EVALUATING THE IMPACT OF URBAN GREEN SPACE ON HUMAN THERMAL COMFORT OF SELECTED CITIES IN GHANA

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A project work submitted to the Department of Meteorology And Climate Science,

Kwame Nkrumah University of Science and Technology

in partial fulfillment of the requirements for the degree

of

BSc Meteorology and Climate Science

College of Science

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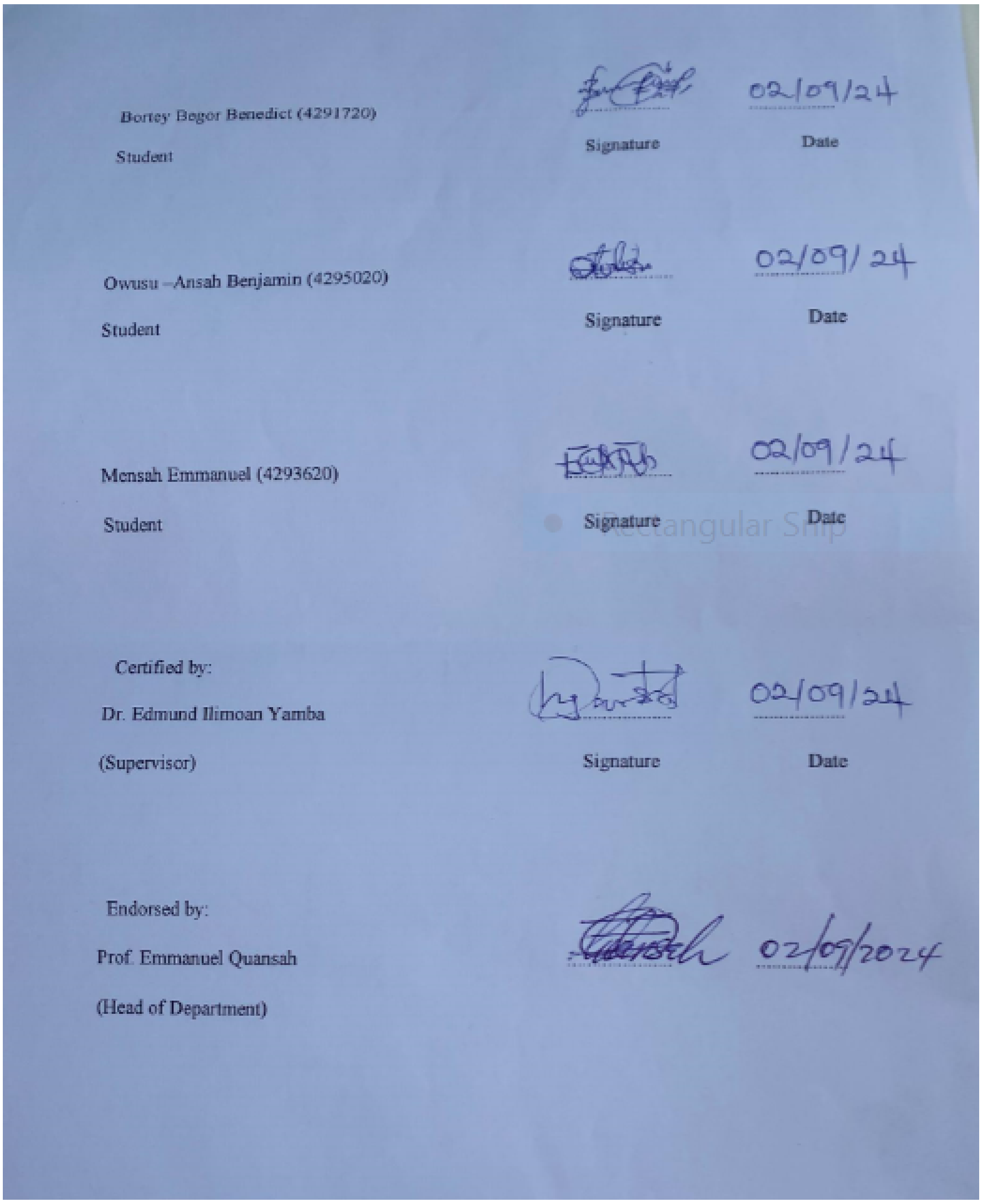
February 2024

Declaration

I hereby declare that this submission is my own work towards BSc Meteorology and Climate Science and that, to the best of my knowledge, it contains no materials previously published by another person or material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.



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Acknowledgement

This research endeavor is devoted to the Divine Lord Jesus Christ, whose grace and fortitude sustained us throughout this journey.We extend our attitude to our parents for their unwavering support, invaluable wisdom, and motivation, as well as to all those who contributed to the success of this endeavor. Additionally, we express our appreciation to our mentor and supervisor, Dr. Edmund Ilimoan Yamba, whose insightful guidance steered us through this project. We are also grateful to all lecturers in the Department of Meteorology and Climate Science, we are extremely thankful and indebted to them for sharing their expertise and encouragement. And to all those who in one way or the other offered us a helping hand during the entire period of this work, We say thank you and God bless you all.

Abstract

In this study, we evaluated the impact urban green spaces have on human thermal comfort over selected cities in Ghana. We extracted the Universal Thermal Climate Index (UTCI) data spanning the period 1981-2020 from ERA5 reanalysis for six cities namely Yendi, Navrongo, Kintampo, Kumasi, Accra, and Tarkwa, representing various climate zones in Ghana. To investigate the differences in thermal comfort across the nation, the study made use of hourly averages, monthly averages, annual trends, and geographic plots. Most of the regions, especially Navrongo and Yendi, showed a higher UTCI, thus shortly entering the "Very Strong Heat Stress" zone in March, April, and May. Accra was observed to remain in the "Comfort Zone" for much of the averaged year, only entering "Moderate Heat Stress" briefly; other locations experienced wider swings between comfort zones and heat stress zones. March and April were generally seen to be the hottest months throughout the average year.. Peak afternoon values were seen evident in the average hourly UTCI plot with Navrongo, Kintampo and Kumasi exceeding 35°C . The results of this study showed a total warming of 1.20°C for Kumasi, with an annual change in rate of 0.03°C/year, which is quite shocking. Kintampo and Tarkwa were both evidently proven to have their rainy seasons from April to October, this was due to their UTCI trends. Additionally, we investigated the warming pattern of Kumasi, a city known as "the Garden City," which was found to be higher than that of Accra, a city known as the most urbanized city in Ghana. The study revealed that some of the years in the first decade delineated higher UTCI values, suggesting the presence of warming activities. These findings are useful for urban planning strategies and green infrastructure adaptive strategies, which in turn help curb the effects of the urban heat island.

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List of Abbreviation

- PMV - Predicted Mean Vote
- PPD - Predicted Percentage Dissatisfied
- HVAC - Heating, Ventilation, and Air Conditioning
- IEQ - Indoor Environmental Quality
- SET - Standard Effective Temperature
- PET - Physiological Equivalent Temperature
- MEMI - Munich Energy-Balance Model for Individuals
- UTCI - Universal Thermal Climate Index
- APMV - Adaptive Predicted Mean Vote
- ACS - Adaptive Comfort Standard

CHAPTER 1

Introduction

1.1 Background to the study

Urbanization is a dominant global trend, with more than half of the world's population residing in urban areas, a proportion expected to rise substantially in the coming decades (Nations, 2018) . With this rapid urban growth comes a plethora of challenges, including environmental degradation, air pollution, and the urban heat island effect (Santamouris, 2015). The current urbanization and urban growth rates have brought several challenges; paramount among them is the destruction and decline of natural ecosystems (Paudyal et al., 2019; Lindley et al., 2018). Several studies and reports have shown that human well-being and good quality of life is dependent on biodiversity and ecosystems (services), the benefits provided by nature at different scales (Daily, 1997; Duraiappah, 2011). Cheng et al. (2017) stated that, the survival of one-fifth of the world's population is entirely dependent on the bundle of services provided by ecosystems in both rural and urban landscapes. Like many other ecological systems, urban landscapes often comprise green, blue and brown spaces (Elmqvist et al., 2015; Kabisch et al., 2017). Urban landscapes are networks of natural-human environments that provide diverse and valuable ecosystem services needed by city dwellers.

The World Health Organization gives parks, sports fields, wetlands, woods and natural meadows as examples of green spaces, representing a fundamental component of any urban ecosystem. Urban green spaces (UGS), the focus of this study, is defined as any vegetation found in the urban environment, including parks, open spaces, residential gardens, or street trees (Kabisch and Haase, 2013). Miller et al. (2015) observed green spaces from the dimension of urban forestry and defines urban forest as the sum of all woody and associated vegetation in and around dense human settlements, ranging from small communities in rural settings to metropolitan regions. Lindley et al. (2018) also introduced another dimension to the scope of green spaces in urban areas and throws more light on green infrastructure (GI) as an approach to dealing with the challenges faced in developing countries due to the trade-off of green spaces for heated surfaces. There is also unanimity or similarities of concepts such as vegetation and urban areas in these diverse definitions. A combination of excessive surface and ambient temperatures, a lack of shade,ventilation and cooling breezes, and the persistence of heat creates conditions that jeopardize human health and well-being (Elliott et al., 2020). Due to the combined effects of climate change and rapid urbanisation, the urban thermal environment in African cities is undergoing dramatic changes. Warmer temperatures and increased frequency of extreme events associated with climate change exacerbate how the urban thermal environment is affected by anthropogenic processes (Li et al., 2022). Increasing impervious surfaces and decreasing blue and green spaces in and around urban areas reduce atmospheric moisture contributed by evaporation and transpiration of latent heat flux of urban areas (Ramamurthy and Bou-Zeid, 2014; Yu et al., 2017; Ige et al., 2017; Wang et al., 2014). Urban thermal environment dynamics and impacts can vary significantly with complex interactions between biophysical variables (e.g., breeze circulation,relative humidity, vapor pressure and soil properties) (El Kenawy et al., 2020; He, 2018). Furthermore, urban areas change the albedo and nocturnal radiation (Offerle et al., 2005), while urban transportation contributes to greenhouse gas emissions that are likely to increase the local temperature (Grimmond, 2007).

As of 2012, when the last national population and housing census was conducted in Ghana, the country had reached a point of rapid urbanisation, causing people to migrate from all over the country towards the major cities, Accra and Kumasi. Kumasi is thus at the threshold of rapid urbanisation as the census showed that the city had reached a growth rate of 5.47% compared to the nations at 2.5%, and Accra, the national capital, at 3.5% (Service, 2012). As people become increasingly committed to living in an urbanised high-tech society, understanding the importance of plant's influence on the quality of life, human well-being and social development cannot be overemphasised. Kumasi, the Ashanti Regional Capital, the second-largest city in Ghana, had all the advantages offered by its natural landscape, particularly urban trees. However, the landscape is being depleted at a fast rate, making it lose almost all the advantages of a tropical rain forest ecology (Quagraine, 2011). This trend of development results in the incidence of Urban Heat Island (UHI).

A typical feature associated with urban thermal environmental changes is the formation of the urban heat island (UHI) (Peng et al., 2016). UHI refers to the phenomenon of higher urban temperatures than the rural surroundings and affects temperatures in the air and at the surface (Oke, 1982). Urban inhabitants can be more susceptible to higher heat-related risk than rural residents due to UHI (Chapman et al., 2017).

In this study, we draw on the works of (Kabisch and Haase, 2013) and that of (Lindley et al., 2018), who both defines urban green spaces and infrastructure to include any vegetation found in the urban environment, including parks, green open spaces, residential gardens, mangroves, street trees and green infrastructure." The social, ecological, cultural, economic, psychological benefits, among others associated with creating and maintaining green spaces in urban landscapes, have been well discussed by scholars (Lee et al., 2015; Van den Berg et al., 2015; Heikinheimo et al., 2020; Basu and Nagendra, 2021) and also to the Thermal comfort as defined in the ISO 7730 standard is that condition of mind which expresses satisfaction with the thermal environment (Appah and Holt, 2012).

1.2 Statement of the problem

Kumasi Metropolis for example, earmarked among the major cities under the Millennium City Initiative (MCI), has not received adequate attention on green infrastructure, Urban heat island (UHI) and its prognosis (Sarfo et al., 2023).

The removal of green spaces for heated surfaces exacerbates extreme heat events (EHEs) of greater than 40.6^{o}C (Meyers et al., 2020; Nangombe et al., 2019; Chen et al., 2022).

There has been scarce works on the impact of urban green space on human thermal comfort on the selected cities in the climatic zones of Ghana. Available works focused more on the health of humans rather than taking into consideration the greenery impact on the psychological, social and economic lifestyles of the individual. The people who are mostly impacted by heat discomfort in relation to green spaces might differ based on a number of variables, including climate, socioeconomic position, and resource accessibility in addition to geographic location. These individuals include; the elderly, children and infants, outdoor workers, people with chronic illnesses as well as homeless individuals. Achieving thermal comfort with regards to green spaces involves conducting surveys to gauge public perception and awareness. Implementation of policies and initiatives to promote green spaces and sustainable urban development.

1.3 Objectives

Main objective: Evaluating the impact of urban green space on human thermal comfort of selected cities in Ghana.

Specific objectives:

1. To quantify the cooling effects of urban green spaces (vegetation) on the micro-climate of Ghana.

2. To assess the seasonal variations in the effectiveness of green spaces (vegetation) in providing Human thermal comfort.

3. Study how heat stress has been increasing over the last 40 years in Ghana.

1.4 Research Questions

1. How does the presence of urban green spaces (vegetation) in the selected cities affect the local micro-climate and, by extension, the thermal comfort of its residents?

2. How do seasonal variations influence the effectiveness of urban green spaces (vegetation) in improving thermal comfort in the selected cities?

3. How does extreme heat affect the health of individuals in the selected cities?

1.5 Research significance and justification

Urban green spaces are vital in mitigating the adverse effects of urbanization by improving air quality, reducing urban heat island effects, and enhancing human thermal comfort (Organization et al., 2016) . In cities like Accra, Kumasi, and Tamale, rapid urban growth and increasing temperatures due to climate change heighten the need for sustainable urban planning that incorporates green spaces. The presence of green areas not only contributes to a healthier micro-climate by reducing heat stress but also supports psychological well-being, social cohesion, and physical activity, which are essential for improving quality of life in urban environments (Capolongo et al., 2018) . This study is crucial for providing insights into the role of urban green spaces in enhancing human thermal comfort, which has direct implications for public health and urban resilience. As Ghana aims to meet its Sustainable Development Goals (SDGs), particularly Goal 3 (Good Health and Well-being), Goal 11 (Sustainable Cities and Communities), and Goal 13 (Climate Action), understanding the influence of urban green spaces on thermal comfort is key to ensuring cities are livable, resilient, and sustainable (Guterres, 2018).

Incorporating green spaces into urban development plans in Ghana could help alleviate heat stress, reduce energy demands for cooling, and promote healthier lifestyles, thereby fostering more sustainable and resilient urban communities.

1.6 Organization of the thesis

The study is structured into five sections. The first chapter delves into the research background, problem statement, aim, and motivation. Chapter two provides an overview of literature concerning the impact of urban green space on human thermal comfort in Kumasi. Chapter three covers the study's area, data collection methods, and employed methodologies. Results and discussions are presented in chapter four, while chapter five offers recommendations.

CHAPTER 2

Literature Review

In the midst of the couple of works that have been finished by exploring "the impacts of urban expansion on green space availability and delivery of ecosystem services in the Accra metropolis", is the study done by Puplampu and Boafo (2021) , where the analysis of Accra's land cover changes from 1991 to 2018 was conducted using Landsat satellite imagery, revealing a notable transformation of natural areas into urban spaces. It utilized the i-Tree Canopy model to quantify the economic and environmental value of the city's green spaces, highlighting their benefits in carbon capture, air purification, and water runoff prevention. Additionally, qualitative insights from engagements with stakeholders provided a nuanced understanding of public perceptions and identified challenges related to urban planning, enriching the study's findings with contextual understanding.The study investigated Accra's urban growth from 1991 to 2018 and its impact on green spaces, revealing a significant loss due to extensive urban expansion. Existing green spaces, valued at USD 39,089,611 for services like air purification and flood control, faced challenges such as high maintenance costs, despite public acknowledgment of their benefits. To address these issues, the study proposes sustainable measures including the implementation of a green space policy, awareness campaigns, and integrating green areas into urban planning, while also recommending further research on green infrastructure for future sustainable development in Accra.

Furthermore, Sarfo et al. (2023) presents results from a study on planning for cooler cities in Ghana: the contribution of green infrastructure to urban heat mitigation in Kumasi metropolis. The city of Kumasi in Ghana has experienced significant urban development, resulting in the conversion of forests and farmlands into built-up areas. This expansion has contributed to the Urban Heat Island effect, with areas characterized by more buildings and less vegetation experiencing higher temperatures. The study anticipates further losses in forests, water areas, and farmlands in the future, potentially impacting the city's temperature regulation and water resources, ultimately diminishing Kumasi's reputation as the "Garden City of West Africa" due to the loss of green spaces amidst rapid urbanization.

The study examines the potential of urban green spaces in mitigating Urban Heat Island (UHI) effects within the broader context of the grand urban model, utilizing satellite imagery and existing literature. It highlights the unfavorable changes in land use and urban systems in Ghana's Ashanti region, particularly Kumasi, due to unregulated urban expansion. The study underscores the compounding effects of various climatic stressors exacerbated by institutional shortcomings and insufficient management of urban green areas. Moreover, Mensah et al. (2020) conducted a research on the impact of urban land cover change on the Garden City status and land surface temperature in Kumasi. The study observed substantial growth in Kumasi, Ghana, from 1986 to 2015, marked by a 24.13% increase in built-up areas, covering about 55.81 square kilometers, which correlated with a significant rise in the average land surface temperature by 4.16°C. To mitigate this trend, the study emphasizes the necessity of implementing sustainable urban planning strategies, including initiatives to preserve green vegetation, to address the observed increase in land surface temperatures and foster a more comfortable and environmentally friendly urban environment in Kumasi.The study utilized satellite data and GIS techniques to analyze urban growth in Kumasi, Ghana, from 1986 to 2015, revealing how the expansion of housing and commercial areas transformed green spaces into heat-absorbing surfaces, consequently increasing land surface temperatures. It underscores the significance of smart city planning to alleviate heat stress and enhance air quality, recommending sustainable measures such as integrating green spaces, employing reflective materials in construction, and adopting renewable energy sources to mitigate environmental impact. Overall, the study advocates for innovative strategies to enhance the environmental sustainability and resilience of growing cities like Kumasi.

Another research was conducted on peri-urbanization and the loss of arable land in Kumasi metropolis in three decades: evidence from remote sensing image analysis by Abass et al. (2018). The findings indicate significant land use and cover changes in the Kumasi Metropolis over thirty years, with urban land increasing by 54.6% while arable land decreased by 15.6%. Moreover, a strong positive correlation between the size of arable land and crop output over a fifteen-year period was observed, highlighting the importance of preserving arable land for sustainable food crop production. The study concludes that peri-urbanization has led to substantial reductions in arable land within the Kumasi Metropolis over the examined thirty-year period, posing challenges for food crop production. It emphasizes the necessity of enforcing legislative measures and standards outlined in the 2016 Land Use and Spatial Planning Act to ensure that urban development aligns with sustainable principles and safeguards arable land for agricultural purposes. Nevertheless, Erlwein et al. (2021) conducted a research on the Trade-Offs between Urban Green Space and Densification: Balancing Outdoor Thermal Comfort, Mobility, and Housing Demand. Preserving existing trees significantly lowered the physical equivalent temperature (PET), while constructing underground car parking led to tree removal and increased PET. Loss of trees due to parking space consumption resulted in an average daytime PET increase of 5°C, mitigated to 1.3°C–1.7°C by halving parking space requirements. Adding buildings increased living space more than adding floors but compromised night-time thermal comfort due to ventilation issues.Preserving mature trees in urban redevelopment is essential for mitigating heat stress, particularly in a changing climate. Implementing alternative mobility strategies could aid in balancing densification and urban greening goals.Further research is deemed necessary, especially to include missing geographical regions and ethnicities, and to conduct more psychological thermal adaptation studies, particularly in transient thermal conditions. Qualitative analysis and the consideration of perceived environmental quality are recommended for incorporation into future studies to enhance understanding of outdoor thermal comfort (Shooshtarian et al., 2020).

2.1 Human Thermal comfort

Human thermal comfort refers to the condition of mind that expresses satisfaction with the thermal environment. It is an essential factor in determining the overall comfort and well-being of individuals in indoor and outdoor environments. Several factors influence human thermal comfort, including air temperature, relative humidity, air velocity, and mean radiant temperature. The thermal comfort range varies from person to person and is influenced by factors such as metabolic rate, clothing insulation, and acclimatization.The most widely accepted model for predicting human thermal comfort is the Predicted

Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) model, developed by P.O. Fanger in the 1970s (Fanger et al., 1970) . The PMV model is based on the heat balance equation and predicts the mean value of votes of a large group of people on a thermal sensation scale. The PPD is derived from the PMV and predicts the percentage of people who will be dissatisfied with the thermal environment. The ASHRAE Standard 55 Standard (1992) and ISO 7730 Pourshaghaghy and Omidvari (2012) provide guidelines for thermal comfort conditions based on the PMV/PPD model, taking into account factors such as air temperature, mean radiant temperature, relative humidity, air velocity, clothing insulation, and metabolic rate. The ASHRAE Standard 55 provides specific ranges and combinations of these factors that are considered to be within the thermal comfort zone for a majority of occupants in a given space. For example, the standard recommends an operative temperature range of 20°C to 26°C (68°F to 79°F) for sedentary activities in typical indoor environments with relative humidity between 30% and 60% (Standard, 1992). It is important to note that thermal comfort is not a universal condition, as individuals may have different thermal preferences based on factors such as age, gender, acclimatization, and personal preferences.

Additionally, cultural and societal norms can influence thermal comfort expectations and perceptions (Nicol et al., 2012). To achieve thermal comfort in buildings and outdoor environments, designers and engineers often rely on heating, ventilation, and air conditioning (HVAC) systems, as well as passive strategies such as building orientation, shading, and natural ventilation. Providing occupants with individual control over their thermal environment, through operable windows or personal environmental control systems, can also contribute to improved thermal comfort and satisfaction (Fanger et al., 1970). Thermal comfort is closely linked to indoor environmental quality (IEQ) and has significant implications for occupant health, productivity, and overall well-being. Achieving and maintaining thermal comfort conditions is an important consideration in the design, operation, and maintenance of buildings and urban environments(Frontczak and Wargocki, 2011). In addition to the PMV/PPD model, other thermal comfort models have been developed, such as the adaptive thermal comfort model (Bolund and Hunhammar, 1999), which takes into account the ability of humans to adapt to their thermal environment, and the two-node model (Chiesura, 2004), which considers the human body as two concentric cylinders representing the skin and core temperatures.

2.2 Urban Green Space

Using urban green space (UGS) is one of the most effective ways to mitigate UHIs (Imran et al., 2019). Vegetation not only beautifies the environment Doick et al. (2014), sequesters carbon, and releases oxygen, but it also plays a pivotal role in reducing temperatures (Han et al., 2021). The average temperature of UGS is 1–2 °C lower than the surrounding temperature. The cooling effect of UGS is mainly due to shading and evapotranspiration (Meili et al., 2021). Approximately 80 – 90% of solar radiation can be intercepted efficiently (Kotzen, 2003). The climatic factors such as rainfall and solar radiation vary greatly in different climatic regions, which will affect the shading and evapotranspiration intensity of UGS in different climatic regions (Liu et al., 2021). Therefore, it is important to generate cooling through appropriate planning of UGS in different climate zones. Urban vegetation has a significant UCI effect (Yu et al., 2017). Extensive research has shown that UGS is capable of reducing the temperature by 0.5–2.5 °C with a cooling distance effect extending as far as 60–540 m (Sun et al., 2020; Tan et al., 2021; Yang et al., 2020).

As the world grapples with the challenges of urbanization, climate change, and public health, the importance of urban green spaces cannot be overstated (Bowler et al., 2010). These vibrant oases in the midst of concrete jungles provide a multitude of benefits, from mitigating heat and improving thermal comfort (Dimoudi and Nikolopoulou, 2003) to reducing disease risk and enhancing livability (Shashua-Bar et al., 2009).Urban green spaces are a natural solution to the urban heat island effect, which can increase temperatures by up to 5°C compared to surrounding rural areas (Akbari et al., 2001). Through evapotranspiration, vegetation reduces air temperature, providing relief from the sweltering heat(Dimoudi and Nikolopoulou, 2003).Urban green spaces are also a powerful tool in reducing disease risk. By removing pollutants and particulate matter from the air, vegetation improves air quality, reducing the risk of respiratory diseases like asthma and COPD . Additionally, urban green spaces have been shown to reduce the risk of heat-related illnesses (Bowler et al., 2010), cardiovascular diseases (Shashua-Bar et al., 2009), and mental health disorders(Taylor et al., 2002).Urban green spaces are not just a nicety, but a necessity for creating livable cities. They provide habitat for urban wildlife, promote biodiversity (Shashua-Bar et al., 2009), and enhance aesthetic appeal (Kaplan, 1995). Moreover, urban green spaces foster community engagement, social connections, and a sense of belonging .

2.3 Biological vulnerabilities associated with extreme heat

2.3.1 Heat Stroke (Hyperthermia)

When the core body temperature climbs above 40.5°C, the body's internal processes begin to shutdown. The most dangerous heat-related condition is heat stroke. It happens when the body's temperature becomes uncontrollable: the body's temperature increases fast, the sweating mechanism fails, and the body is unable to cool down. When heat stroke develops, the body temperature can quickly increase to 41°C or more. If emergency care is not provided, heat stroke can result in death or lifelong disability. Heat stroke symptoms include hot, dry skin or excessive perspiration and a high body temperature (39°C), a marked lack of sweating (typically); hot, red or flushed dry skin; quick pulse; trouble breathing; and dilated pupils (Habeeb et al., 2018).

2.3.2 Heat Exhaustion

Excessive sweating in a hot climate reduces blood volume and causes an excessive loss of water and salt, which leads to heat exhaustion. Heat exhaustion symptoms include excessive sweating, extreme weakness or fatigue, dizziness, confusion, nausea, clammy, moist skin, flushed skin, muscle cramps, slightly elevated body temperature, fast heartbeat, loss of appetite, hyperventilation, shallow breathing, cool moist skin, weak and rapid pulse (120-200), low to normal blood pressure, dehydration, decreased blood flow, stress on the circulatory system, and decreased flow of blood to the brain (Habeeb et al., 2018).

2.3.3 Heat Cramps

Heat cramps are painful muscle spasms brought on by excessive sweating, which typically happen when the body loses too much salt and water through perspiration, particularly when the body only replaces water but not salt or potassium. Heat cramps are muscle spasms that happen after exerting oneself in a hot environment and are caused by a decrease in blood supply to the brain, which causes the body to lose salt and water. Due to prolonged periods of excessive perspiration, which results in electrolyte shortages, heat cramps are a common and exceedingly unpleasant condition. The body loses moisture and salt through sweating (Habeeb et al., 2018).

2.3.4 Heat rash

In hot, humid weather, excessive sweating can irritate the skin and lead to heat rash. The mildest form of heat stress, which happens when sweat clogs pores, is heat rash. Even though rash typically only causes minor discomfort (Gauer and Meyers, 2019).

2.3.5 Heat Syncope

Humans in hot conditions may get heat syncope. Generally speaking, syncope is a sudden loss of consciousness brought on by insufficient oxygen and blood flow to the brain. By directing blood away from the brain and onto the legs or other extremities, heat stress can develop(Habeeb et al., 2018).

2.3.6 Cardiovascular Diseases

Heat exposure is a significant yet unrecognized risk factor for cardiovascular disease (Cicci et al., 2022). Warming temperatures may also provide significant problems to public health, particularly in an ageing population. Heat may increase the chances of heart attacks, heart arrhythmias, and heart failure (Liu et al., 2022).

2.3.7 Diabetes

People with type 1 or type 2 diabetes have a more difficult time managing their body temperature and blood glucose when it is hot outside. Insulin, insulin pumps, and glucose monitors can all be damaged by extreme heat (Song et al., 2021).

2.3.8 Pregnancy

Higher temperatures and pollution may raise the likelihood of a baby being delivered prematurely or with low birth weight (Chersich et al., 2020).

2.4 Thermal Indices

Thermal indices are quantitative measures used to evaluate and assess human thermal comfort in various environments. These indices combine several environmental and personal factors into a single value or rating scale, providing a comprehensive assessment of thermal comfort conditions.

2.4.1 Standard Effective Temperature (SET)

The SET is a single value representing the combined effects of air temperature, mean radiant temperature, humidity, and air velocity on thermal comfort. It is based on the two-node model of human thermoregulation and is commonly used in HVAC system design and evaluation (Chun and Tamura, 2005).

2.4.2 Physiological Equivalent Temperature (PET)

PET is a thermal index derived from the Munich Energy-Balance Model for Individuals (MEMI). It considers the energy balance of the human body and expresses the thermal conditions in a commonly understood unit (°C or °F) (Yola, 2018).

2.4.3 Adaptive Thermal Comfort Models

These models, such as the Adaptive Predicted Mean Vote (APMV) and the Adaptive Comfort Standard (ACS), consider the ability of humans to adapt to their thermal environment over time. They provide guidelines for acceptable thermal conditions based on outdoor climate data and occupant behavior (Nguyen et al., 2012).

2.4.4 Thermal Sensation Scale

Thermal sensation scales, such as the ASHRAE 7-point thermal sensation scale, are subjective rating scales used to assess thermal perception and comfort level. They range from -3 (cold) to +3 (hot), with 0 being the neutral point, and are commonly used to gather qualitative data on thermal comfort (Tartarini et al., 2020).

2.4.5 Universal Thermal Climate Index (UTCI)

UTCI is a thermal index developed to assess outdoor thermal conditions and their effects on human thermal comfort and health. It incorporates air temperature, wind speed, humidity, and solar radiation, making it suitable for evaluating various outdoor environments (Jendritzky et al., 2012; Bröde et al., 2012). According to Zare et al. (2018), the Universal Thermal Climate Index (UTCI) is a human bio-meteorology parameter used to assess the linkages between the outdoor environment and human well-being'. It considers external temperature as well as various factors like humidity, wind, and radiation, which significantly affect physiological responses to environmental elements.The UTCI is an equivalent temperature (°C) that measures the human physiological response to the thermal environment. Introduced in 1994, it takes into account air temperature, relative humidity, solar radiation, and wind speed and is regarded as the reference environmental temperature causing strain .

$$\text{UTCI} = f(T_a, T_{mrt}, V_a, V_p) = T_a + \text{Offset}(T_a, V_a, V_p) \tag{2.1}$$

where:

$$T_a = \text{Air Temperature}$$

$$T_{mrt} = \text{Mean Radiant Temperature}$$

$$V_a = \text{Wind Speed}$$

$$V_p = \text{Vapor Pressure}$$

2.4.6 Predicted Mean Vote

The PMV model, developed by P.O. Fanger, predicts the mean thermal sensation vote of a large group of people based on factors such as air temperature, mean radiant temperature, relative humidity, air velocity, metabolic rate, and clothing insulation. The PPD is derived from the PMV and represents the percentage of people likely to be dissatisfied with the thermal environment (Nicol et al., 2012; Standard, 1992).The Predicted Mean Vote (PMV) model, uses heat-balance equations and empirical studies on skin temperature to define thermal comfort. Standard thermal comfort surveys ask subjects about their thermal sensation on a seven-point scale from cold (-3) to hot ($+3$). Fanger's equations calculate the PMV of a group of subjects for a particular combination of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation. A PMV of zero represents thermal neutrality, and the comfort zone is defined by the combinations of the six parameters for which the PMV is within the recommended limits ($-0.5 < \text{PMV} < +0.5$) (Schaudienst and Vogdt, 2017).

$$\text{PMV} = \left(0.303e^{-0.036M} + 0.028\right) L \tag{2.2}$$

where:

$\text{PMV} =$ Predicted Mean Vote Index

$M =$ Metabolic Rate

$L =$ Thermal Load (difference between internal heat production and heat loss to the environment, at comf

2.4.7 Perceived Temperature (PT)

The Perceived Temperature (PT) is an equivalent temperature based on a comprehensive heat budget model of the human body. It has proved its suitability for various applications across a wide range of scales, from micro to global. PT is successfully used both in daily forecasts and climatological studies. It is designed for outdoor conditions and is defined as the air temperature of a reference environment where thermal perception would be equivalent to that in the actual environment (Staiger et al., 2012).

$$M - W_o = C + R + E_{sk} + C_{res} + E_{res} + S_{sk} + S_{cr} \tag{2.3}$$

where:

$$\begin{aligned}
M &= \text{Metabolic rate (W)} \\
W_o &= \text{External work (W)} \\
C &= \text{Convection (W)} \\
R &= \text{Radiation (W)} \\
E_{sk} &= \text{Evaporation from the skin (W)} \\
C_{res} &= \text{Convection through the respiratory system (W)} \\
E_{res} &= \text{Evaporation through the respiratory system (W)} \\
S_{sk} &= \text{Heat storage in the skin (assumed to be 0 W)} \\
S_{cr} &= \text{Heat storage in the core (assumed to be 0 W)}
\end{aligned}$$

The components of the equation represent energy transfer by sensible heat (C), radiation (R), and latent heat (E). Equation (1) distinguishes between fluxes from or to the skin (*sk*), the core (*cr*), and through the respiratory system (*res*). The heat storage components (S) are assumed to be 0 W, constantly assuming a steady state. The unit of all parameters is watts (W) (Fröhlich et al., 2020).

2.5 Reviewed works

In the midst of the couple of works that have been finished by exploring the impacts of urban expansion on green space availability and delivery of ecosystem services in the Accra metropolis, is the study done by Puplampu and Boafo (2021), where the analysis of Accra's land cover changes from 1991 to 2018 was conducted using Landsat satellite imagery, revealing a notable transformation of natural areas into urban spaces. It utilized the i-Tree Canopy model to quantify the economic and environmental value of the city's green spaces, highlighting their benefits in carbon capture, air purification, and water runoff prevention. Additionally, qualitative insights from engagements with stakeholders provided a nuanced understanding of public perceptions and identified challenges related to urban planning, enriching the study's findings with contextual understanding. The study investigated Accra's urban growth from 1991 to 2018 and its impact on green spaces, revealing a significant loss due to extensive urban expansion. Existing green spaces, valued at USD 39,089,611 for services like air purification and flood control, faced challenges such as high maintenance costs, despite public acknowledgment of their benefits. To address these issues, the study proposes sustainable measures including the implementation of a green space policy, awareness campaigns, and integrating green areas into urban planning, while also recommending further research on green infrastructure for future sustainable development in Accra.

Furthermore, Sarfo et al. (2023) presented results on planning for cooler cities in Ghana: the contribution of green infrastructure to urban heat mitigation in Kumasi metropolis. Kumasi has experienced significant urban development, resulting in the conversion of forests and farmlands into built-up areas. This expansion has contributed to the Urban Heat Island effect, with areas characterized by more buildings and less vegetation experiencing higher temperatures. The study anticipates further losses in forests, water areas, and farmlands in the future, potentially impacting the city's temperature regulation and water resources, ultimately diminishing Kumasi's reputation as the "Garden City of West Africa" due to the loss of green spaces amidst rapid urbanization. The study examines the potential of urban green spaces in mitigating Urban Heat Island (UHI) effects within the broader context of the grand urban model, utilizing satellite imagery and existing literature. It highlights the unfavorable changes in land use and urban systems in Ghana's Ashanti region, particularly Kumasi, due to unregulated urban expansion. The study underscores the compounding effects of various climatic stressors exacerbated by institutional shortcomings and insufficient management of urban green areas.

Moreover, Mensah et al. (2020) conducted a research on the impact of urban land cover change on the Garden City status and land surface temperature of Kumasi. This study observed substantial growth in

Kumasi, Ghana, from 1986 to 2015, marked by a 24.13% increase in built-up areas, covering about 55.81 square kilometers, which correlated with a significant rise in the average land surface temperature by 4.16°C. To mitigate this trend, the study emphasizes the necessity of implementing sustainable urban planning strategies, including initiatives to preserve green vegetation, to address the observed increase in land surface temperatures and foster a more comfortable and environmentally friendly urban environment in Kumasi.

The study utilized satellite data and GIS techniques to analyze urban growth in Kumasi, Ghana, from 1986 to 2015, revealing how the expansion of housing and commercial areas transformed green spaces into heat-absorbing surfaces, consequently increasing land surface temperatures. It underscores the significance of smart city planning to alleviate heat stress and enhance air quality, recommending sustainable measures such as integrating green spaces, employing reflective materials in construction, and adopting renewable energy sources to mitigate environmental impact. Overall, the study advocates for innovative strategies to enhance the environmental sustainability and resilience of growing cities like Kumasi.

Another research was conducted on peri-urbanization and the loss of arable land in Kumasi metropolis in three decades: evidence from remote sensing image analysis by (Abass et al., 2018). The findings indicate significant land use and cover changes in the Kumasi Metropolis over thirty years, with urban land increasing by 54.6% while arable land decreased by 15.6%. Moreover, a strong positive correlation between the size of arable land and crop output over a fifteen-year period was observed, highlighting the importance of preserving arable land for sustainable food crop production. The study concludes that peri-urbanization has led to substantial reductions in arable land within the Kumasi Metropolis over the examined thirty-year period, posing challenges for food crop production. It emphasizes the necessity of enforcing legislative measures and standards outlined in the 2016 Land Use and Spatial Planning Act to ensure that urban development aligns with sustainable principles and safeguards arable land for agricultural purposes.

Nevertheless, Erlwein et al. (2021) conducted a research on the Trade-Offs between Urban Green Space and Densification: Balancing Outdoor Thermal Comfort, Mobility, and Housing Demand by . Preserving existing trees significantly lowered the physical equivalent temperature (PET), while constructing underground car parking led to tree removal and increased PET. Loss of trees due to parking space consumption resulted in an average daytime PET increase of 5°C, mitigated to 1.3°C–1.7°C by halving parking space requirements. Adding buildings increased living space more than adding floors but compromised night-time thermal comfort due to ventilation issues.Preserving mature trees in urban redevelopment is essential for mitigating heat stress, particularly in a changing climate. Implementing alternative mobility strategies could aid in balancing densification and urban greening goals.Further research is deemed necessary, especially to include missing geographical regions and ethnicity, and to conduct more psychological thermal adaptation studies, particularly in transient thermal conditions. Qualitative analysis and the consideration of perceived environmental quality are recommended for incorporation into future studies to enhance understanding of outdoor thermal comfort (Shooshtarian et al., 2020).

CHAPTER 3

Data and Research Methodology

3.1 Study Area

Ghana is located in sub-Saharan Africa, between latitudes 4° and 12° N and longitudes 4° W and 2° E, and experiences a tropical climate. The majority of Ghana experiences a tropical savanna climate , with the southwest of the country experiencing a tropical monsoon climate.It is distinguished by dry and wet seasons, consistently high daily outside temperatures, and year-round solar radiation, which eliminates the need for space heating in structures. The country's two wet seasons are in the south, from April to July, and in the north, from September to November. The northern region experiences only one wet season, which occurs from May to September. Ghana is claimed to have annual cooling degree days of 2687 and 1707, respectively, at base temperatures of 18.3 and 21.1 °C (Atalla et al., 2018); thus, comfort cooling is required in Ghanaian buildings, and this is typically achieved with mechanical air-conditioning systems or passive strategies, such as window opening, and solar control measures, such as external window shading. The current mean outdoor air temperature, relative humidity, wind speed, and solar radiation are about 27.2 °C, 83%, 3 m/s, and 1833 W/m2, respectively, for Accra, the capital city of Ghana (Meteotest, 2009).

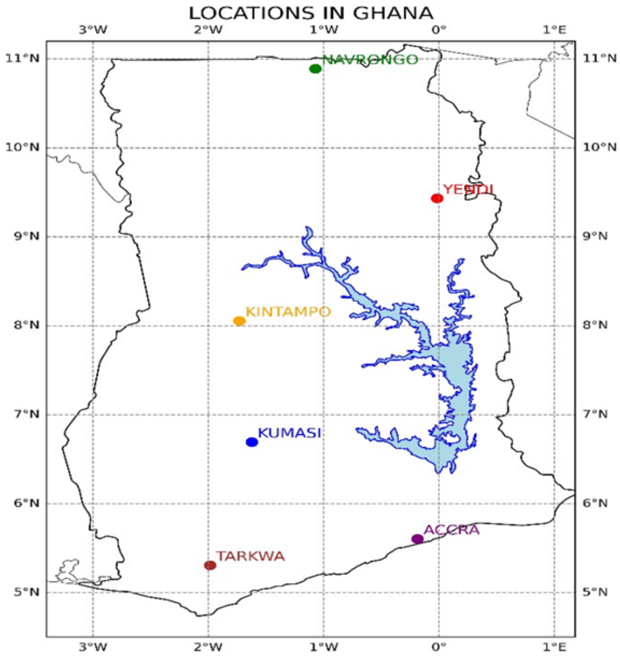

Figure 3.1: Map of Ghana showing the selected cities.

3.2 Data

The Universal Thermal Climate Index (UTCI) data, obtained from the ERA5 (European Center for Medium-range Weather Forecast Reanalysis Fifth generation) reanalysis dataset, covers the period from 1981 to 2020. This dataset includes key variables such as air temperature, relative humidity, wind speed, and mean radiant temperature, providing a comprehensive view of climatic conditions. The data is available at an hourly temporal resolution, allowing for detailed analysis of short-term weather variations. With a spatial resolution of 0.25° x 0.25°, the dataset offers fine-grained geographic coverage, making it suitable for regional climate studies.

3.3 Analysis

The ERA5 reanalysis data for UTCI from 1981 to 2020 was processed using Python to analyze thermal comfort across multiple locations in Ghana, including Accra, Kumasi, Kintampo, Navrongo, Yendi, and Tarkwa. Both annual and monthly UTCI averages were computed to study temporal and spatial trends. Hourly plots were also generated to examine diurnal variations, identifying peak heat stress periods.

Additionally, scatter plots were used to determine long-term trends, calculating the rate of change in UTCI per year and the total warming over the 40-year period.

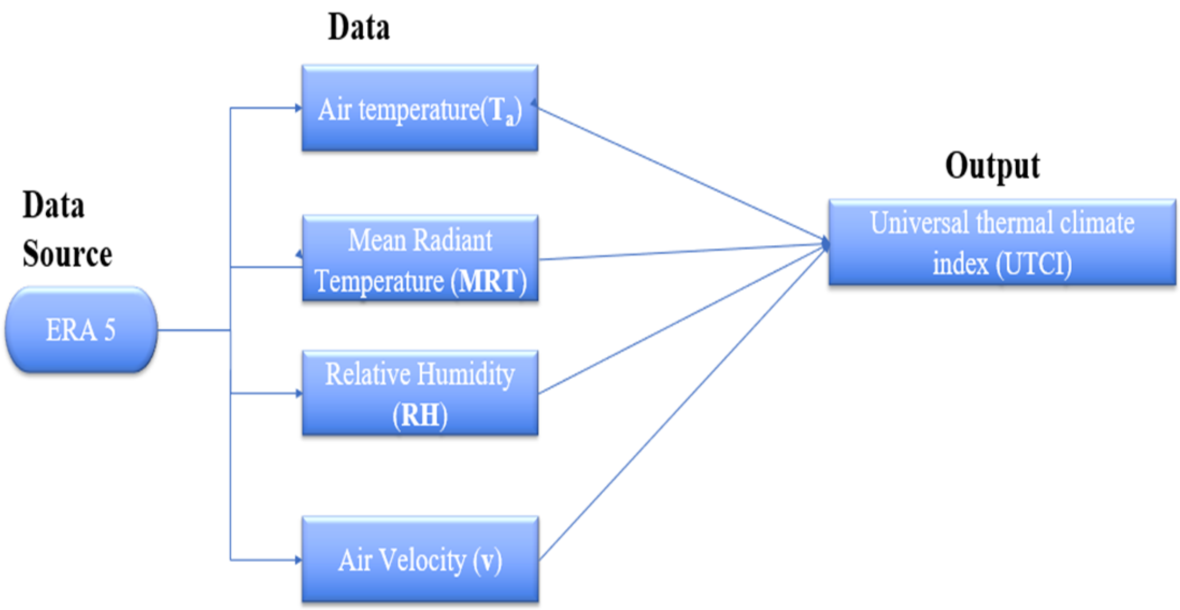

Figure 3.2: Flowchart showing the data and methodology used for calculating the Universal Thermal Climate Index (UTCI).

The UTCI is computed using: UTCI = Ta + offset (Ta, MRT, R.H, and V) (Błażejczyk et al., 2013)

Where offset between UTCI and Ta depends on the air temperature (Ta), mean radiant temperature (MRT), relative humidity (RH) and air velocity (v).

Table 3.1: UTCI Heat Stress Categories

Heat Stress Categories	**UTCI (Universal Thermal Climate Index)**
Comfort Zone	< 26°C
Moderate Heat Stress	26°C to 32°C
Strong Heat Stress	32°C to 38°C
Very Strong Heat Stress	> 40°C

CHAPTER 4

Results and Discussion

4.1 Results

4.1.1 The Spatial Averaged Monthly Universal Thermal Climate Index (UTCI)

The Figure 4.1 below is the spatial plot for Ghana showing the average monthly Universal Thermal Climate Index (UTCI) over forty (40) years spanning from 1981 to 2020. Each month is color coded, with red indicating higher UTCI (warmer temperatures) and blue indicating a lower UTCI (cooler temperatures). The Guinea Savanna (Northern parts) shows cooler temperatures from December to February, the Transition, Forest and Coastal zones depict warmer temperatures in the months of December, January and February. A cooling trend is seen from March to June in these zones with a gradual rise in warmer conditions. The southern part of the country remains cooler in these months which demonstrates the moderating effect of water bodies in the coastal areas. By April to October, the Sudan Savannah shows higher UTCI values, the UTCI values depicted in these months are greater than that in May and June.

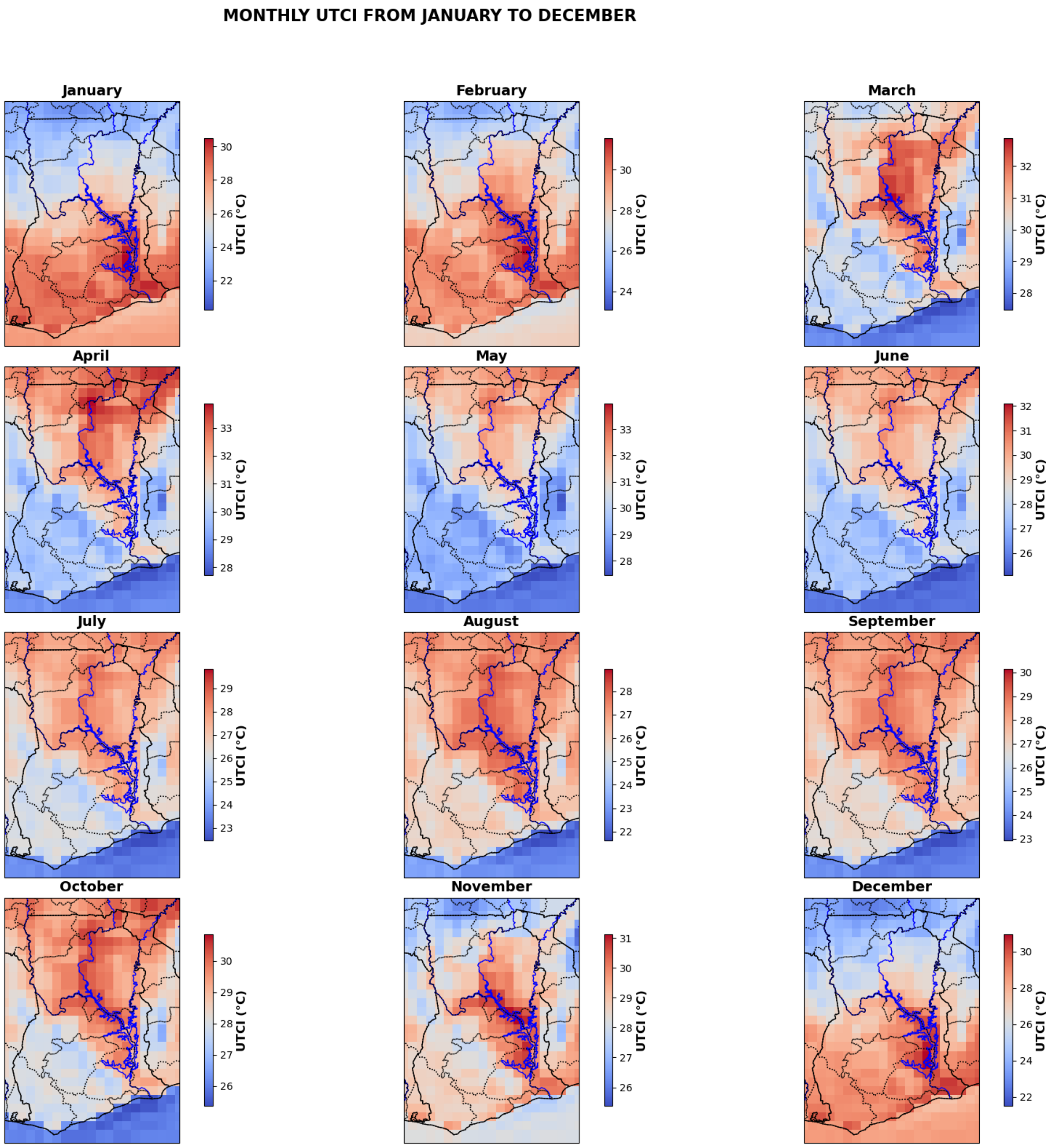

Figure 4.1: The seasonal spatial plot for Ghana over forty(40) years spanning fron 1981 to 2020 .

4.1.2 The Average Hourly Universal Thermal Climate Index (UTCI)

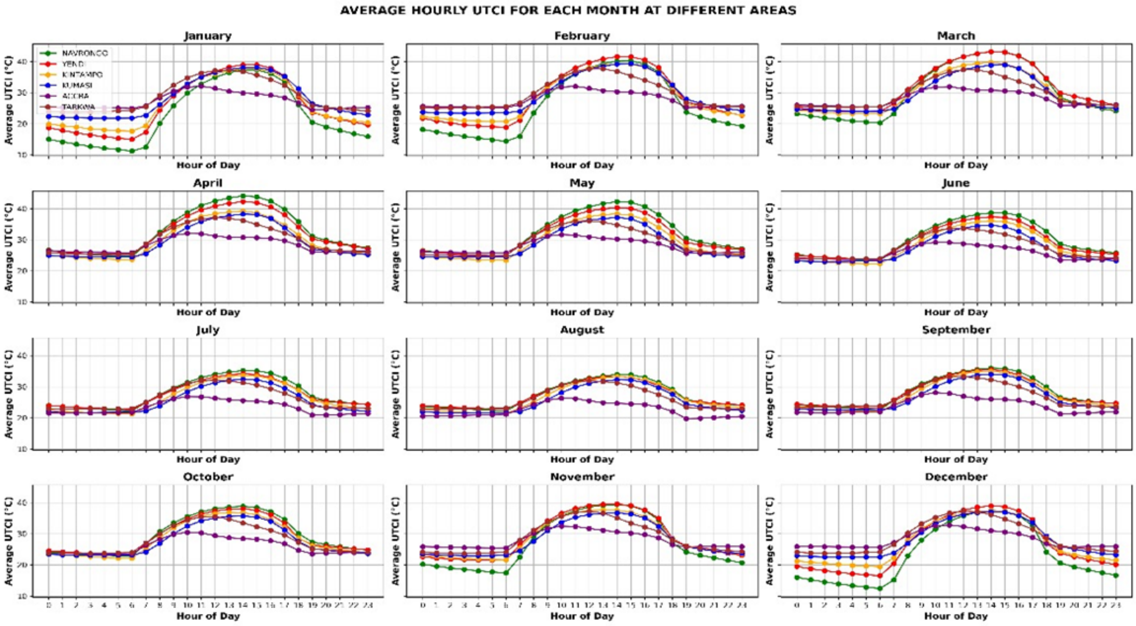

Figure 4.2: The average hourly Universal Thermal Climate Index (UTCI) output for different areas across all months of the year. .

The locations generally show a consistent daily pattern with UTCI values lowest in the early morning hours (around 5-6 AM) as well as evening hours from 5pm and peaking in the afternoon hours around 12 to 4pm. There are clear seasonal differences in UTCI values and patterns. Summer months (June-August) show lower UTCI values whiles the winter months (December- February) have higher UTCI values. This diurnal pattern shows how solar radiation influences the daily temperature cycle. Some locations consistently show higher or lower UTCI values compared to others. For example, Kumasi which represents a lower elevation area generally shows UTCI values which follows the trend of Yendi or Navrongo across the months. The UTCI values typically range from about 10°C to about 45°C across all locations and months. Peak afternoon values for some regions (especially Yendi, Navrongo and Kumasi) often exceed 35°C UTCI, indicating potential heat stress conditions. Throughout the months, Yendi is mostly seen to have the highest UTCI value especially in February, March, November and December.

4.1.3 The Annual Average Universal Thermal Climate Index (UTCI).

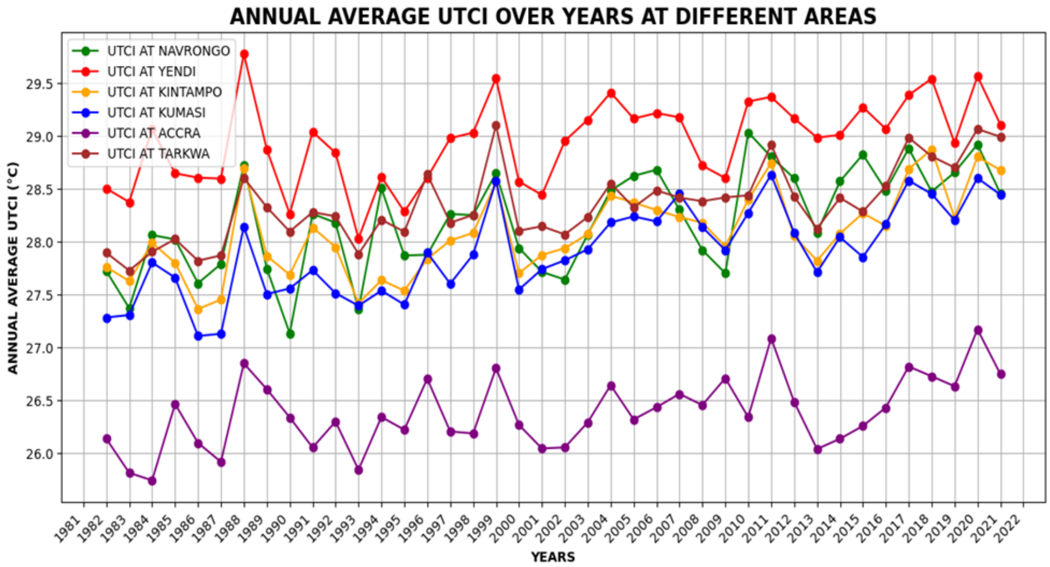

Figure 4.3: The annual average Universal Thermal Climate Index (UTCI) for different areas in Ghana from 1981 to 2020

There's a general upward trend in UTCI values across most locations over the 40-year period, suggesting a warming climate. This trend is not uniform across the years, thus showing a year-to-year variability. Yendi, on every occasion shows the highest UTCI values which is mostly above 29.5°C. Navrongo and Kintampo follows the trend of Yendi generally in the middle range with a UTCI value of about 28.5°C and 28°C respectively. Tarkwa shows high variability mostly in alignment with that of Yendi and Navrongo in terms of higher UTCI values. Kumasi, a region found in the forest region is seen to have a UTCI value which is close to that of Navrongo and Kintampo. Years like 1987, 1998, 2010 show UTCI peaks across the locations suggesting warming activities. In relation to short term climate variation, all the selected areas show significant year-to-year changes. The first decade (1981-1990) depicts some of the highest UTCI values recorded for most locations. 1988 stands out as one of years with an unusual high UTCI values for most locations, whiles 1984, 1994, and 2013 show lower UTCI peaks for several locations.

4.1.4 The Average Monthly Universal Thermal Climate Index (UTCI)

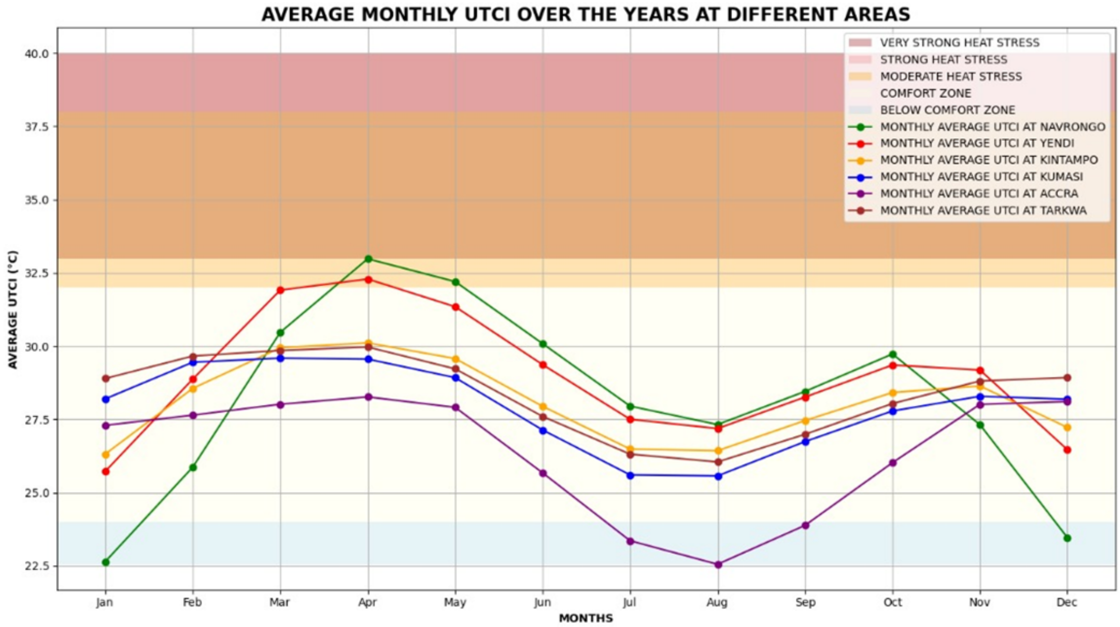

Figure 4.4: The Average Monthly Universal Thermal Climate Index (UTCI) over the years for different areas in Ghana.

The locations depict a seasonal pattern with peaks from March to May and lows in July and August. This pattern corresponds to the dry and rainy season in the country. Analysis of the data reveals that Yendi and Navrongo experience the highest UTCI values throughout the year. Kumasi, Kintampo and Tarkwa generally dip a little from the pattern of Yendi and Navrongo. Accra is seen to have the lowest of peaks except for the months of November and December. The figure shows variety coded heat pressure zones, ranging from "Below Comfort Zone" to "Very Strong Heat Stress". Most areas experience "Moderate Heat Stress" to “Strong Heat Stress" during peak months. Yendi and Navrongo momentarily enter the "Very Strong Heat Stress" zone from March to May. Accra remains in the "Comfort Zone" for much of the year, only entering "Moderate Heat Stress" briefly, other locations experience wider swings between comfort zones and heat stress zones. March and April are generally seen to be the hottest months throughout the average year.

4.1.5 Scatter Plots Depicting The Annual Average Universal Thermal Climate Index (UTCI)

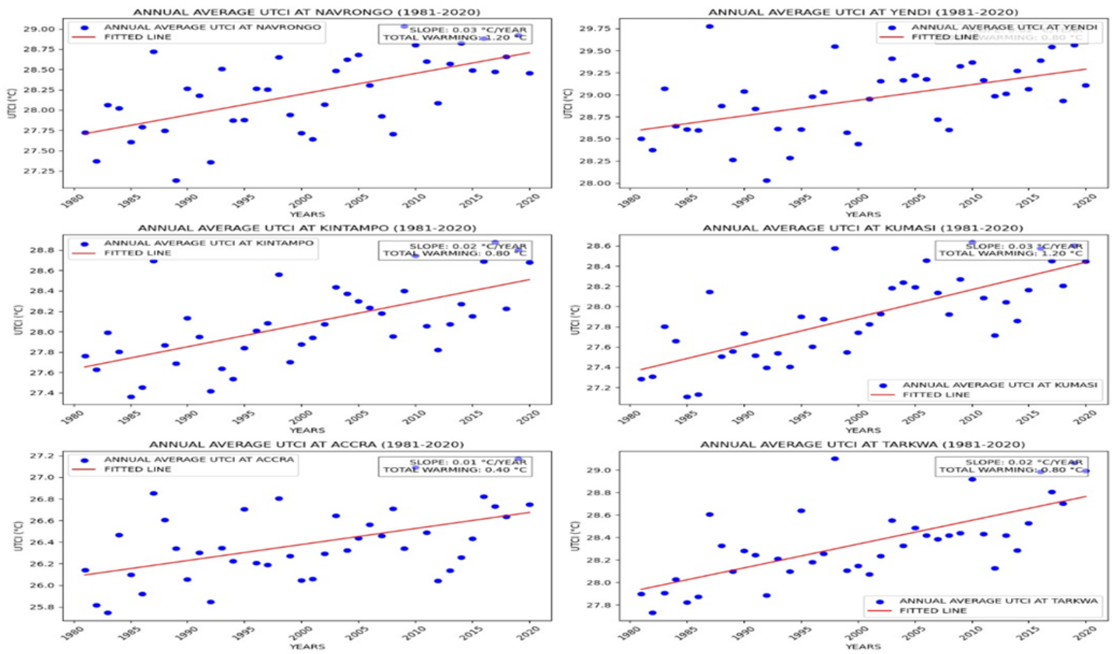

Figure 4.5: Shows six scatter plots depicting the Annual Average Universal Thermal Climate Index (UTCI) for different locations in Ghana from 1981 to 2020. The locations generally show a warming pattern over the 40-year period as shown by the positive slopes.

This figure shows six scatter plots depicting the Annual Average Universal Thermal Climate Index (UTCI) for different locations in Ghana from 1981 to 2020. The locations generally show a warming pattern over the 40-year period as shown by the positive slopes. Navrongo has a slope (annual change in rate) of 0.03 °C/year with a total warming of 1.20°C, thus indicating a very steep warming pattern. Yendi has a slope of 0.02 °C/year with a total warming of 0.80 °C depicting a variable but consistent warming trend. Kintampo has a slope of 0.02 °C/year with a total warming of 0.80 °C quite similar to that of Yendi. Kumasi shows an annual change in rate of 0.03 °C/year, a total warming of 1.20°C corresponding to that of Navrongo indicating a trend of increased warmth. Accra has slope (annual change in rate) of 0.01 °C/year with a total warming of 0.40 °C showing the lowest warming rate among all locations which could possibly due to the curbing effects of the oceans. Finally, Tarkwa shows a slope of 0.02 °C/year with a total warming of 0.80 °C with the moderate warming unchanging from that of Yendi and Kintampo. The locations in the northern region have the highest UTCI values, the coastal area which is Accra has the lowest peak and least warming. Kumasi and Kintampo found in the forest and transition zones respectively has a fairly warming trend close to that of the northern region.

4.2 Discussion

The UTCI data from ERA5 was examined and computed to show the thermal condition of the selected cities across the country. We evaluated the thermal stress across a forty-year period and produced various stress related time series as well as a spatial plot. The large diurnal variation in the average hourly plot suggests consistent geographical or environmental factors that influence UTCI at each location. The southern coastal areas consistently show lower Universal Thermal Climate Index (UTCI) values year-round, which could be as a results of the sea's moderating influence on local thermal conditions. While cities are not specifically identified, the consistently high UTCI values in the transition zone may be as results of UHI effects on urban areas making them experience increased thermal stress. Navrongo, a city found in the Sudan Savannah zone is shows its UTCI decreasing from the month of May to the September. Yendi also has a decreasing UTCI from the month of April through to that of October. This evaluation supports the claim that the Sudan Savannah zone has its precipitation from May to September, whiles the Guinea Savannah also has its rainfall from May through to October, which was made by Yamba et al. (2023) when they were re-classifying the agro-climatic zones in Ghana. The UTCI of these zones starts to increase from January through to April, this shows an increase in temperature proving the period of dry season in these zones. Increased UTCI values shows a pattern which in turn leads to increased heat stress, possibly affecting human health, increasing energy demands, and affecting economic activities in the cities. The UTCI scale shows monthly fluctuation, with certain months displaying a wider range of values, indicating different thermal stress levels over the region throughout the year. Kumasi is mostly seen to have a UTCI value close to that of Yendi which indicates that the city known as the "garden city" is gradually losing it vegetation cover. It is known throughout the country that Accra is the largest and most urbanized city in the country but from the results, it is seen to have the lowest warming trend, far lower than that of Kumasi. This finding proves that Kumasi which is known as the second largest city after Accra has a very steep warming trend. In an article byKoranteng et al.

(2019), it is said that when the city was planned in 1945, a large proportion was earmarked for landscape green spaces. Today, all the beautiful gardens such as the Adehyeman gardens, parks and gardens at Patasi, Abbey's Park, lawns and at the city centers have been encroached upon due to rapid urbanization. Also, in Koranteng et al. (2019), the Environmental Protection Agency (EPA) of Ghana estimated that annual mean temperature values of 0.6ºC, 2.0ºC and 3.9ºC will be the increment levels of the country in the years 2020, 2050 and 2080 respectively. Urban heat island (UHI) effects are evident in locations with high UTCI values, especially in areas with no water bodies. This is because water bodies aid in evaporation, the phase change associated with evaporation needs heat from its surroundings leading to a cooling effect on the environment.

CHAPTER 5

Conclusion and Recommendations

5.1 Conclusion

In summary, the study provided us with outcomes of the warming pattern of cities in the various climatic zones. This was accomplished by using a 40-year Universal Thermal Climate Index (UTCI) spanning from 1981 to 2020. Our study found a total warming of 1.20 °C for Kumasi, with an annual change in rate of 0.03 °C/year, this was found to be the same as that of Navrongo. Accra was seen to have the lowest total warming pattern which is quite alarming for the other cities since it's the most urbanized city. Kintampo and Tarkwa both have their rainy seasons from April to October, this is evident in their UTCI trend. The increase in the UTCI values of these selected cities proves the aftermath of depletion in greenery by means of urbanization. The change in warming pattern poses a threat to individuals in the various cities, it increases the risk of heat related illnesses like heat cramps, heat exhaustion, heat rashes and others. Increase in temperatures in turn leads to energy demand, that is energy consumption during cooling needs. The limitation associated with our work was the inability to gather data with respect to the greenery associated with the various cities in Ghana.

5.2 Recommendations

More research works should be directed towards the link between the Universal Thermal Climate Index (UTCI) and various illnesses. Authorities should take these factors and health risks into consideration when planning as well as incorporating adaptation strategies. Green urbanization is the way to go in this era, we must include green roofing and green infrastructure in our building and urban designs. Maximization of urban greenery will in turn increase our carbon sink capacity, thus aiding in climate adaptation. Laws can be enacted on the protection of outdoor workers from the heat during daytime work.

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