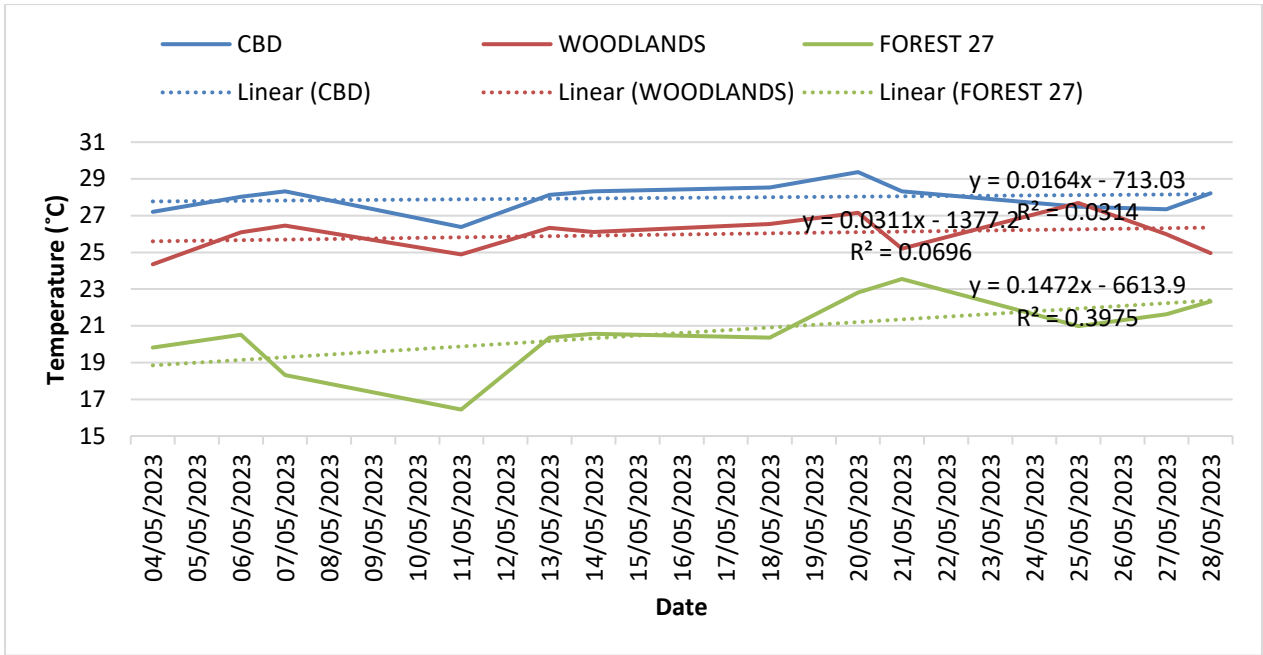


Figure 8. Maximum time graph for the month of May 2023

### 5.2.2. Ambient air temperatures for June 2023

The trend lines of minimum temperature-time graph in the month of June showed significant negative slopes for all three locations indicating significant minimum temperature changes during the month of June. (CBD:  $r^2=0.5936$ ,  $p=0.002$ ; Woodlands residential area:  $r^2=0.4522$ ,  $p=0.013$ ; Forest 27:  $r^2=0.517$ ,  $p=0.006$ ; respectively): This implies that there was a significant drop in temperatures from these locations as the month progressed. The rate of change was higher in the CBD ( $b= -0.1703$ ) compared to Woodlands residential area ( $b= -0.1266$ ) and Forest 27 ( $b= -0.0888$ ) (Figure 9).

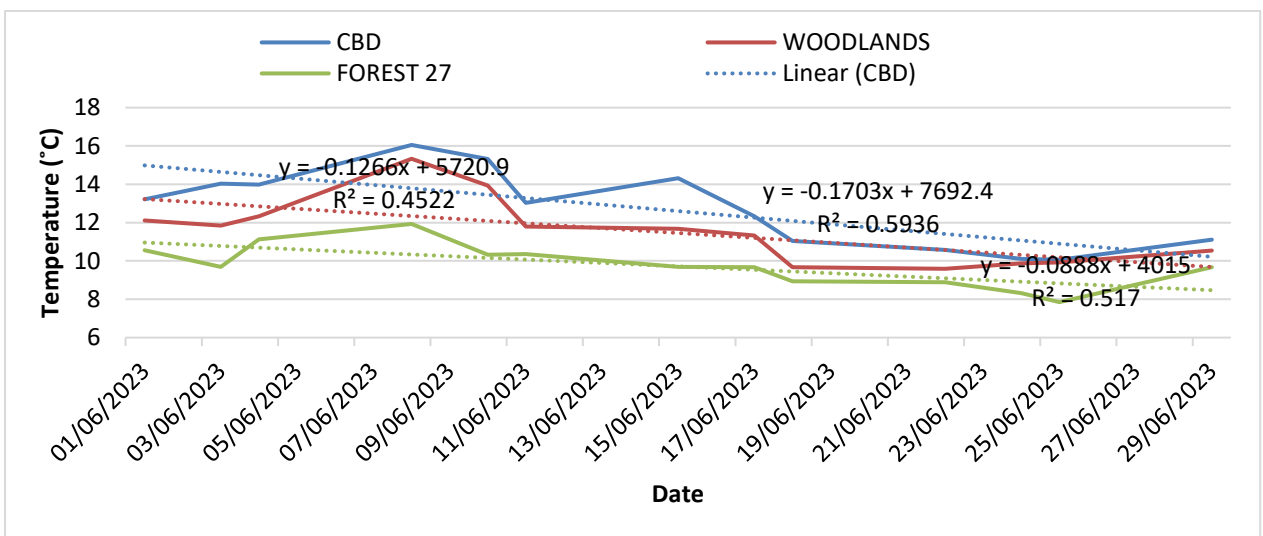


Figure 9. Minimum temperature time graph for the month of June 2023

The trend lines of maximum temperature-time graph in the month of June for CBD and Woodlands residential area showed that there was a significant change in maximum temperature over the month of June in CBD and woodlands residential area (CBD:  $r^2=0.5419$ ,  $p=0.004$ ; Woodlands residential area:  $r^2=0.4478$ ,  $p=0.012$ ; respectively): indicating that there was significant decrease in maximum temperatures from these locations in the month of June. However, the trend line for maximum temperatures in Forest No.27 showed that there was no significant change in maximum temperature over the month of June in CBD and forest No. 27. ( $r^2=0.1831$ ,  $p=0.145$ ). The rate of change was higher in the CBD ( $b= -0.1815$ ) compared to Woodlands residential area ( $b= -0.168$ ) and Forest No.27 ( $b= -0.0493$ ) (Figure 10).

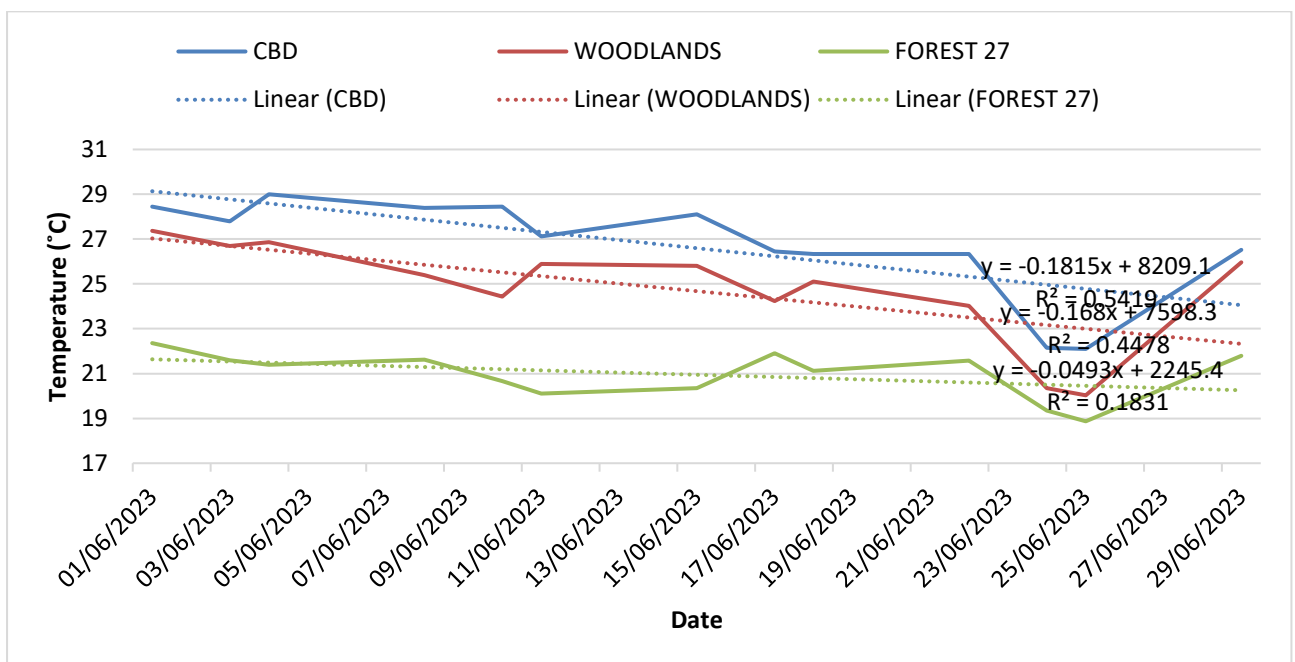


Figure 10. Maximum temperature time graph for the month of June 2023

### 5.2.3 Ambient air temperatures for July 2023

Trend lines of minimum temperature-time graph in the month of July showed significantly positive slopes for all three locations indicating significant minimum temperature changes during the month of July (CBD:  $r^2=0.1221$ ,  $p=0.221$ ; Woodlands residential area:  $r^2=0.1552$ ,  $p=0.163$ ; Forest 27:  $r^2=0.0571$ ,  $p=0.411$ ; respectively): indicating that there was minimal increase in temperatures from these locations as the month progressed. However, the rate of change was higher in the CBD ( $b=0.0572$ ) compared to Woodlands residential area ( $b=0.0467$ ) and Forest 27 ( $b=0.0251$ ). (Figure 11).

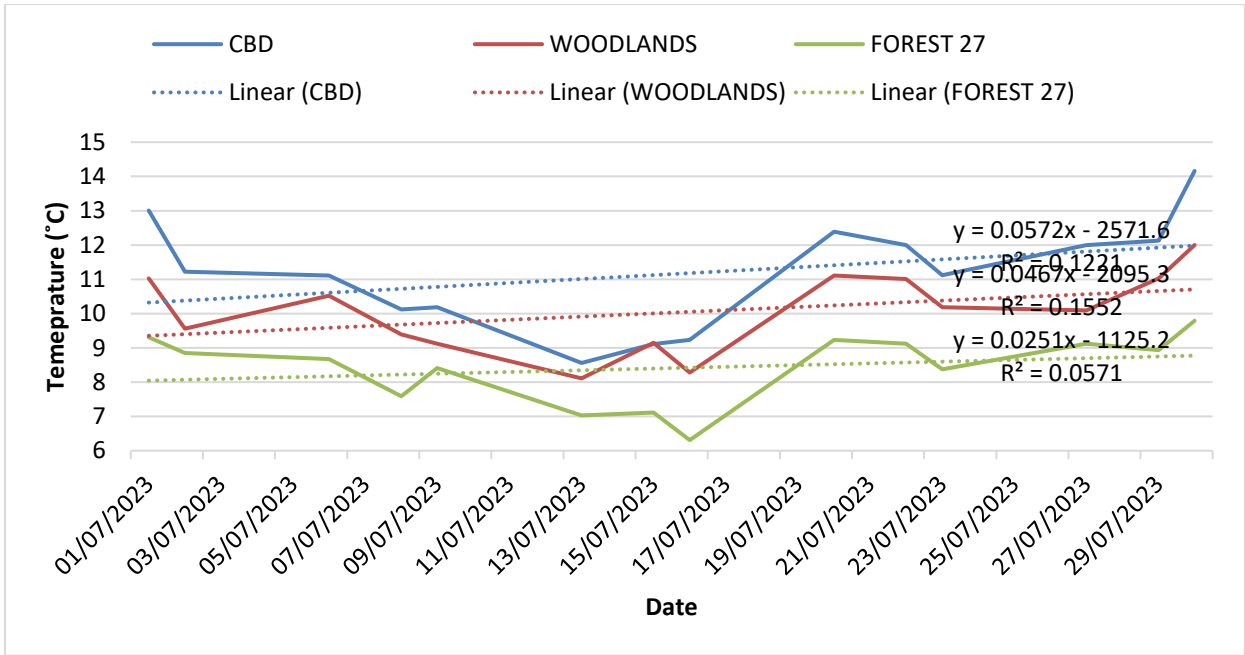


Figure 11. Minimum temperature time graph for the month of July 2023

Trend lines of maximum temperature-time graph in the month of July for CBD and Woodlands residential area showed there was no significant difference (CBD:  $r^2=0.3714$ ,  $p=0.021$ ; Woodlands residential area:  $r^2=0.3952$ ,  $p=0.016$ ; respectively): indicating that there was a significant increase in maximum temperatures from these locations in the month of July. However, the trend line for maximum temperatures in Forest No.27 showed a significant decrease in temperature changes in the month of July ( $r^2=0.0302$ ,  $p=0.553$ ). The rate of change was higher in the CBD ( $b=0.1729$ ) compared to Woodlands residential area ( $b=0.1587$ ) and Forest No.27 ( $b=0.0695$ ) (Figure 12).

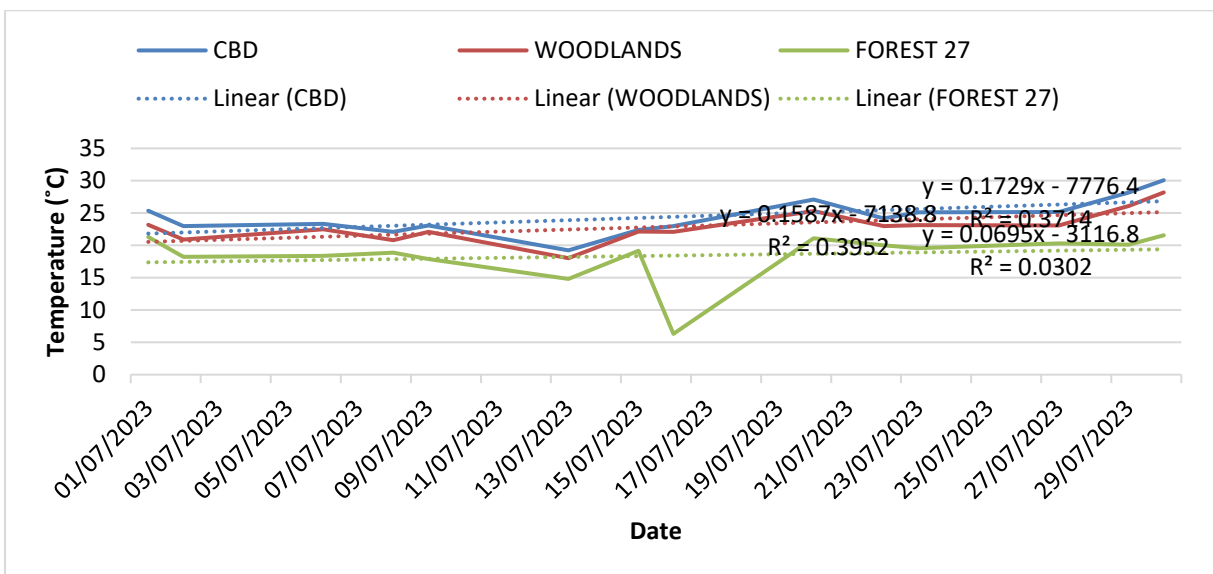


Figure 12. Maximum temperature time graph for the month of July 2023

### 5.3. Correlations between Temperature Changes in the CBD, Woodlands and Forest 27

Table 9 shows that there was a strong correlation in temperatures in the CBD and Woodlands residential area ( $r=0.887$ ,  $p=0.001$ ). The temperatures in woodlands residential area raises at a higher rate as the temperatures in the CBD rise. However, in Forest No. 27, the correlation with the CBD ( $r=0.666$ ,  $p=0.001$ ) and Woodlands residential area ( $r=0.644$ ,  $p=0.001$ ) was generally low. That means the forest takes longer to respond to temperature changes than does the CBD and Woodlands residential area. This explains why forest No.27 has lower temperature than the CBD. The vegetation cover in forest No.27 provides cooling. The value of  $p$  is less than 0.05. The results are statistically significant, meaning the relationship is unlikely to be due random chance. It is due to the differences in the variables under discussion.

**Table 9: Correlation between the variables**

Parameter	Variables	CBD	Woodlands	Forest 27
<b>CBD</b>	Pearson Correlation	1	0.887	0.666
	Sig. (2-tailed)		0.001	0.001
	N	39	39	39
<b>Woodlands</b>	Pearson Correlation	0.887	1	0.644
	Sig. (2-tailed)	0.001		0.001
	N	39	39	39
<b>Forest 27</b>	Pearson Correlation	0.666	0.644	1
	Sig. (2-tailed)	0.001	0.001	
	N	39	39	39

### 5.4. Outputs of General Linear Model

To examine the “shape” of the temperature change-location relationship, the researcher hypothesized that there would be a negative linear relationship between time of temperature readings and the location where the temperature readings were taken. The null hypothesis ( $H_0$ ) stated that there are no mean differences among mean temperature readings in the different locations. Table 10.

**Table 10: Test of within-subjects Effect**

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Month	Sphericity Assumed*	926.823	2	463.412	303.075	<b>0.001</b>
	Greenhouse-Geisser	926.823	1.559	594.310	303.075	<b>0.001</b>
	Huynh-Feldt	926.823	1.614	574.188	303.075	<b>0.001</b>
	Lower-bound	926.823	1.000	926.823	303.075	<b>0.001</b>
Error (month)	Sphericity Assumed	116.206	76	1.529		
	Greenhouse-Geisser	116.206	59.261	1.961		
	Huynh-Feldt	116.206	61.338	1.895		
	Lower-bound	116.206	38.000	3.058		

\*Used the "Sphericity Assumed" df, Mean Square, Error, & sig.

There was a difference among the group means during the temperature recording months in the studied places CBD, woodlands residential and forest 27,  $F(2, 76) = 303.075$ ,  $p < 0.001$ , Mean Square (MSe) = 1.529. (See table 11). This test within subject effect analysis helped to determine whether location dependent factors significantly influenced temperature variation within Lusaka district.

**Table 11: Tests of within-subjects contrasts**

Source	Month	Type III Sum of Squares	df	Mean Square	F	Sig.
Month	Linear	874.283	1	874.283	441.591	<b>0.001</b>
	Quadratic	52.540	1	52.540	48.729	<b>0.001</b>
Error (month)	Linear	75.234	38	1.980		
	Quadratic	40.972	38	1.078		

This test within subject examined how the difference within the same subject (UHI) changes across different levels of a factor in this case the different locations. The difference in the temperature reading in the three locations helps us analyse how intense UHI is in Lusaka CBD in comparison to woodlands residential and forest No. 27. It explains whether vegetation cover has significant altered UHI intensity over time.

Presentation of findings on the role of urban forest in regulating the UHI was done using Google images which was supported with the temperature readings recorded in the three study sites.

### 5.1.2. Lusaka Central Business District.

Lusaka Central Business District is a growing city. It is characterized with dense buildings and less green spaces. (Figures 13 and 14). The dense buildings reduce the flow of air, creating a canyon effect. This is about warm air being trapped, creating UHI. The minimal green spaces reduce the cooling effect that vegetation can provide.



Figure 13. Google Map of CBD showing building densities and area of vegetation



Figure 14. CBD with less green spaces

### 5.1.3 Woodlands residential

The morphology of woodlands residential (Figure 15) shows that it has moderate number of trees or forest in between the buildings. UHI can still occur, though at a lower intensity. This is because some cooling effect from forest does counterbalance the heat produced by the nearby infrastructures. This explains why woodlands residential have lower temperature in comparison to Lusaka CBD.

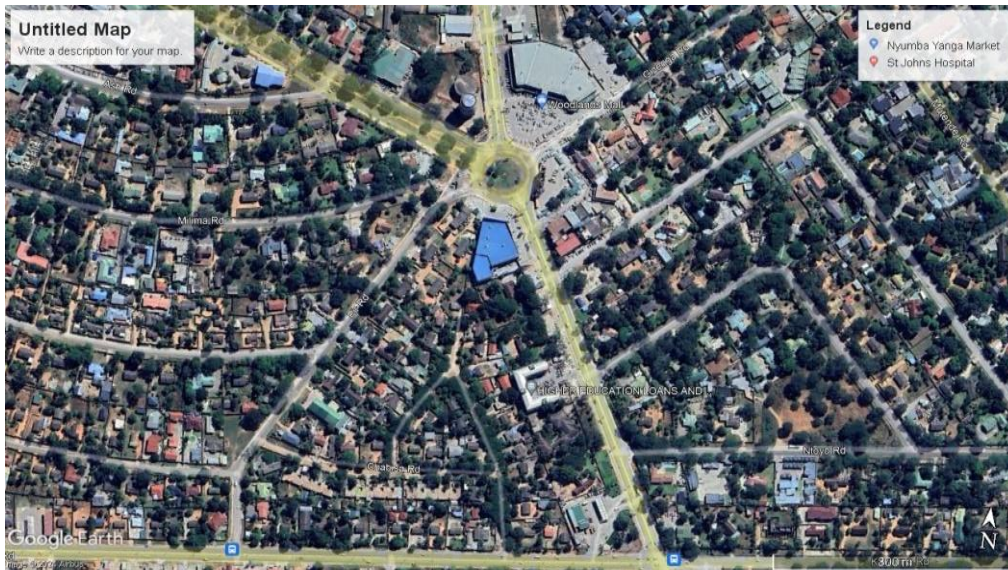


Figure 15. Google map showing part of woodlands residential

### 5.1.4 Forest 27

Forest No. 27 is predominantly dense woodland with minimal built infrastructure. Figure 16 illustrates the land cover and land use patterns, enabling correlation with the recorded temperature data.

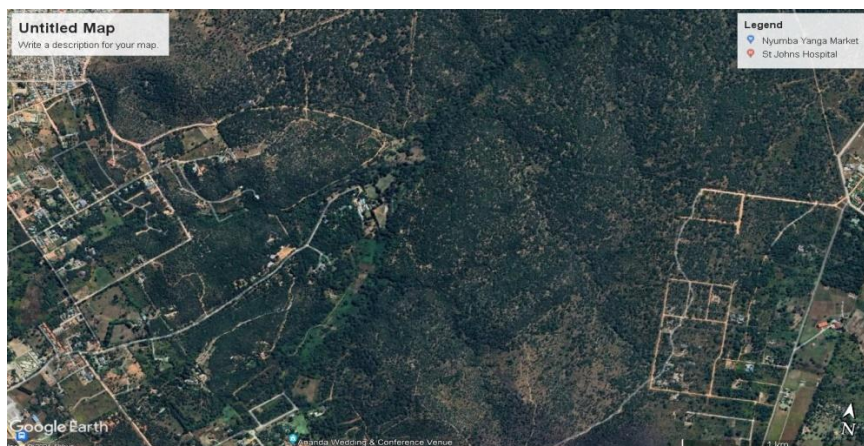


Figure 16. Google map showing part of forest No.27

## CHAPTER SIX

### DISCUSSION OF FINDINGS

#### 6.0 Introduction

This chapter provides a discussion of findings as presented in chapter five above in line with main themes of this research

#### 6.1. UHI in selected cities in the world.

The empirical evidence presented in this study highlights the significant and multifaceted impact of the Urban Heat Island (UHI) effect on urban centres in Lusaka district. The pronounced temperature disparities observed between urban and rural areas confirm and expand upon existing research that documents comparable trends in various African cities (Omonijo et al., 2017; Adelekan, 2010). Specifically, this study reveals temperature differentials of up to 3.5°C, which closely align with Omonijo et al.'s (2017) findings from Lagos, Nigeria, where temperature variations reached as high as 4°C between urban and rural settings. This study examined how urban forests can help regulate the UHI effect in Lusaka district. The results collected from the three areas, namely, CBD, woodlands residential and forest 27 indicate that the UHI affects Lusaka district. UHI were more prevalent in the CBD than in forest 27 with a mean increase of 6.7°C CBD compared to forest 27. This finding indicates that the temperature in the CBD affluent with buildings ranges from 12.4 - 26.3°C, presumably due to fewer green areas and wind than average and a high number of exposed people. This finding supports the findings of a cross-country study conducted by Leal Filho et al. (2021), who discovered that the vast differences in the share of green urban areas, ranging from 1.8 percent in Belgrade and 5 percent in Lagos to 46 percent in the Greater Sydney area and more than 46 percent in Beijing, indicate that these cities are already being exposed to UHI effects at different levels, a trend also described by Gunawardena et al (2017). Because the percentage of green areas is a proxy for heat sensitivity and natural resilience to heat stress, actions that increase vegetated and blue areas may foster adaptive capacity and reduce exposure to heat island-related thermal distress, particularly during hot seasons.

Despite the fact that their beneficial effect on thermal comfort (TC) has long been recognized, and there is growing recognition of their importance as an adaptation and resilience tool (Broto and Bulkeley, 2013), current urban expansion processes tend to deplete urban green resources (Nowak and Greenfield, 2018). This trend may be exacerbated in developing countries with

high rates of urbanization, such as Zambia. Current green areas are thus expected to fall short of keeping outdoor TC in cities within a comfortable range under existing climate change scenarios (Gill et al., 2007), a trend that may cause great thermal discomfort and, among other things, negatively influence their livability. As a result, increasing the share of a city's green areas as much as possible may be required to generate real improvements in urban wellbeing (Gill et al., 2007; Zölch et al., 2016).

The fact that UHI impacts Lusaka's CBD, to varying degrees, suggests that addressing the UHI effect effectively remains a complex phenomenon that necessitates a comprehensive analysis of a variety of influencing parameters in order to identify appropriate adaptation tools. However, the data gathered in this study indicate that the CBD has fewer green areas than woodlands suburbs and forest 27, making it difficult to mitigate the UHI effect in central and commercial districts and downtown areas. This finding contrasts with the findings of Leal Filho et al. (2021), who found that green areas, which are beneficial to mitigating the UHI effect, i.e., a certain baseline, can be found in all sampled cities. It was discovered that the disparity in results also indicated that some city planning schemes, such as connected parks, leisure areas and additional green areas as potential beneficial influence of green resources. Afforestation will help in providing the green spaces which will be needed in the CBD in order to reduce the UHI.

#### **6.2.0. The role of vegetation in reducing surface and air temperature.**

According to literature, trees covers are thought to have a beneficial effect on outside thermal comfort in cities (Norton et al, 2015, Zolch et al 2016). Green groves and forests have a cooling effect on air temperature. In this study, it was discovered that tree grooves were scarce in Lusaka CBD. The fraction of the ground covered by vegetation and trees is very small. 1.9 km stretch in Cairo road. As seen on Google map comparing vegetation cover in Lusaka CBD and forest No.27. The absence of large area for vegetation and trees in Lusaka CBD impacts UHI in several ways one of which is temperature. The CBD recorded higher temperature average 25<sup>0</sup> compared to forest No. 27, which had an average of 18.2<sup>0</sup>. The temperature differences as shown in data presentation in the trend line results, gives the more reason why urban forest should be encouraged in order to mitigate the effect of UHI. This is because vegetation especially trees have shown a lot of benefits in reducing the effect of UHI. Trees intercept solar energy. The shade provided by trees help reduce surface temperature, trees cool buildings by cooling the air through evapotranspiration. With urban forest trees will be able to reduce the

UHI experienced in Lusaka because trees will absorb the carbon dioxide. The carbon dioxide is emitted by several activities in the cities. Green space has a significant impact on TC particularly during heat waves.

Despite the fact that opportunities for creating new green areas in the CBD may be limited, green spaces distributed evenly throughout the city may help reduce vulnerability to UHI. This is because land cover including green space and buildings can influence temperature levels. The shades provided by trees reduce surface temperature; reduced temperature offers thermal comfort to urban resident making outdoor space more livable

### **6.3.1. The occurrence of the UHI effect in Lusaka urban**

A comparative analysis of temperature profiles across three locations—Lusaka's Central Business District (CBD), the Woodlands Residential Area, and Forest No. 27—reveals noteworthy spatial variations in the UHI effect. The temperature data from the three areas was analyzed using linear trends. This helped the researcher to observe changes in one variable in this case, temperature changes, as they were associated with changes in another variable. In this case the green spaces in the three areas. Temperature readings presented in chapter five helped the researcher to conclude that indeed UHI occurs in Lusaka. The Lusaka CBD exhibits the highest daytime temperatures, peaking at 32.5°C. This heightened temperature is attributable to the area's dense concentration of built environments, extensive pavement, and heightened anthropogenic activities. In contrast, Forest No. 27 presents the lowest average temperatures, around 25.5°C, which can be attributed to its rich vegetation cover and minimal impervious surfaces that effectively mitigate the UHI impact. The Woodlands Residential Area, with an average temperature of 28.5°C, emerges as an intermediary case, reflecting a moderate UHI effect due to the coexistence of residential structures and green spaces. This is in line with Assaf and Assaad, (2023) who discussed that the UHI is high in urban areas due to economic development. High levels of urbanisation in the Lusaka CBD have contributed to the occurrence of the UHI.

### **6.3.2. The severity of the UHI in Lusaka CBD in comparison to woodlands residential and forest No.27.**

The parts of Lusaka district selected for this were Lusaka CBD, woodlands residential and forest No. 27. To assess the severity of the UHI in Lusaka CBD the influence of factors such as population density, industrial activities, carbon emission and transportation were evaluated.

The study discovered that there is a close relationship between population density, transportation and heat released. Places with high population density at the time of data collection, the temperature was high. In this case the population density and carbon emission from vehicles was high in the Lusaka CBD at the time of data collection compared to woodlands residential and Forest No.27. The crowded city contributed to high temperatures due to high release of carbon dioxide from the people. Emission from vehicles also contributed to the severity of the UHI in the Lusaka CBD. The CBD experiences large traffic in flow in and out of town. The factors discussed above contribute to the severity of the UHI. The findings of the research are in collaboration with Kim, S.W. and Brown, R.D., (2021) they discussed that Urbanization has led to changes in the physical environment of cities which has rapidly changed due to economic development and increased concentration of the population in the cities. The population increase of traders in the Lusaka central business town, the emission from vehicles has contributed to the CBD experiencing severe UHI in comparison to woodlands residential and forest No.27. (Ullah, et al., 2023). discussed that land use has contributed to escalating temperature in the urban areas.

### **6.3.3. Assessment of the role of urban forest in mitigating the UHI effect in Lusaka.**

Images from Google earth showing land cover and vegetation cover were assessed, the Anova output for the test of within subject contrast and test within subject effects and Field survey were done. Assessing the extent of built up area versus green space was done. In this case a comparison of Lusaka CBD, woodlands residential and forest No.27 was done. Land use layout and design of buildings in Lusaka CBD, woodlands residential and forest 27 were studied from Google map. Building densities, height and arrangement were done. Based on the assessment it was discovered that the area with high density buildings and less vegetation recorded high temperature readings. Khamchiangta and Dhakal (2019) in his paper he studied how heat intensity is related to building coverage. From the data collected Lusaka CBD which has a high density of building recorded higher temperature reading. Observing the rapid urban expansion and numerous infrastructure developments in Lusaka CBD in relation to the high temperature indicates that Lusaka CBD is suffering UHI effect and its associated environmental and social challenges. Woodlands residential which is moderately forested recorded moderate temperature mean. This is because woodlands residential have a good number of trees and green belts which promote cooling island hence reducing the effect of UHI. From the research findings it is revealed that urban forest can significantly mitigate the UHI intensity. Forest No.27 which has a lot of green area recorded reduced ambient average

temperature of 18<sup>0</sup>c compared to Lusaka CBD with less vegetation which recorded an average ambient temperature of 23<sup>0</sup>c. Land change and pattern of urban land use are critical factors that influence on regulating UHI. If some of the land can be revegetated, green spaces in Lusaka CBD will increase therefore help regulate the effect of UHI. With less trees surface temperature are expected to escalate.

## CHAPTER SEVEN

### CONCLUSION AND RECOMMENDATIONS

#### 7.0 Introduction

The study of the UHI effect has long been a hot topic in the field of urban ecology and environmental issues. With the growing impact of population growth, rapid urbanization, and global climate change on the urban ecological environment, an increasing number of scholars and policymakers have begun to focus on UHI issues. This chapter provides a conclusion and recommendations in relation with the findings as presented in chapter six above, in line with main themes of this research.

#### 7.1 Conclusion

According to the study, Lusaka CBD is generally 2.6 - 6.4° hotter than forest 27 areas. That is why we conclude that indeed Lusaka district experiences UHI. The UHI is caused by a combination of factors related to both the built environment and human activities. The presence of impermeable surfaces, such as pavements and buildings, absorbs and retains heat during the day and gradually releases it during the night, making urban areas warmer than surrounding rural areas. This is because of presence of fewer trees and green spaces which can absorb this heat and provide cooling. When the urban environment is densely built and green spaces are scarce, cities are more vulnerable to the UHI effect. This study's findings have shown that urban forest is an important aspect in regulating the UHI. Urban forest can be increased by urban revegetation. Urban revegetation could be a counter measures to help reduce the effect of UHI. Urban revegetation to be seen as a forecast future solution in light of increasing climate change and urbanization

#### 7.2 Recommendations

- The government through the department of forest in the ministries of green economy and local government should make an effort to increase urban vegetation around the city center.
- Existing green urban areas in outliers of the CBD should be better maintained so that the valuable ecosystem services they provide are not jeopardized in the long run. The local government authority to ensure this is adhered to by the people who clean the city area.

- As climate change affects more areas, the government through the department of forestry and private sector must collaborate to promote urban revegetation as an effective cooling strategy.
- It is critical that city planners consider potential UHI effects when initiating new building projects or modifying existing ones. Institutions such as ZIA, EIZ and ZIP are key stakeholders in relation to city planning.
- Policymakers should prioritize research and development on UHI mitigation strategies and climate-resilient urban planning in Zambia. This can be achieved through collaborations between government agencies, academic institutions, and international organizations to develop context-specific solutions to the UHI effect.
- To address the socioeconomic implications of the UHI effect, policymakers should prioritize the development of affordable housing and social services in areas with high population densities and built-up areas. This can be achieved through the implementation of inclusive urban planning policies and the allocation of resources for social services such as healthcare, education, and sanitation.

### **7.3. Further Research**

- Empirical research to create a comprehensive and comparable database on UHI intensity in Zambian cities and towns across a range of climatic conditions.
- Further research to be done on UHI where LULC analysis and Landsat images are to be used.
- Given the potentially negative effects of UHI on human health and well-being, additional assessments are needed to quantify the health risks of UHI, which must be combined with local vulnerability factors.
- In Zambia, conduct research to determine the extent of the impact of UHI on the environment, energy use, economics, and health.

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## APPENDICES

### Appendix I: Tentative Timeline

The table below shows a work plan of this research from proposal development to final submission.

<b>Tentative Timeline YEAR ONE</b>												
<b>Activity</b>	<b>Jan</b>	<b>Feb</b>	<b>Mar</b>	<b>Apr</b>	<b>May</b>	<b>Jun</b>	<b>Jul</b>	<b>Aug</b>	<b>Sept</b>	<b>Oct</b>	<b>Nov</b>	<b>Dec</b>
Identification of topic												
Literature Review												
<b>Tentative Timeline YEAR TWO 2023-2024</b>												
Writing of Proposal												
Submission to Ethics												
Data Collection												
Data analysis												
Writing of final report												
Proof reading and Correction of Research report												
Binding of Research Report												
Submission of Report												

## Appendix II: Budget

1. Data collection (Transport)	K8000
2.Data analysis	K1500
3. Printing, and binding of reports	K1000
4. Contingence funds (10% of total)	K1,050
5. Grant total	K11,550

### Appendix III: Data Collection Sheet

DATA COLLECTION SHEET OF AMBIENT TEMPERATURE USING THE PSCHROMETER

MONTH	DATE	CBD			WOOLANDS			FOREST		
		MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX
MAY 2023	4									
	6									
	7									
	11									
	13									
	14									
	18									
	20									
	21									
	25									
	27									
	28									
	JUNE 2023	1								
3										
4										
8										
10										
11										
15										
17										
18										
22										
24										
25										
29										
JULY 2023		1								
	2									
	6									
	8									
	9									
	13									
	15									
	16									
	20									
	22									
	23									
	27									
30										



THE UNIVERSITY OF ZAMBIA  
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**APPROVAL OF STUDY**

**IORG No. 0005376**  
**NASRECREC IRB No. 00006465**

26<sup>th</sup> May, 2023

**REF NO. NASREC-2023- MAY – 008**

Ms.Lambi Claudia,  
The University of Zambia,  
School of Natural Sciences,  
P.O. Box 32379,  
**LUSAKA.**

Dear, Ms.  
Lambi

**RE: “ THE ROLE OF URBAN AFFORESTATION IN REGULATING THE URBAN HEAT ISLAND EFFECT IN LUSAKA ”**

Reference is made to your protocol dated as captioned above. NASREC resolved to approve this study and your participation as Principal Investigator for a period of one year.

REVIEW TYPE	ORDINARY REVIEW	APPROVAL NO. NASREC-2023 MAY - 008
Approval and Expiry Date	Approval Date: 26 <sup>th</sup> May, 2023	Expiry Date: 25 <sup>th</sup> May, 2024
Protocol Version and Date	Version - Nil.	25 <sup>th</sup> May, 2024
Information Sheet, Consent Forms and Dates	• English.	To be provided
Consent form ID and Date	Version - Nil	To be provided
Recruitment Materials	Nil	Nil
Other Study Documents	Questionnaire.	

Specific conditions will apply to this approval. As Principal Investigator it is your responsibility to ensure that the contents of this letter are adhered to. If these are not adhered to, the approval may be suspended. Should the study be suspended, study sponsors and other regulatory authorities will be informed.

### **CONDITIONS OF APPROVAL**

- No participant may be involved in any study procedure prior to the study approval or after the expiration date.
- All unanticipated or Serious Adverse Events (SAEs) must be reported to NASREC within 5 days.
- All protocol modifications must be approved by NASREC prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address.
- All protocol deviations must be reported to NASREC within 5 working days.
- All recruitment materials must be approved by NASREC prior to being used.
- Principal investigators are responsible for initiating Continuing Review proceedings. NASREC will only approve a study for a period of 12 months.
- It is the responsibility of the PI to renew his/her ethics approval through a renewal application to NASREC.
- Where the PI desires to extend the study after expiry of the study period, documents for study extension must be received by NASREC at least 30 days before the expiry date. This is for the purpose of facilitating the review process. Documents received within 30 days after expiry will be labelled “late submissions” and will incur a penalty fee of K500.00. No study shall be renewed whose documents are submitted for renewal 30 days after expiry of the certificate.
- Every 6 (six) months a progress report form supplied by The University of Zambia Natural and Applied Sciences Research Ethics Committee as an IRB must be filled in and submitted to us. There is a penalty of K500.00 for failure to submit the report.
- When closing a project, the PI is responsible for notifying, in writing or using the Research Ethics and Management Online (REMO), both NASREC
- and the National Health Research Authority (NHRA) when ethics certification is no longer required for a project.
- In order to close an approved study, a Closing Report must be submitted in writing or through the REMO system. A Closing Report should be filed when data collection has ended and the study team will no longer be using human participants or animals or secondary data or have any direct or indirect contact with the research participants or animals for the study.
- Filing a closing report (rather than just letting your approval lapse) is important as it assists NASREC in efficiently tracking and reporting on projects. Note that some funding agencies and sponsors require a notice of closure from the IRB which had approved the study and can only be generated after the Closing Report has been filed.
- A reprint of this letter shall be done at a fee.

- All protocol modifications must be approved by NASREC by way of an application for an amendment prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address or methodology and methods. Many modifications entail minimal risk adjustments to a protocol and/or consent form and can be made on an Expedited basis (via the IRB Chair). Some examples are: format changes, correcting spelling errors, adding key personnel, minor changes to questionnaires, recruiting and changes, and so forth. Other, more substantive changes, especially those that may alter the risk-benefit ratio, may require Full Board review. In all cases, except where noted above regarding subject safety, any changes to any protocol document or procedure must first be approved by NASREC before they can be implemented.

Should you have any questions regarding anything indicated in this letter, please do not hesitate to get in touch with us at the above indicated address.

On behalf of NASREC, we would like to wish you all the success as you carry out your study.

Yours faithfully,



*Dr. Mususu Kaonda*

**VICE-CHAIRPERSON  
THE UNIVERSITY OF ZAMBIA NATURAL AND APPLIED SCIENCES RESEARCH  
ETHICS COMMITTEE - IRB**

CC: Director, Directorate of Research and Graduate Studies  
Assistant Director (Research), Directorate of Research and Graduate Studies  
Assistant Registrar (Research), Directorate of Research and Graduate Studies