TITLE PAGE

EXAMINATION OF THE SPATIAL CHARACTERISTICS OF URBAN HEAT ISLAND IN WARRI METROPOLIS, DELTA STATE, NIGERIA

A DOCTORAL DISSERTATION

PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF DOCTOR OF PHILOSOPHY (Ph.D) IN GEOGRAPHY AND METEOROLOGY

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DEDICATION

I dedicate this work to God Almighty for His guidance throughout the course of study, and to my late father, Chief Pius Nosiovwe Origho.

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ABSTRACT

Land ambiet surface temperature is gradually rising in all cities in the world due to increasing levels of land use change and conversion especially in urban centres. Since 1991 when Delta State was created, Warri has undergone tremendous transformation in its land use and land cover due to rapid urbanization. Thus, Urban Heat Island (UHI) has become one of the greatest problems associated with urban growth and industrialization in the area. As a result, increased temperature associated with UHI has exacerbated threats to human existence. It is on this basis that this research examine the characteristics of urban heat island in Warri metropolis, Delta State, Nigeria. The objective therefore is to investigate the emergence of urban heat island in Warri by examining meteorological records of diurnal temperature ranges and the impact of urban heat on socio-economic activities. The study adopted empirical and exposit facto research survey through the use of integrated remote sensing and geographic information system to identify landuse/landcover types in Warri metropolis, including their temporal transformation and association with surface temperatures from the landsat TM and landsat ETM imageries of 1987, 2001, 2009 and 2011 respectively. The study discovered that as the built-up area increased in size, so was the surface temperature, bare surface, cultivated land and water bodies, while natural vegetation decreased in area extent. These changes were responsible for the rise in mean surface temperature from 1987 to 2011, indicating a 3.3^0c temperature increase. The study revealed a direct relationship between the changing pattern among the various landuse/landcover types and the variations in the surface temperatures of these landuse/landcover types within the period of study. Thus, if the rate of decline in vegetation cover is not checked, Warri metropolis may witness continuous increases in its radiant surface temperature as the cooling effect of vegetation cover is lost to impervious surfaces that litter the urban landscape. Therefore, tree planting should be encouraged in the area coupled with population control through the development of satellite towns in the suburbs to absorb the excess population in order to curb the effect of urban heat island on the environment and health of the people.

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LIST OF ACRONYMS AND ABBREVIATIONS/SYMBOLS

UHI	Urban Heat Island
ELHI	Boundary Layer Heat Island
CLHI	Canopy Layer Heat Island
SHI	Surface Heat Island
HVAC	Heating Ventilation and Air Conditioning
KT300	Thermometer Model
CBO	Community Based Organisation
CBD	Central Business District
MDG	Millennium Development Goals
SVF	Sky View Factor
WMO	World Metrological Organisation
GMT	Greenwish Mean Time
PMP	Paired Measurement Programme
THI	Temperature Humidity Index
GIS	Geographic Information System
ITD	International Discontinuity
SPDC	Shell Petroleum Development Company
NNPC	Nigeria National Petroleum Cooperation
GHG	Green House Gases
LST	Land Surface Temperature
NDVI	Normalized Difference Vegetation Index
NMA	Nigerian Meteorological Agency
NASA	National Aeronautics and Space Administration
USGS	Us Geological Survey
ROI	Region of Interest
DN	Digital Number
LULU	Landuse and Landcover
ANOVA	Analysis of Variance
UCL	Urban Cool Island
DSC	Delta State Company

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

It has long been recognized that the inhabitants of urban centers are subjected to climatic conditions that represent a significant modification of the pre-urban climatic state (Howard, 1833). One of the fundamental elements that set a city apart from its rural surroundings is the weather condition that prevails over it. In urban areas, buildings and paved surfaces have gradually replaced the pre-existing natural surfaces resulting in radiant energy being absorbed into roads, and rooftops, raising the surface temperature of urban centres up to 3.5°C higher than the ambient air temperatures (Taha, Sailor and Akbari, 1992). This phenomenon is known as "Urban Heat Island," a name given to the characteristic warmth of both the atmosphere and the lithosphere in cities compared to their non-urbanized surroundings (Voogt, 2004). Urban heat Island may be up to 10-15°C under optimum conditions (Oke, 1982). For almost 200 years, climatic differences between urban and rural environments have been recognized (Taha, 1997), of which temperature is the most obvious (Unger, Simeghy, and Zoboki, 2001). Of the many factors contributing to urban heat Island, changes on surface physical characteristics (including landscape geometry, thermal conductivity and wind speed), as well as, the concentrated release of anthropogenic heat, are believed to be the major causes of urban heat island (Unger et al., 2001).

Urban heat islands develop when a large fraction of the landcover in an area are replaced by built surfaces that trap incoming solar radiation during the day and then re-radiate it at night (Quattrochi, Luvau, Rickman and Estes, 2000; Oke, 1982). According to these authors , three types of heat islands may be identified and they include Canopy Layer Heat Island (CLHI), Boundary Layer Heat Island (BLHI), and Surface Heat Island (SHI).

The first two refer to a warming of the urban atmosphere; while the last refers to the relative warmth of urban surfaces. The Urban Canopy Layer (CLHI) is the layer of air closest to the surface in cities, extending upwards to approximately the main building height. Above the urban canopy lies the Urban Boundary Layer (BLHI), this may be one kilometer or more in thickness by day, shrinking to hundreds of meters or less at night (Oke, 1995). It is the Boundary Layer Heat Island that forms a dome of warmer air that extends downward of the city. Winds often change the dome to a plume shape (Kalu, 1979).

Heat Island types vary in their spatial form (shape), temporal (related to time), characteristics and some of the underlying physical processes that contribute to their development (Voogt and Oke, 2003). Air temperatures for canopy layer heat Island or boundary layer heat Island are directly measured using thermometers, whereas the surface heat Island is measured by remote sensors (Roth, Oke and Emery, 1989).

Rapid global urbanization has brought in unknown changes to humans, other life forms and the physical environment. Changes caused by urbanization on humans include diseases associated with crowding (tuberculosis, pneumonia, respiratory illness and psychological disorders) (Harrison and Gibson, 1976; Lelvis Bock and Ackrill, 1993). Urban effects on other life forms include physiological changes in urban flora and fauna and their diversity, (Sukopp and Werner, 1982) disease, as well as growth retardation in vegetation (Stulpnagel, Horbert and Sukopp, 1990).

Urbanization effects on the physical environment are apparent on air and water quality (Urban Air Pollution, 1992) and the microclimate (Oke, 1987). Thus, a study of urban heat Island can help to understand the air quality, energy use, water use efficiency and human comfort of an area.

The microclimate caused by the Urban Heat Island (UHI) has the effect of increasing the demand for cooling systems in commercial and residential buildings. Increased demand for energy can cost consumers and cities thousands of additional naira in air conditioning bills in order to maintain comfort levels.

In addition, increased electricity generation by power plants lead to higher emission of sulfur dioxide, carbon monoxide, nitrous oxide and suspended particulates, as well as carbon dioxide, a green house gas known to contribute to global warming and climate change.

This phenomenon, called urban heat Island is produced by the modification of the energy balance in built up areas due to the thermal behavior of buildings and street materials. The diffusion of heat is also changed in urban space. The local scale time and space variations of temperature are linked to factors like building morphology and surface cover or models. These last parameters are the bases of a classification of the urban land use in Warri Metropolis.

Urban heat Island phenomena are the key subjects to be studied for the urban micro-climate. It has been studied for a long time because its characteristics vary in the different locations due to meteorological conditions and unique features of cities and towns. Satellite imagery and ground measurement offer data to study urban heat islands in relation to energy and water conservation, human health and comfort, air pollution dispersion and total air circulation. The present study addresses the surface temperature estimation using satellite imagery and paired measurement program to analyze characterization of heat island in Warri.

1.2 Statement of the Problem

Urban heat island (UHI) has become an important problem that is associated with urbanization and industrialization of cities. As a result, increase in temperature associated with UHI has exacerbated threats to human health (thermal stress). Experience in many cities have revealed that temperatures are higher at night than during the day, more pronounced in winter than in summer, and is most apparent when winds are weak (Zhang et al. 2004; Song and Zhang, 2004). For example, in Beijing, the difference in mean air temperature between the city center and surrounding fields can be as much as 4.6^0C (Zhang et al. 2004; Song and Zhang 2003).

As UHIs are characterized by increased temperature, they can potentially increase the magnitude and duration of heat waves within cities. The nighttime effect of UHIs can be particularly harmful during a heat wave, as it deprives urban residents of the cool relieve found in rural areas during the night (Clarke 1972). Thus, during heat waves, death rates are often much higher in cities than in outlying environs (Henschel et al. 1969; Buechley et al; 1972; Clarke 1972; Jones et al. 1989; Smoyer, 1998).

The dominant causes of urban heat Islands, identified so far include heat trapping by urban scape geometry, alterations of urban thermal properties, changes in grass cover and man-made (anthropogenic) heat input (Emmanuel, 1993). In urban areas, temperatures can be above suburban areas (FEPA, 2001).Temperatures are normally high in the central district compared to the suburban areas around the city and usually greatest at night. Rapid population growth exerts and aggravates pressure on living space with a consequent deterioration in environmental quality (FEPA, 2001).

Warri is a fast growing city in Delta State (Efe, 2002a) .The city today is under the pressure of urbanization and industrialization, due to the presence of oil companies. The city has undergone an uncontrolled development. The city has developed paved surfaces and buildings substituted with the natural vegetation. Concrete surfaces like parking lots, roofs and roads attract the greatest amount of heat. Large masses of reinforced concrete and steel structure buildings absorb and produce huge amounts of heat, which in turn are radiated to the surroundings (Efe and Ojoh, 2013).

In recent times there has been a tremendous growth in human population in Warri. The city it has grown from being a rural area to an urban area (Oriero, 1998; Efe, 2002a). Warri is one of the rapidly growing cities in Nigeria, with a population rising rapidly from 19.526 in 1933, 55,256 in 1963, 280,000 in 1980, 500,000 in 1991 to 536,023 in 2006 (Annual Abstract of Statistics, 2008). It has a high population density that is concentrated in the core areas of the city. These areas include; Warri-Sapele Road, Agbassa, Okere, Okumagba Avenue, Igbudu, lyara, Jakpa Road and Airport Road, P.T.I. Road, Udu and Ekpan (Efe & Ojoh, 2011). Thus, as population increases so also the urban heat increases as well (Lankao & Gnatz, 2008). According to Cheke (2012) the urban heat warming bias of Warri metropolis is 4.18°C with a population of 536,023.

The population density in the city has also increased because of the increasing number of migrants searching for better working opportunities, services, and facilities (Efe, 2002a). Consequently, storey buildings and high commercial buildings that dominate the skyline have occupied the city, and they have a dramatic effect on the microclimates of the city. Furthermore, human activities have intensified the amount of heat generated from transportation systems, industrial plants and high voltage and air conditioning (HVAC) systems that are installed in buildings to lower the internal temperature to suit human thermal comfort inside the buildings. As a result, urbanization and human activities are major factors affecting modification s in the microclimatic condition of the study area. In the high-density areas such as Okumagba Avenue, Warri-Sapale Road, Deco Road, Jakpan Road, lack of greenery and low quality of albedo in urban spaces are quite important issues of the high temperature in Warri. There is the need to examine the characteristics of Urban Heat Island in Warri.

1.3 Aim and Objectives

The aim of this study is to examine the spatial difference in the temperature of urban space as well as the magnitude of urban heat in Warri metropolis. To achieve the aim of study, the following specific objectives are stated:

1. To examine study the urban heat island characteristics in Warri using land sat ETM thermal imagery and field observations using digital thermometers (KT 300)
2. To investigate the emergence of urban heat island in Warri by examining meteorological records of diurnal temperature ranges.
3. To generate isotherm maps for various zones of Warri Metropolis.
4. To examine the impacts of urban heat on socio-economic activities of the people of the area.

1.4 Research Questions

The research questions on this study are;

1. What is urban heat island?
2. What is the relevance of temperature – humidity index in UHI study?
3. How do we determine points of temperature heat island in Warri metropolis?
4. What is the urban heat island magnitude for Warri urban centre?
5. How can we solve the problems of urban heat island in Warri metropolis?

1.5 Research Hypotheses

Based on the objectives of the study, the following hypotheses are formulated to investigate the urban heat island characteristics in Warri.

Hypothesis 1

Ho: There is no significant variation in temperature within Warri metropolis.

Hypothesis 2

Ho: There is no significant relationship between land-use change and surface temperature characteristics in Warri metropolis.

1.6 Scope of the Study

The study is limited to Warri urban space and covers the period from January 1985 to December 2014. The parameters used in the study include temperature, humidity, rainfall, obtained from NIMET in the area.

This research work is restricted to the characterization of urban heat Island in Warri.

1.7 Justification of the Study

According to the estimates by the United Nations (1990, 1999) nearly half of the world's population currently live in urban areas. Within western nations, this number can approach 75percent. Therefore, urban heat islands are of interest primarily because they affect so many people. The impact on the world's population is far-reaching.

Urban Heat Islands have the potential to directly influence the health and welfare of urban residents. Within the United States alone, an average of 1,000 people die each-year due to weather events (Changnon, Kunkel and Reinke 1996). As UHIs are characterized by increased temperature, they can potentially increase the magnitude and duration of heat waves within cities.

Research has found that the mortality rate during a heat wave increases exponentially with the maximum temperature (Buechley, Van Bruggen and Trippi, 1972), an effect exacerbated by UHIs. The nighttime effect of UHI can be particularly harmful during a heat wave, as it deprives urban residents of the cool relief found in rural areas during the night. Increased temperatures and sunny days lead to the formation of low-level ozone from volatile organic compounds and nitrous oxides, which already exist in the air.

As UHIs lead to increased temperature within cities, they contribute to worsened air quality. Another consequence of urban heat Island is the increased energy required for air conditioning and refrigeration in cities that are in hot climates. Besides the obvious effect on temperature, UHIs can produce secondary effects on local meteorology, including the altering of local wind patterns, the development of local wind pattern, the development of clouds, and fog, the number of lightning strikes and the rates of precipitation. Since urban heat island affects inhabitants of cities in different forms, it becomes necessary to conduct a study on its health implications and the possibility of mitigating the effects of urban heat Island in the city.

1.8 Significance of the Study

The result of this study shall be of great significance to policy makers and town planners because it will explain the nature, causes, processes and effects of urban heat islands. In addition, it will provide a comprehensive review of the essential issues that “urban builders” must examine and the questions they must answer when choosing the architectural design and structural design and structural composition of our urban centres.

The findings of this research work will be of immense benefit to urban policy makers at local national and international levels, including climate change centres and community based organization (CBO) concerned with urban development, and the inhabitants of Warri. It will also act as a catalyst in rekindling interest on urban climatology in Nigerian higher institutions and research centres.

The outcome of this study will serve as a reference for health institutions, environmentalists individuals, government and private enterprises by educating them on the need to adopt policies that will help reduce urban warming and health risk. Furthermore, it is a valuable tool for the climatologist, environmentalist and related fields of urban micro-climate as well as a reference work to others who intend to carry out this type of study. The results of this research will go a long way in helping to alleviate the effects of urban heat island on the inhabitants of Warri metropolis through education and implementation of the suggestions made in this research.

Finally, this work will assist in achieving the Millennium Development Goals (MDG), which commits the international community to supporting a sustained program of progress towards environmental, social and economic development aimed at ensuring environmental sustainability in our urban centres; thus, it will be of great benefits to international organizations

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 Theoretical Background

"The urban heat island (UHI) can be described as a situation where temperatures are higher in urban areas than in the surroundings" (Montavez, 2002). In other words, heat island is a high density city area, which has higher temperature than the surrounding suburb areas. Based on the FEPA report (2001): "urban air can be 2-6°C hotter than the surrounding countryside during summer". In addition, Voogt (2004) remarked that, "urban heat island are formed is a condition where unexpected climate changes occur when rapid urbanization takes places in the city centers. Moreover, the temperature of various exterior surfaces increases and the city air considerably become warmer in the late afternoon (Voogt, 2004). Heat islands are formed as cities replace their natural land cover with concrete pavements, buildings and other infrastructure. These changes contribute to higher urban temperatures in a number of ways. Firstly, displacing trees and removing soil and vegetation takes away the natural cooling effects that shading and water evaporation from soil and leaves ordinarily provide. Meanwhile, tall buildings and narrow streets can heat the air trapped between them and reduce airflow. In addition, waste heat from vehicles, factories and air conditioners add warmth to the surrounding; further exacerbating the heat island effect, causing the surface temperature of urban structures to become 2.5°C higher than periphery air temperature (Taha, Sailor and Akbari, 1992).

The phenomenon of Urban Heat island was first described and investigated by Luke Howard in the 1810s. The temperature difference usually is larger at night than during the day and most apparent when winds are weak. Seasonally, UHI is seen during both summer and winter. Howard (1933), is credited to have carried out the first systematic study of urban climate modification (Landsberg, 1981). He compared the temperature records of a city weather station (London) with that of the surrounding rural areas. According to Howard (1933) the main causes of UHI is the modification of the land-surface by urban development, which uses materials, which effectively retain heat.

The heat island is an example of unintentional climate modification when urbanization changes the characteristics of the earth's surface and atmosphere (Voogt, 2004). Although early causative studies attempted to link UHI to city size, recent research has shown that canyon geometry and surface thermal properties of urban buildings are the most important causes of urban heat island (UHI) (Oke 1982, 1989; Arnfield, 1990). Botkin and Killer (1998) and Christenson (2004) observed that as cities add roads, buildings, industries and people, heat islands are created in urban areas because of the relative increase in temperature in cities more than their surrounding environment. Accordingly, urban heat islands are characterized by "Islands" the isotherms, or lines of equal temperature, form a pattern that resembles an "Island loosely, following the shape of the urbanized region, surrounded by cooler areas. There is often a sharp rise in the canopy layer air temperature at the boundary of rural and suburban areas. The theoretical framework was tailored according to Okes Model (1987), which stated that a larger city with a cloudless sky and light winds just after sunset, the boundary between the rural and the urban areas exhibit a steep temperature gradient to the urban heat island. It further stated that, the rest of the urban area appears as a "plateau" of warm air with a steady but weaker horizontal gradient of increasing temperature towards the city centre. This increase in temperature towards the city centre according to the model increase in attitude to the distinct intra urban land uses, such as residential, commercial, industrial, institutional, administrative and mixed residential land uses (figure 2.1).

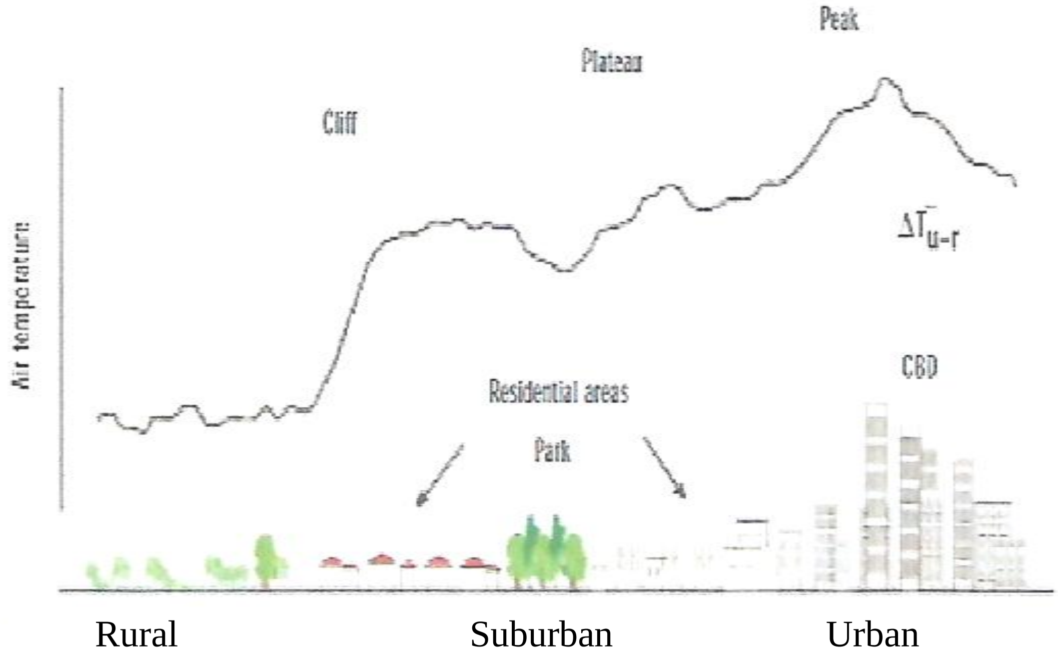

Figure 2.1 *Theoretical urban temperature cross section (Oke, 1987)*

2.2 Energy in the Atmosphere

Modification of the earth’s surface through urbanization can have a dramatic impact on local climate. One of them is a phenomenon known as the Urban Heat Island (UHI) effect. UHIs are characterized by “Islands” of warm surface air centered on urbanized landscapes and surrounded by progressively cooler air over suburban/rural areas. The urban-rural surface air temperature contrast varies diurnally and is one measure of the Urban Heat Island (UHI) effect. Urban Heat Islands result from factors that differentiate the urban from the non-urbanized landscape, including: anthropogenic energy releases from heating-ventilation-air conditioning systems, energy emissions from industrial processes and motorized vehicles, the amount of available surface moisture and differential heat capacities of urban building materials versus natural structures.

The temperature of air near the surface, or boundary layer, is strongly influenced by the energy flux and physical characteristics of the surface. The natural energy balance between solar radiation input, long-wave emissivity and sensible heat transfer results in a diurnal cycle of heating and cooling of the earth's surface and atmospheric bonding layer. In contrast, significant diurnal variation in air temperature is not observed above the surface influenced layer of the atmosphere or the free troposphere and above.

In order to examine the urban heat Island effect, we can consider the energy fluxes through a shallow layer at the surface containing air and surface elements. The external energy source for this layer is solar radiation. The net radiative energy, Q net is controlled by the relative magnitude of short-wave and long wave radiation entering and leaving the layer. The radiative energy budget can be accounted for with Equation

$Q_{net} = K_{dsr} + K_{usr} + L_{dir} + L_{uir}$ (2. 1) - - - - - -(2.1)

Where, K_{dsr} K_{usr} refer to upwelling and down-welling solar short-wave radiation flux and L_{dir} and L_{uir} refer to down-welling and upwelling infrared radiation (Oke, 1987, Stull, 1988). K_{dsr} is a function of solar zenith angle.

K_{usr} depends on K_{dsr} and the solar albedo of the surface. The higher the albedo of the surface the less energy is absorbed by the surface and more solar energy is reflected back into the atmosphere. L_{dir} is long wave dependent on the temperature of the surface. Equation 2.1 can be used to establish the amount of net energy that is potentially available for surface heating.

A surplus of radiative energy is available during most of the day and that a deficit exists during the nighttime. In general, the surface air temperature rises when Q net is increasing and cools when Q net is decreasing. The atmosphere and surface interact within a one hour response time (Stull, 1988).

Net radiation, Q net is a forcing term that results in partitioning of energy into sensible heat leaving the box through conduction (QH), Latent heat of evaporation conduction to the subsurface (Q soil) and storage of energy within the box (Qs) (Stull, 1988).

Q net = Q sensible heat + Q soil + latent heat + Qs----------- (2.2)

The amount of energy stored is a function of the mass and heat capacity of the layer and the rate at which energy is lost and absorbed. The ambient temperature within the shallow layer will be a function of the amount of energy stored there. The nature of the surface, its albedo, water content, heat capacity and thermal conductivity all play a role in partitioning the net radiative energy. The ambient temperature is an element of the microclimate modified by such surface properties (Oke, 1987). The Urban Heat Island project allows us to investigate the impact of surface features on the microclimate.

In an urbanized environment, there are significant modifiers of the natural cycle of heating and cooling. These include:

1. Human - made structures such as streets and buildings generally have a lower albedo than natural surfaces and therefore absorb more visible radiation (Oke, 1987). Artificial structures also add mass to the earth's surface and therefore can store (and release) more energy than an undeveloped surfaces (reduces Kr, increased L, increase Qs).
2. Urban surfaces tend to heat up faster than natural surfaces that retain water (increase Qs). Evaporation of water removes energy from surfaces and leads to cooler surface temperature. Urban surfaces are designed to quickly eliminate standing water, in contrast to natural surfaces, such as vegetation, that retain water.
3. Introduction of anthropogenic heat sources from heating and ventilation systems, industrial processes and internal combustion engines. In general, energy consumption will generate heat as by-product (directly warms the atmosphere, increase Qs and also increase Ld).

Since more energy is stored in the urban environment, these modifiers result in relatively slower nocturnal cooling rates in urbanized environments. This results in warmer average temperatures in urban areas relative to non-urbanized areas. However, this “average” effect is complicated by the presence of parks, forested areas, rivers and streams and other “non-urban features that exist in the landscape. This, detailed spatial investigations of the UHI can reveal microclimatic details that explain how various surface features enhance or mitigate the UHI effect.

General meteorological conditions also affect the magnitude of the UHI effect. The UHI is maximized under conditions of minimal cloud cover (increased solar input), low wind speeds (reduced mixing of air) and high vertical stability (thermal inversions). The horizontal and vertical motions of air reduce the rural -urban microclimate contrast. Cloud -cover at night absorbs and re-radiates long-wave radiation emanating from the surface back to the ground so that surface cooling everywhere is diminished and tends to reduce the UHI effect.

The “Heat Island” is expanding for many big cities in the world, and the phenomenon is analyzed in terms of local regional energy balance, economic activities, and climatic aspect and so on. It is discussed as the site specific issue. However, it is occurring in many places on a global scale with different intensity. It seems to be important to analyze the heat island phenomenon among cities in different geographic locations to understand its mechanism and forecast its progress, because there exist different stages of the heat island and they are growing at different developmental stages.

Figure 2.2: shows the conceptual framework of this study. The first step is the generation of visible and near infrared band data from which land cover classification is estimated. The land classification is categorized into paved surfaces, bare surface, forested surfaces, water bodies and built-up areas. It is from these surfaces that emissivity level

(outgoing long wave radiation) is determined, which may be low, moderate or high. The high emissivity areas will correlate with bare or built-up areas (urban zones); moderate emissivity will correlate with vegetated areas (rural areas) while low emissivity will represent water body or coastal areas. High emissivity will give rise to high urban temperatures. In an urbanized environment, the significant modifiers of natural cycle of heating and cooling include; human-made structures (buildings, paved surfaces, good conductor roofs); anthropogenic heat sources: industrial processes, internal combustion engines and heating and ventilation systems. The heat from these sources cumulates to give rise to pockets of high temperatures in urban centers that we call urban heat island (UHI). Thus, areas with high infrastructural development, industrial concentration and high density buildings and large population will always encourage UHI.

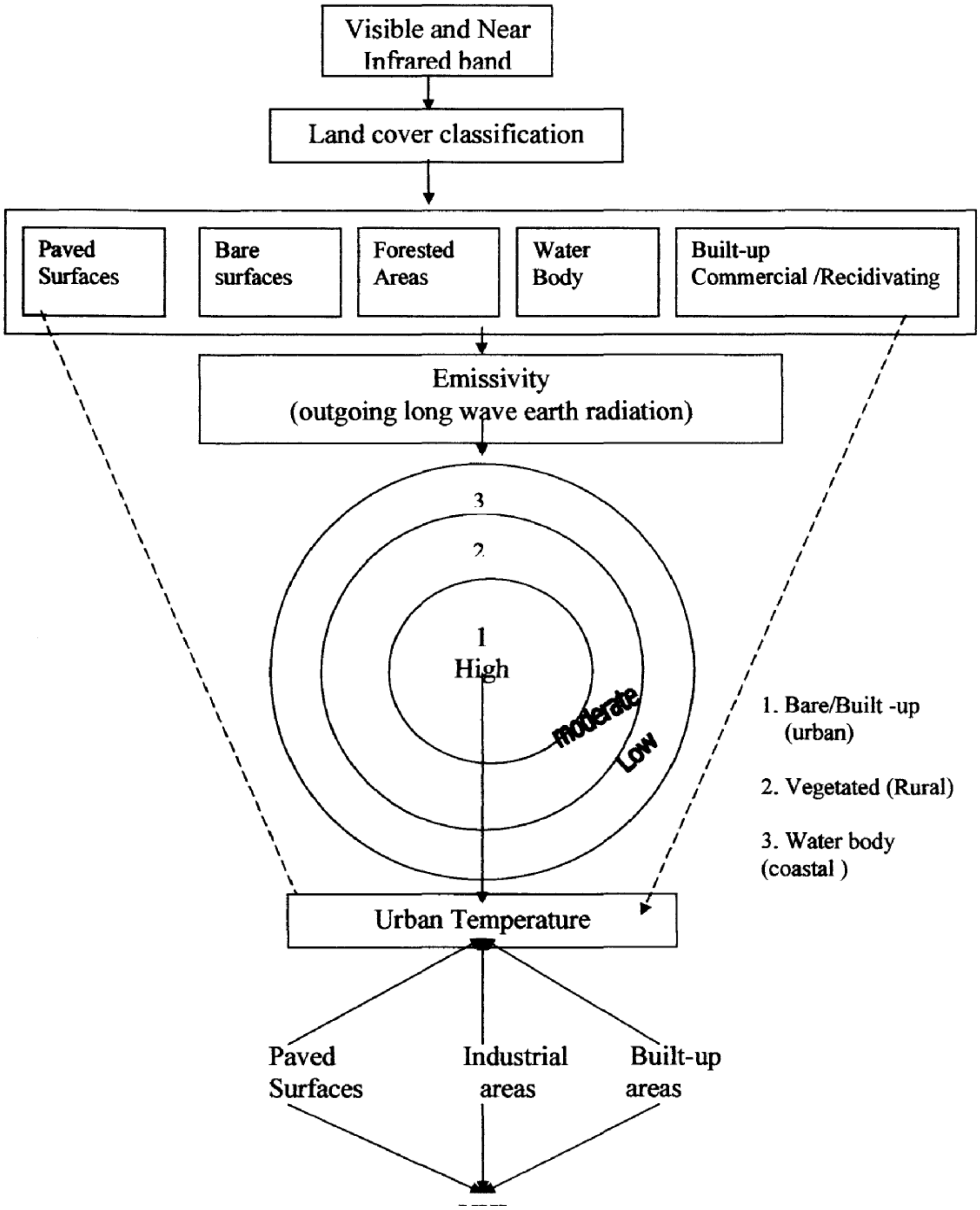

Fig. 2.2: Application of thermal Rays in studying UHI

Source: Adapted from Enete (2008)

2.3 Review of Related Literature

The follows are the review of related literature to buttress the study.

2.3.1 Characteristic of Urban Heat Island

According to Oke (1987) urban heat island reveals the typical air temperature features/characteristics of a city as described below: First, there is a steep temperature gradient in the urban and sub-urban areas, sequel to clear differences in building densities between the two areas. Secondly, the urban areas have relatively higher but more stable temperature. The temperature peaks over the downtown areas. The behaviour of urban heat island according to Airfield (2003) with some recent studies is that UHI intensity decreases with increasing wind speed (Unger Suneghy & Zoboki, 2001; Morris and Simmonds, 2001).

i. The intensity of UHI is greatest during anticyclone conditions (Morris and Simmonds, 2000; Tumanov Stan-sion, Lupu, Soci and Oprea 1999).
ii. UHI intensity is best developed in warmer half of the year (Morris and Simounds, 2010).
iii. UHI intensity is greater at night (Runnals and Oke, 2000).
iv. UHI may disappear by day or the city may be cooler than the rural environs (Runnals and Oke, 2000).
v. UHI intensity tends to increase with increase in city size and or population (Runnals and Oke, 2000).
vi. Rates of heating and cooling are greater in the countryside than in the city (Runnals and Oke, 2000).

2.3.2 Causes of Urban Heat Island

Urban heat islands are caused mainly due to the reduced radiant heat loss to the sky from the ground level of densely built urban centers. Most of the radiation is emitted from the roofs and walls of upper storey of buildings and lack of greenery in urban spaces and on the building surfaces.

The weather conditions and geographic location of cities as well as their urban characteristics affect the development of UHI in cities. The Heat Island Group (2005) also mentioned that: "presence of more gloomy urban surfaces, absence of vegetation and urban geometry are three main causes of UHI".

2.3.3 Urban Dark Surface

Because of reflectivity or low "albedo", gloomy surfaces contribute to HI (heat islands Hi) (Voogt, 2004). According to the Heat Island Group: "albedo is a kind of material which reflects more sunlight than the dark surfaced materials." Covered land and buildings with gloomy and dry surfaces, absorb sunlight. This produces thermal energy, causing the surface to become hotter"

2.3.4 Lack of Vegetation

It is also obvious that the continuous increase in built-up surfaces, throughout urbanization, constitutes the main reason of UHI formation. Using green surfaces for built-up activities has negative impact on two cooling mechanism: shade and evapotranspiration. Shade and evapotranspiration cools the atmosphere by blocking the sun radiation from the low albedo surfaces and by absorbing the water in the leaves also help to remove heat from the air (The Heat Island Group, 2005). According to Oke (1991):

“(a) As a result of interchange between screened skyline and buildings canyon radiative geometry cause to remove the lack of long wave emission from street canyons. Several road and building surfaces in the middle of canyons feel the radiation

(b) The heat which generated by gloomy (dark color) surfaces during the day, the facade material of buildings and pavements are important because this heat will re-emit to the atmosphere above the city during the night. Moreover, the reduction of vegetation due to the replacement of buildings and streets with natural landscapes cause to decrease air temperature through transpiration and evaporation. (c) Anthropogenic heat is produced by animals, human beings and as well as other stationary sources.

(d) The effective albedo of the system is decreased by canyon radiative because of the double reflections of the short-wave radiation by the canyon surfaces. (e) More energy is putting into latent and sensible heat by the reduction of evaporating surfaces.

2.3.5 Urban-Geometry

Urban geometry indicates the amount of buildings’ space and dimensions within a city, which is a supplementary parameter that affects urban heat island growth, especially at night. Wind flow and energy absorption are affecting the intensity of urban heat island. The air temperature in city centers is higher than the rural areas, especially at night (CPPD, 2008). CPPD researchers (2008) sometimes concentrate on a direction of urban geometry named urban canyons that could be illustrated by a relatively narrow road lined by tall and large buildings. In day time, urban canyons could have comparing effects on one side; tall buildings could make on the other. Asimakopoulos et al. (2001) states that: human activities in different types, for instance, loss of vegetation (deforestation) or changing the use of surfaces form greenery to buildings, highways; are capable of influencing the climate. On a local scale, it is vital as well, because they transform the albedo, thermal and moisture performance and surface roughness. As a summary, Asimakopoulos (2001) expressed the following: as the causes of UHI roots.

The complex exchange of heat between buildings in urban streets acts as canyons retaining heat. The thermal properties of bui1ding materials kept the heat within the fabric of urban areas. This heat is released from combustion of fuels, and animal metabolism. The urban greenhouse effect helps increase the heating effect of the incoming radiation on the polluted and heated urban atmosphere. Reduced evaporative cooling due to impervious surfaces, turbulent transfer of heat by air movement, from within streets is reduced.

2.4 Factors Affecting the Intensity of UHI

Urban heat island intensity depends on the amount or number (population) of people living in the area, morphology and size of the urban area. The changes between the maximum city temperature and contextual suburban temperature introduced as urban heat island intensity (UHII) (Ferrar, 1976; Oke, 1982).

Urbanization in terms of increased urban density and increased use of automobiles, increased impervious surfaces has resulted in increased urban temperatures. The temperature elevation in the center of the cities is the largest during the nights, conveying that the heat island phenomenon is nocturnal. “UHI is a phenomenon in which the urban temperature is higher than its surrounding rural regions which may happen in between the day or night”(Givoni, 1998). He also pointed out the following points: “during clear and still-air nights the biggest differentiation of the urban temperatures occurs like about 3-10°C. Besides, according to Bonan (2002) high density, mix use areas are about 5 to 7°C hotter than surroundings districts that have single use with less density. According to him, the city centers in many urban areas are 2°C warmer than sub-urban areas. There are several items that influence the rising temperature in cities. Consequently, UHI could be separated into two groups which is made by variety of issues: (1) meteorological parameters, like wind speed, cloud cover and humidity; (2) different factors of the urban structure (urban parameters), like the size of cities, the built-up areas density, and the buildings' heights ratio to the distances between them and population size, anthropogenic heat and urban canyon could strongly affect the size of the urban heat island. Chandler (1976), Landsberg (1981) and Oke (1982) also mentioned vegetation cover, water body of the city, population size, speed of wind, topography, anthropogenic heat, water overflow in the main city and meteorological parameters that increase the intensity of urban heat island.

2.4.1 Location of the City

"Topography, wind speed and direction, temperature, humidity, fog, precipitation, inversion prevalence varies in different location of specific region. The main cause of differences in these variations are the length between city and sea, height from the sea level, bearing of slopes, and the situation and the topography of urban area" (Givoni 1998).

2.4.2 The Size of the City and Population

Increasing the size of the urban areas, moving the large amount of people from the suburbs to the urban areas are causes of urbanization. Standard of living such as vehicular traffic, air conditioning in the summer, intensity in the use of electrical power for heating in the winter, and industrialization plus the density and size of the population are the reasons for the urban heat island phenomenon. As described before by Oke (1982) "the intensity of urban heat island and the population of the city have a direct relationship. Accordingly, there is a direct relationship between higher population in cities and the heat island intensity."

2.4.3 Density of Built-Up Area

Local climate in each discrete urban area affects the density of the several built-up surfaces. Givoni (1998) states that two types of factors affect the temperature variations between the urban and the rural areas; (1) the cloud cover, humidity, and wind speed that are climatic factors; and (2) the size of cities, building density, and the relation of buildings' heights in comparison with the distance between them that are the city parameters. In addition, "other parameters can also affect UHI formation like high density, shading and inappropriate orientation. If proper interventions are advised and implemented in the city planning decisions, better climate conditions can be handled" (Che-Ani, et. al. 2010).

2.4.4 Urban Geometry

"The repetition of urban canyon is characterized, be the urban (city) geometry of a city." (Emmanuel 2005). "Pollutant dispersion studies, energy consumption of buildings, heat and mass exchange between the buildings and the canyon air are important and depend on air circulation and temperature distribution within urban canyons" (Asimakopoulos et al. 2001). Emmanuel (2005) describes the definition for urban canyon as the three-dimensional space bounded by a street and the buildings that enclose the street. Urban canyons restrict the view of the sky dome (characterized by the sky view factor SVF), cause multiple reflection of solar radiation, and generally restrict the free movement of air. Building height and the street width ratio helps to define the geometry of the long urban canyons.

2.4.5 Thermal Properties of Fabric

According to some of the authors (Landsberg 1981; Oke 1982; Quattrochi, 2000) "stone, concrete, asphalt and the gloomy materials have a tendency to hold heat at the surface". Akbari (1997), Taha (1997), Konopacki (1998) were all agreed on: "These kinds of materials attract the solar (heat) radiation during the day and retain it in urban fabric at night;

urban surface released this stored heat slowly. The correct and the useful albedo is the one that is absorbing less amount of solar radiation. In the urban area where there have been, use of high albedo material in building exterior surfaces (white ones); it is proven that these materials decrease the urban temperature.

2.4.6 Surface Waterproofing

On one hand, UHI increases due to the lack of porosity materials in urban surface, great number of water-resistant surfaces and non-reflective surfaces, on the other hand evaporation decreased in the city according to lack of vegetated and moisture trapping surface. Goward et al (1985) stated that, green areas and soft landscaping elements are regulating the surface temperature, more than gloomy and low-albedo materials in surfaces (Goward et al. 1985) and "evapotranspiration reduce heat lost due to a lack of vegetation" (Lougeay et al. 1996).

2.4.7 Anthropogenic Heat

"Anthropogenic heat further contributes to the UHI's effect into the urban atmosphere" (Taha, 1997). As a result of high population density, an urban center seems to have higher energy demands than suburban areas. However, Landsberg (1981) believed: "high demand for energy in the winter is the result of the heat island effect that is increasing due to the demand for air-conditioning through the summer- time". Beside Oke (1982) believed that: fossil-fuel burning and electric power generation in local and regional urban areas cause high percentage of air pollution.

2.4.8 Air Pollution

In general, wide ranges of pollution are generated in the urban areas. Smoke from cars, industrial activities and air conditioners are three most important sources of air pollutants. Variations of the contribution of industrial sources to air pollution from one urban area to another occur due to the type and the number of the industrial facilities in a town or city. Different types of land uses have different impacts on heat island especially industrial and commercial zone and their inappropriate locations generate high temperature in the cities. High densely populated areas, surroundings and commercial areas can be considered as the most significant parameter to produce heat.

2.4.9 Wind Speed

The UHI intensity increases because of warm air stagnated in the urban canyon due to the high-density building and low albedo surfaces. Constrained evaporation also prevents good wind speed in the city. As stated above the characteristics of the UHI are related to both the intrinsic nature of the city, such as its size, population, building density and land uses, and external factors, such as climate, weather and seasons (Oke, 1982). Also, there is a close relationship between UHI intensity and population (Landsberg, 1979; Lo and Faber, 1997). The geographical locations of cities are important, including the nature of soils, the presence of water, topographical features, vegetation and land uses. There is also a relationship between UHI intensity and area city size (Oke, 1982).

2.5 Effects of Urban Heat Island

Urban environmental features can be a threat to the viability and to the locations such as where the less number of people would prefer to be in built-up areas, and downtowns for other uses such as commercial, residential, or entertainment. “These changes in the preferences of the people make them to migrate and this result in urban expansions in many cities. Due to the migration of these people from the city centers, these areas become stable for years (Estes et. al. 2003).

As has been occurring in many developing countries, UHI events affect the local nature and population in different ways, including the quality degradation of air, leading source for air pollution. As temperature increases, the demand for energy to power air-conditions requiring power to increase their output. In summer time, the demand results in higher emission of the pollutants they generate and leads to air pollution" (Oke, 1981).

"The UHI effect can elevate the air temperature, work as stabilizer effect to sun radiation and may subsidize to formation of ozone. If urban heat island can be mitigated, the important reduction of ozone level will be the result. This can reduce the budget for greater knowledge of relationship between urban heat island and ozone levels" (Oke, 1981).

2.5.1 Urban Heat Island and Discomfort

Heat stress is usually the discomfort felt in the humid tropics, although it often plagues into the temperate and the mid latitude regions during summer in the form of "heat waves". Even in these regions, Sanchez (1984) observed that thermal discomfort or stress assumes different shapes depending on whether the settlement is rural or an urban area (with reference to "heat island effect").

Physiological comfort or discomfort is experienced on the more sensitive areas of the skin surface, which acts as the initial receptors before sharing the discomfort across the body systems, and thereby triggering various feedback mechanisms in order to maintain the thermal heat balance of the body.

The feedback mechanisms can either be voluntary or involuntary. Voluntary involves the conscious efforts to regulate the skin and internal temperatures through clothing, physical activity or cultural adaptations; while the involuntary involves unconscious actions like sweating, shivering, goose bumps, blood flow (Vascomotor), etc.

In establishing thermal balance, feedback mechanisms may help to achieve heat balance, however, it may not be comfortable. Therefore, it may be necessary but not sufficient condition for comfort. Thus, in human thermal ‘balance context, we are comfortable when the heat load and the dissipation rate are equal (thermal equilibrium) - without resorting to any of the feedback mechanisms (WMO, 1996). Consequently, we are “uncomfortable” when feedback mechanisms are required. Therefore, discomfort arises in an environment, where the heat load exceeds the dissipation rate (a hypothermic environment) or when the dissipation rate exceeds the heat load (a hypothermic environment).

2.5.2 Impact of Climatic Elements on Human Comfort

Food and shelter are the mainstay of man’s life on earth. His food requirement is ultimately met through conversion of solar radiation to usable energy, a conversion in which the role of climate is highly significant. The nature of his shelter depends largely upon the climate. Therefore, there is nothing on earth that cannot be affected by climate.

Basically, the two areas that are affected or influenced more by climate are man’s health and comfort. They help in determining the state of the human comfort within a given area. The physiological comfort defined by Ayoade (1983) is a state of feeling in which a person has no wish to increase or decrease isolation. It is a condition of mind that expresses satisfaction with the thermal environment. It is also stated by Ayoade (1983) that there are large variations from one person to another, due to the heat balance of one body to another that is the environmental conditions required for comfort may not be the same for everyone. However, through the process of extensive laboratory and field data collected, it provides the necessary statistical data to define conditions that specified percentage of occupants will find thermally comfortable (Crowe and Moore, 1973).

Warri metropolis has two seasonal periods. These are the dry season comprising of 5-6 months and the wet season of 6-7 months. The temperature within this region is highest during the dry season, ranging from 32°C to 35°C.

Two major air masses dominate the climate of Warri. They are the tropical maritime and the tropical continental air masses. The tropical maritime is formed over the Atlantic Ocean to the south and is therefore, warm and moist. It moves inland generally in a southwest to the northeast direction, while the tropical continental air mass is developed over the Sahara desert and it is warm and dry. It blows in the opposite direction, northeast to southwest.

The tropical continental air mass is associated with dry season and the northeast trade winds. Within these periods, there is flow of dry dusty air from the northern region. This causes ill- health to man such as catarrh and cough. For instance, Critchfield (1974) in Ayoade (1983) has individuals or group emotional out-burst, seem to reach their peak at the onset of or during hot unpleasant weather. People tend to prefer the indoor jobs to those outdoor jobs because of their prevailing temperatures and the uncomfortable nature of the atmosphere, (Ayoade, 1983).

The tropical maritime air mass creates the wet season, which gives the south east monsoon winds, certain weather condition which is most conducive for the inhabitants of Warri. For example during the wet season, though there might be ill-health such as cold, rheumatism etc, after the rain they may be cloud cover cool air which reduces the effect of temperature (Ayoade, 1983). The temperature ranges in the wet season are quite lower than the dry seasons and the tendency for agitatedness is equally low (Ayoade, 1983). Instead, people work for longer period of time, if necessary statistical analysis on health reports, have shown that during the wet season, which is more favorable to man's comfort, has a high rate of pregnancy conception, among the reproductive group (Calot and Blayo, 1982).

In June, the northerly flow of air component has weakened and only the southerly flow predominates, it brings a lot of rain. In September, the tropical continental air mass begins to intensify over the territory and the north east trade winds become the dominant wind from October to March bringing with it dry cloudless but dust laden conditions associated with the harmatten (FCDA Reports, 2000). The days are very hot, due to absence of clouds in the night, there are considerable losses of heat by radiation from the earth. The sharp drop in temperature often below dew point gives rise to early morning temperature inversion, mist and fog thus occurring. (FCDA Report, 2000).

The element of weather and climate describe the state of the atmosphere at a particular time and place. It could be dry, wet or hot and cold. The extreme of these conditions have the devastating influences on human comfort and well being.

The catastrophic weather conditions of storm, tropical cyclones and floods kill many thousands of people every year (Adefolalu, 1997). Adefolalu (1997) further stressed that noncatastrophic weather can also have varied and significant impacts on human health. For instance weather affects the level of air pollution in a city; rainfall can increases the local pollution of malaria mosquitoes. People in tropical areas that rely on seasonal rains for agriculture, their food supply and hence nutritional status are highly seasonal because the wet season is considered a hungry season, because the harvest of the is period of the year has began to run out as crops are just growing. This is also considered the sick season hence malnutrition increases vulnerability to infection (Adefolalu, 1997).

Many homes require an indoor temperature in the range of 17°C and 31°C. Temperatures outside their range are not comfortable for human being to live. The tolerance range varies from one individual to another and tends to get lower with age. The temperature of the surrounding air is the most significant factor for human comfort. It is also influenced by other factors such as humidity, wind, and sunshine. Humidity has a pronounced effect on our sensation of temperature, especially when conditions are hot; wind has a significant effect on our wellbeing when conditions are cold or very hot (Fasegha et al., 1999).

The seasonal occurrence of dust haze pollution during the harmattan season has been previously documented by many research studies across Nigeria (Adefolalu 1968, Ama, 1971; Adebayo, 1978; Adefolalu 1984; Adefolalu et al; 1990). Laboratory analysis concludes that the increasing intensity of thick dust veils, contains carcinogenic, apart from confirmed presence of DDT, Aldenn and other chemical used as pesticide and herbicide which serves as major threat to health.

In his study, Adefolalu (1984) found that there is an increasing occurrence of respiratory problems during the Harmattan accounting for 42% of the twelve months totals between April, 1977 and March, 1978. Adefolalu, (1984) also stressed that the common kinds of respiratory infections (Pneumonia and bronchitis) are associated with the rainy season when surface wetness and lower temperature are critical factors.

Nieuwolt (1982) in his book tropical climatology explained that the human body is kept at a constant temperature of 36.7°C and defense mechanism prevent excessive loss of heat or too much heat absorptions. Nieuwolt (1982) pointed out that physiological temperature does not only depend on the temperature of the air, but also on the efficiency and speed of evaporation, which is controlled by a number of other factors. The most important of these factors is the humidity of the air, when the air is humid, the evaporation or perspiration is limited and a feeling of oppressiveness is created. The combination of high temperature and high humidities are sometimes indicated as the sultriness of the air (Bluthgen, 1966). Dry air on the other hand, allows a rapid cooling of the skin as much latent heat is used for the evaporation of the perspiration and high air temperature and endured much better with low humidity.

Where air is stagnant, the layer of air around the body not only heats up approximately body temperature, but is also soon saturated with water vapour, thus restricting further cooling of the skin by evaporation. In sunshine also, the skin absorbs a great deal of heat, although the actual air temperature is possibly the same as in the shade.

Nieuwolt (1982) concluded that the main factor controlling physiological temperature remains the temperature of the air. The other factors only contribute to the differences in the sensation of the air temperature created in living organism. These sensations depend on individual characteristic, such as general body weight, or type of clothing worn and the physical activities carried out. It is also influenced by psychological factors and adjustment to the prevailing climatic conditions. It can adjust to the prevailing climatic conditions. It cannot therefore be measured or calculated directly, but it is usually expressed as the percentage of a number of tests from persons feeling thermal stress under carefully controlled laboratory condition.

When quantitative relation between environmental conditions occurs, the reactions of human beings are investigated; emphasis is usually put on the effect of temperature and humidity of the air. These two factors are easily controlled and measured and it is generally accepted that they are the two most important factors controlling the physiological temperature.

It is stressed by Griffiths (1976) that if there is an appreciable increase in the amount of ultraviolet light normally received by the body, such as occurs on high mountains, intense sunburn, conjunctivitis and cataracts can result. The white settler at high attitude tends to perspire a great deal and skin ailments become difficult to cure and heal. Intense radiation can lead to heat stroke, whether or not there is an increase in ultra violet radiation.

Oliver (1973) indicated that man is subject to a constant barrage of near ultraviolet, visible and infrared radiation. Each of these directly affects the body and body function, because they determine both the effect of thermo regulation and the photochemical responses that occur in the skin. He (Oliver, 1973) stressed further that skin cancer occur much more frequently in the southern United States, because compared to the northern States, exposure to radiant energy is greater. Auerbach (1961) concluded that-skin cancer also appears more prevalent in outdoor than indoor workers.

2.5.3 The role of temperature on socio-economic activities of man

2.5.3.1 Social Activities

Siple (1949) has given detail of a classification of the world according to clothing requirement based to a large degree, upon the climate. In this, he distinguishes seven main zones while making the point that because of the different metabolic rates of active or inactive persons, it is difficult to make sweeping general statements as to the exact clothing needed. According to Siple (1949) the seven clothing zones include (i) minimum clothing zone is the tropical and jungle type (ii) hot dry clothing zone- the desert type (iii) the one layer clothing zone-the subtropical or optimum comfort type (iv) two layer clothing zone-temperate cool winter type; (v) three-layer clothing zone temperate cold winter type (vi) four-layer maximum clothing zone-sub artic winter type and (vii) the activity balance zone -Arctic winter type. This represents the extreme cold stress, conditions under which comfortable heat balance cannot be maintained by any simple increase of clothing insulation alone.

Under conditions of hot or cold stress it is necessary for the body to be insulated, or at least partly cut off from the source of the thermal trouble. In general, this is affected, for man, by the wearing of clothing.

In keeping the home, climate influences both our daily area and way of living. The weather can be our ally or our enemy, and this fact is particularly true when considering the influence that climate has upon household management (Griffiths, 1926). For example food or its method of preparation or cooking is affected by climate through variation in temperature, humidity, sunlight and pressure. Dietary habits are similarly influenced by climatic condition.

Westerterp-Plantenga et al, (2003) assessed the effect of ambient temperature that is 16°C compared to 22°C, on energy intake, energy expenditure and respiratory quotient in men discovered that at 16°C, compared to 22°C, energy metabolism was increased, due to increases in sleeping metabolic rate and diet induced thermogenessis. Overeating under libium circumstances at 16°C attenuated the decrease in rectal core body temperature.

Lyam (2003) pointed out that social activities increase during the work free periods or when less work is on the fields during the dry season people particularly women and children engage in dances that are practiced at leisure time. Changes in climate patterns bring about changes in disease patterns. Warmer temperature and wetter climate enhance the breeding condition for organism that transmits disease. Warmer and wetter climate in Rwanda, has increased the incidence and geographic range of malaria. In Pakistan, a regional temperature increase of 0.5^0C has contributed to the transmission of malaria cases from a few hundred in 1980 to 25, 000 in 1990. Redistribution of other diseases like yellow fever, dengue fever are now evident at higher altitudes and latitude, as seen in India and Columbia in South America. People with heart problems are most affected during heat waves (Woodrow, 1998).

2.5.3.2 Economic Activities

The main climatic elements in agriculture are temperature, moisture in all its form, sunlight; winds and evaporation. All crops have minimal optimum and maximal temperature limit for each of their stages of growth (Griffiths, 1976). These limits can vary appreciably for example, tropical crops such as cacao, dates etc, need a high temperature throughout the year while winter rye can withstand freezing temperatures during it’s long winter dormant period. In general, a high temperature is not as destructive as low temperature, provided that moisture supply is sufficient to prevent wilting. Certain plants can be killed by chilling temperatures.

Guyot (1956) investigated the grape yield and found it above 8°C, while the quality was correlated with a quadratic expression in hours of sunshine during July. The yield of tomatoes varies enormously from place to place in the United States. Neiuwolt (1982) noted that temperature generally limit the growing season.

As temperature conditions are frequently below the optimum for most crops, there exist close correlation between yields and temperature. Yields of highland crops such as pyrethrum, coffee and potatoes are inversely correlated with temperature, (Muturi, 1968). For many other tropical crops, both the quantity and quality of the produces are reduced by high temperature, mainly because some diseases and pests occur more frequently under warm conditions

Chin and Wang (2005) also noted in their study that the radial growth response of climate of white spruce in open grown conditions was examined at two measurement height in order to examine the role sampling height play in dendro-climatic analysis. Regardless of the sampling height considered, the result indicates that white spruce at its southern distribution limit responded strongly to moisture stress intensified by high temperature.

The temperature regime of a particular location will affect the timing of planting and harvesting and the rate at which the crops develop. With adequate moisture, the temperature growing season is largely determined by temperature in mid-latitude regions. This generally extends from the last frost in the spring to the first frost in the fall.

In industry and commerce, workers comfort will vary with conditions and even when the building have been sensibly and efficiently constructed there is often need for artificial cooling and heating, thus adding greatly to the overhead expenses. Griffiths (1976) observed that for some operations there exist a linear relationship between cost and output and the temperature below thresholds.

Both power and communication in many parts of the world are transmitted by overhead cables. During periods of high temperature, the wires expand and appreciable sagging occurs. Temperature variation also influences transmission and the functioning of apparatus, such as switches, insulators and transformers (Pochop, 1960). Mountain runoff, timing of runoff, in turn determine the availability of water for competing agricultural, municipal, industrial, hydropower, recreational and ecological uses.

Bergman et al, (2000) in a study of seasonal variation in rate of methane production from peat of various botanical substrate quality found that the quality of organic matter, in combination with changes in temperature, explains the seasonal variation in methane production and this affects the quantity of methane available.

Climate, is tied to a particular location, so that when individuals decide to move themselves and their productive activities to a certain place, they are also choosing the climate in which they will live and operate. For most economic activities climate is only one of many factors influencing choice of location. The connections are obvious for hydro electric power (HEP), where drought conditions can quickly lead to reduced generation (Trenberth et al, 2000).

Oliver (1973) reported that in Great Britain there has been a distinct migration of the labour force away from the north towards the south, which experiences warmer, sunnier summer. Just as climate acts as an asset in attracting a labour market, it can also act as deterrent.

As pointed out by Obasi (1997) climate shapes our culture, many of our settlement and all our landscapes, it largely determines food production and its variability also caused famine. Adefolalu (1997) noted that the benefits derived from favorable weather are more difficult to quantify than loses, but the productive sector of the economy of all nations derive huge benefit from rain fed agriculture, energy, wind and other forms of weather-induced life support systems which are beyond prices.

The review of relevant literature has shown that weather and climate have an impact on the life of man on earth. The impact of temperature has been studied in other parts of the world as it affects the socio-economic wellbeing of man.

2.6 Studies in Urban Heat Island

2.6.1 Historical Trends in UHI Studies in the Tropics

In the past ten years, empirical studies of the UHI have confirmed the expansion of geographical research beyond the traditional mid-latitude zones to the tropical, subtropical and semi-arid climatic zones. Urban heat island nature have been documented recently in Pune, India, Mexico city (Jauregui and Luyando, 1998; Deosthali, 2000; and Guadajara, Tereschenko and Filomov, 2001) Mexico, Athens, Greece, (Livada, Santamouris, Niachou, Papnikolaou, and Mihalalahou 2002), Aveiro, Portugal (Pinho and MansoOrgaz, 2000); Valencia (Gpmez, Gaja, and Reig (1998) and Granada (Montavez, Jiminez and Sara 2002) Spain, Tel-Aviv, Israel (Saaroni, Ben-Der, Bitan and Potchter 2000); Buenos Aires, Argentina (Uerola and Mazzco, 1998); Fairbanks, Alaska (Magee, Curtis, and Wendler, 1999); Seoul, Korea (Kim and Balk, 2000); and Singapore (Goh and Chang, 1999).

Such studies provide an important test of theories and empirical relationships developed in mid latitude cities. For instance, Goh and Chang (1999) confirmed that canyon geometry expressed as the height/width rates is an important explanatory variable that may also be used in urban planning in tropical cities. The wisdom of population based adjustments is also questioned by Bohn (1998). In Vienna, population has increased 2.5 folds, rural land use, changed, and living floor space has increased in intensity over the period.

As an alternative to population based corrections, Gallo and Owen (1999) suggested that satellite based adjustment for the UHI bias may be possible by considerations of the normalized differences in vegetation index and surface radiant temperature.

Sunberg (1951) was the first to relate the UHI intensity to meteorological conditions. In a similar vein, recent studies that focused on weather influence have highlighted the pivotal role of cloud cover in UHI formations of a strong UHI, further investigation on this region by Morris and Simmonds (2001) showed that wind speed explains only a small amount of the variation in the observed UHI magnitude. Rather, clear sky conditions resulted in the most developed UHI were associated with increasing amounts of cloud cover, similar results have been found for Vancover, Canada by Runnells and Oke (2000). Awuh (2013) found that, urban heat island has an effect on the health of urban dwellers in Douala which is usually in the form of heat related illnesses and symptoms.

2.6.2 Overview of UHI Studies in Nigeria

Studies on city climate are few in the tropical world (Characterjee, 1964). As cited in Enete (2009) the study of urban climate is still at an infant stage in Nigeria. One city that has witnessed a tremendous study of its microclimate in Nigeria is Ibadan, the largest truly indigenous city in sub-Saharan Africa with an area of about 27, 249 sq. km and a population of 2,550,593 (2005).The earliest documented urban climate research was that of Oguntoyinbo (1970) in which he studied the albedo and reflection fluxes of urban and rural surfaces in Ibadan. His findings indicated a mean albedo of 12 percent for urban surfaces and 15 percent for rural surfaces. Oguntoyinbo (1973) further examined the impact of urbanization on the climate of Ibadan. In the study, temperature and relative humidity data were collected across the city during the daytime using simple thermo-hygrographs and whirling hygrometers. Primary data collected were complemented with data from the airport and other agrometeorogical stations within the city. The study indicated 7% lower relative humidity in the city during the daytime.

Since the pioneering works by Oguntoyinbo, other urban climate studies were undertaken in the 1980s, largely on the issue of the urban heat island phenomenon (example, Ojo, 1981; Adebayo, 1985; Omogbai, 1985; Ama, 1989; and Oniarah, 1990). A common characteristic of all these studies is their empirical nature. Ojo (1980) studied the spatial and temporal variation of temperature across the city of Lagos using temperature data taken from traverses across the city. Findings of the investigation showed the urban heat island effect of 2°to 4° in the zone of dense traffic and main traffic corridors of Mushin/ Oshodi areas of the city at noon or in the late afternoon. Ojo(1981) also examined the land-use energy balance relationships in metropolitan Lagos.

The first comprehensive urban climate study, however, is that of Adebayo (1985) in which he analyzed the spatial, diurnal and seasonal characteristics of global radiation, surface albedo, net long-wave radiation, and latent and sensible fluxes of energy for Ibadan city. The study was based on data collected on a daily basis (0600-1800hours GMT)for one year in twenty stations located all over the city. The study showed that global radiation values for different land uses ranged between 0.62 and 0.64 min^{-1} in the urban center, a decrease of about 14 percent. The effects of the pollution view and the reduced sky view factor within the canopy were identified as being responsible for the decreasing global radiation towards the city centre. Mean values for albedo ranged between 15 and 28% in the rural areas to between 8 and 10% in the city centre, while the net radiation at the urban centre was about 15% higher than that of the rural area. Decreases in surface albedo, and therefore increases in the amount of energy absorbed at the surface, and long wave radiation by atmospheric pollutants are factors responsible for the increase in net radiation toward the centre of Ibadan city.

It was also shown that net long wave radiation in the city centre increased by as much as 16-17% over the rural environment. The study also indicated a decrease in relative humidity from 80% in the rural area to 75% in the urban centre. The urban heat island effect was also described for the city of Ibadan. During the wet season, an increase of 1.0°C to 1.5°C in the temperature towards the city centre was observed. The effect was more pronounced during the harmattan season with a temperature difference of 2.5°C to 3.0°C and in the middle of the dry season a temperature difference of 8°C was observed. This value observed by Adebayo (1985) is quite high compared to the 3.6°C-4°C in the afternoon of November as observed by Oguntoyinbo (1973) for Ibadan. Factors responsible for this marked differences include the fact that the studies were undertaken within a time interval of twelve years of each other. Within this period, Ibadan has witnessed rapid expansion due to a spate of development projects sited in the city between the early 1970s and early 1980s. This expansion contributed to the influx of migrants into the city thereby increasing the human population from 847, 000 in 1975 to 1.1 million in 1985. Also, there was rapid expansion of the urban area into its rural surroundings during this period. Much of the original city landscape was thus transformed to concrete surfaces and structures.

This pattern of development has continued in many urban centers in the country such that the urban canopy in cities across the country has witnessed marked transformation. Cities there changed from comprising largely low-single story buildings to multi-story buildings. Zinc and asbestos roofing sheets are also giving way to aluminum roofing sheets with resulting changes in radiation characteristics of the surfaces. The contemporary urban morphology of Nigerian cities is therefore very different from that of the 1970s and 1980s.

Enete (2009) evaluated the microclimate of Enugu at several sites using Paired Measurement Programme (PMP) and Landsat/ETM Satellite Imagery. Further analysis of microclimate variations in the city was carried out using Temperature-Humidity Index (THI).

The results indicate that urban climate modifications at day and night were very different. A downtown-centered heat island was observed at night in both dry and rainy seasons, while there was a mix of cool and heat islands at day especially during rainy seasons. The daytime variations were strongly correlated to the amount of tree shading. During the night, city climate was highly correlated to sky-view factors and thermal properties in the city. Tree-cover inhibited nighttime thermal comfort due to the reduced sky view. The thermal comfort classification for the city was basically two: they range between 25.4°C and 27°C which is a class where over 50% of the population feels stressed; and the range of 32°C and above, where most of the population suffers discomfort.

Moreso, in the city of Makurdi, north-central Nigeria, surface urban heat island (SUHI) has been studied by Tyubee and Anyadike (2012). According to the duo, surface urban heat island (SUHI) is a product of radical and irreversible change in land use and land cover associated with urbanization. The study utilized remote sensing, in conjunction with Geographic Information System (GIS), in exploring the spatial, seasonal and temporal variability of surface urban heat island characteristics over fifteen year period as a result of land use and land cover changes in the area. A total of twelve Landsat TM/ETMX images were acquired and analyzed for the surface urban heat island characteristics. The result shows areas of water, forest, undergrowth and cultivated land have increased by $4km^2$, $37km^2$, and $119km^2$ from 1991 to 2006. Conversely, the area of built-up land increased by $179km^2$ during the same period. Spatially, the minimum and maximum land surface temperature ranged from 27.5^oC in water bodies to 50.7^oC over built-up land, representing surface urban heat island intensity of 23.2^oC. The study attributed the spatial, seasonal and long term changes in surface urban heat island (SUHI) characteristics of Makurdi to the changes in land use and land cover driven by urbanization.

In a similar study, Elenwo (2015) in Port-Harcourt, south-south Nigeria opined that urban centres are consistently exhibiting higher temperatures than their surrounding sub-urban rural areas. According to the researcher, the large amount of heat generated from urban structures such as road materials and pavement materials and other anthropogenic heat sources are the main causes of Urban Heat Island (UHI). In carrying out this research, Elenwo (2015) used both primary and secondary sources of data including direct measurements and readings on road and pavement materials. Accordingly, there was consistency in rising temperature at different time of the day to these materials. Asphalt has the greatest effect of increasing the urban temperature four degrees higher, followed by concrete, three degrees rise in temperature and earth (ground) by two degree rise and vegetation by one degree rise in temperature. Thus, the overall effect on the residents of Port-Harcourt, south-south Nigeria ranges from increase in hotness of the day resulting in suffocation, sleeplessness, restlessness, especially at night.

2.7 Impacts of Urban Land use in Warri

Urbanization is defined as the shift from rural to an urban society which involves an increase in the number of people in the urban areas. It is usually the outcome of social, economic and political development that lead to urban concentration and growth of large cities, changes in land use and transformation from rural to metropolitan pattern of organization and governance (Angotti, 1993).

In Nigeria, urban growth is not a recent phenomenon. Since the emergence of ancient cities such as Benin, Kano and Zaria between the 14^{th} and 17^{th} century, there has been a steady evolution and multiplication of urban centres (Ojeifo and Eseigbe, 2012). The rate of multiplication however became greater from the 1960's with more urban centres emerging. As at 1960 only four major administrative centres existed, these centres were

Lagos, Ibadan, Enugu and Kaduna. By 1967, the centres rose to 13, it became 21 centres in 1987. The centers rose to 30 administrative state headquarters in 1991. Similarly administrative changes were undertaken at the local government level resulting in the emergence of towns which are new headquarters of local government areas (Onokerhoraye and Omuta, 1994). Urbanization rate for Nigeria is 4.4% and about 4.6% on the average for sub-Saharan Africa, compared to 0.4% urbanization rate in Europe (Arokoyu, 2002; Adeyemo, 2002).

Studies have shown that there remains only few landscapes on the earth surface that still remain in their natural state. Due to anthropogenic activities, the earth's surface is being significantly altered and man's presence on the earth and his use of land has had a profound effect upon the natural environment, thus resulting into an observable pattern in the land use/land cover over time (Lambin et al, 2003, Jiang et al, 2004, Asthana and Asthana, 2005; Zubair, 2006; Long et al 2003).

The most significant characteristics of man's induced changes in the urban environment area is the variation in thermal properties of the built up and surfaces, soil land impervious surfaces which result in more solar energy being stored and converted to sensible heat, and also the removal of shrubs and tree which serve as a natural cooling effects of shading and evapotranspiration (Pickett et al, 2001). This contributes to the reduction in outgoing longwave radiation by hindering the lost of sensible heat and distribution of heat (Oke, 1982; Bonan, 2002; Ifatimehin, 2007). The reduced vegetation cover, increased in impervious surface area and the morphology of buildings in the urban centres, combine to lower evaporative cooling by storing heat during the day and releasing such during the night to warm the surface air (Bonan, 2002). A built up of ambient land surface temperature in the urban centres of 2-3 degrees higher than the surface surrounding suburban environment (Pickett, 1997) are witnessed in relatively areas, greater cover of vegetation, cultivated lands and as well as greater areas of wet soils (Adebayo and Zemba, 2003; Ifatimehin, 2008). These thermal differences are contributing to the development of a micro climatic condition otherwise referred as the urban heat island.

The metropolitan city of Warri has witnessed remarkable expansion, growth and development activities such as buildings, and road construction, since its inception. This has resulted in increased land consumption and changes in land use and land cover. This modification certainly has consequences on the land surface temperature. Up till now, few detailed and comprehensive attempt (as provided by a remote sensing data and GIS) has been made to evaluate land use change and its effects on land surface temperature in a developing world city. It is therefore necessary for a study such as this to be carried out. It will avoid the associated problems of a growing and expanding city like many others in the world. The rapid population growth in Warri has brought about urban expansion resulting in the increased exploitation of natural resource and by extension, brought about a change in the surface temperature due to the input of harmful substances ($C0_2$, methane) and pollutants into the atmosphere, resulting to urban heat effect, increased pollution, urban warming effect, health implication and above all, an alternation of the micro climate. These effects have been identified at several times by different researchers (Ifatimehin and Ufuah, 2008; Ifatimehin and Musa, 2008; Ujoh et al, 2010) include loss of vegetation, loss of prime agricultural land, alternation of the micro climate and degradation.

It is on this premise that the Nigerian government seeing the situation decided to strategize on how to make the urban areas functionally efficient by evolving in 2002 National Housing and Urban Development Policy (Agboola, 2003). Prior to this policy, there were other policies and laws which were not properly defined and do not serve present day realities (e.g the 1861 Town Improvement Ordinance, the 1946 Town and

Country Planning Law Cap 155 No. 4, the Local Government Reform of 1976 and Land use Degree of 1978. The Nigerian Urban and Regional Planning Law Degree 88 of 1992).

However, virtually little has been done to update the state of knowledge of the urban climate of Nigerians cities, and a good example of such a city with little information as far as urban heat island update characteristics is concern in Warri. Since metropolis have been areas of high population attraction (Efe and Ojoh, 2013) the presence of oil companies have continued to attract population into Warri and it's environ. Since the land area is static, consequently increasing the heat emissions from the companies, vehicular movements and humans themselves, there is the need to examine ways in which this increased heat affects the inhabitants of Warri. Thus, this work Examination of the Spatial Characteristic of Urban Heat Island in Warri metropolis is designed to fill this gap.

CHAPTER THREE

STUDY AREA

3.1 Location and Size

Warri is located in the northern bank of Warri River about 30miles (48km) upstream from the port of Forcados on the Bight of Benin. It is a conurbation of several communities including Warri, Effurun to the North, Ekpan to the West, Aladja to the East and the Bight of Benin to the southwest. It has a coastline of approximately 160km along the Bight of Benin. Warri is located between longitudes 5^0 45E and 5^0 46^1N and latitudes 5^0 46^1N and 5^0 48^1N. Warri metropolis is drained by an intricately woven network of rivers, creeks, rivulets and canals. It is a low-lying plain consisting mainly of recent unconsolidated sediments. There is marked absence of imposing hills that rise above the general land surface. General surface elevation is about 50M above sea level.

In the Niger Delta Region of Nigeria, one city that has had its fair share of urban-rural pull is Warri in Delta State. Its history dates back to the 15^{th} century, when it was visited by the Portuguese missionaries (Ekeh, 2005). Subsequently, it served as the base for Portuguese and Dutch slave traders. Warri developed into a major port city during the late 1800s, when it became a centre for palm oil trade and other major items such as rubber, palm products, cocoa, groundnuts, hides and skins, serving as the cargo transit point between the River Niger and the Atlantic ocean.

Warri Metropolis

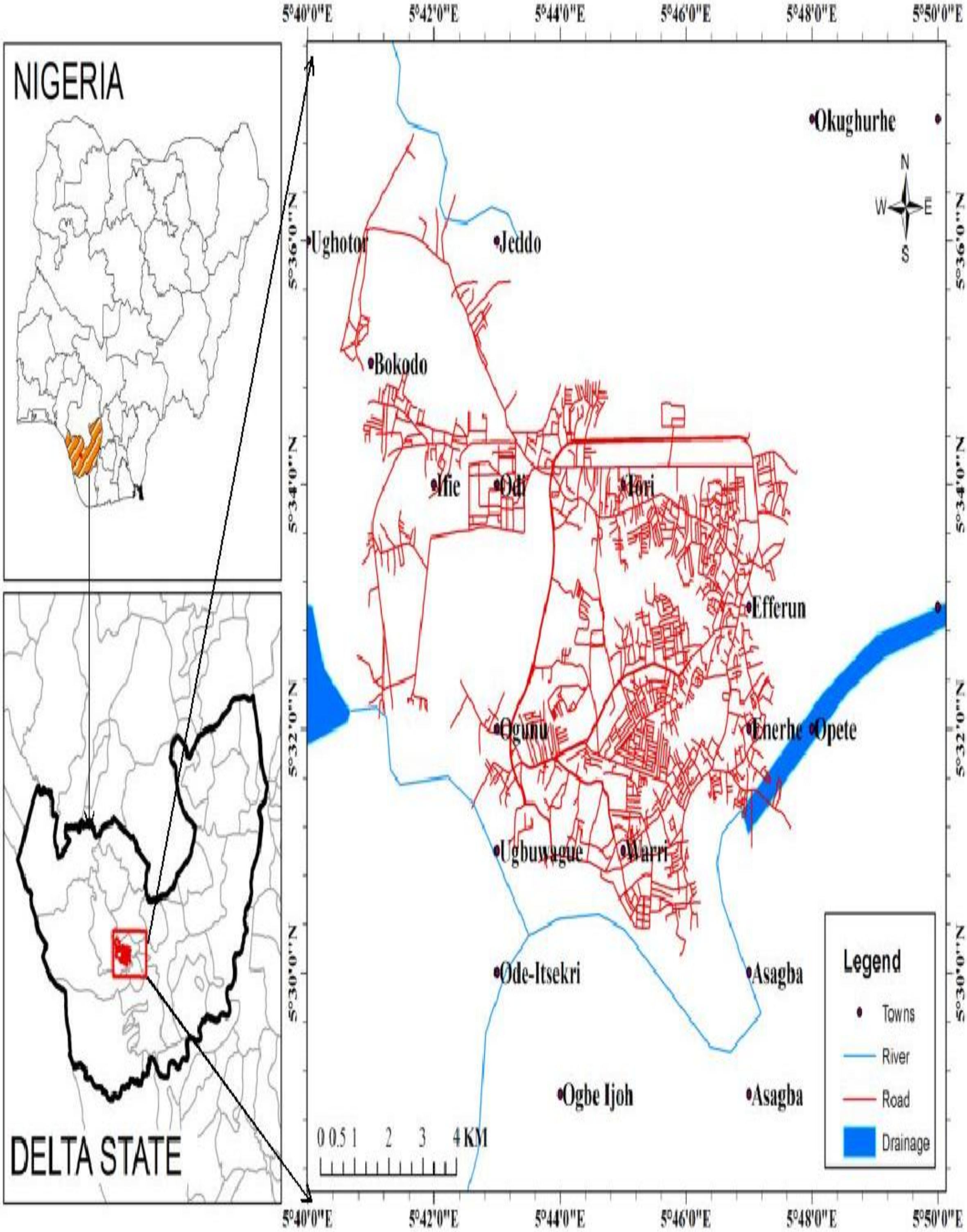

Figure 3.1: Map of Warri Nigeria Showing the Study Area.

Source: Adaped From Gbobo, A.E. et al, 2014

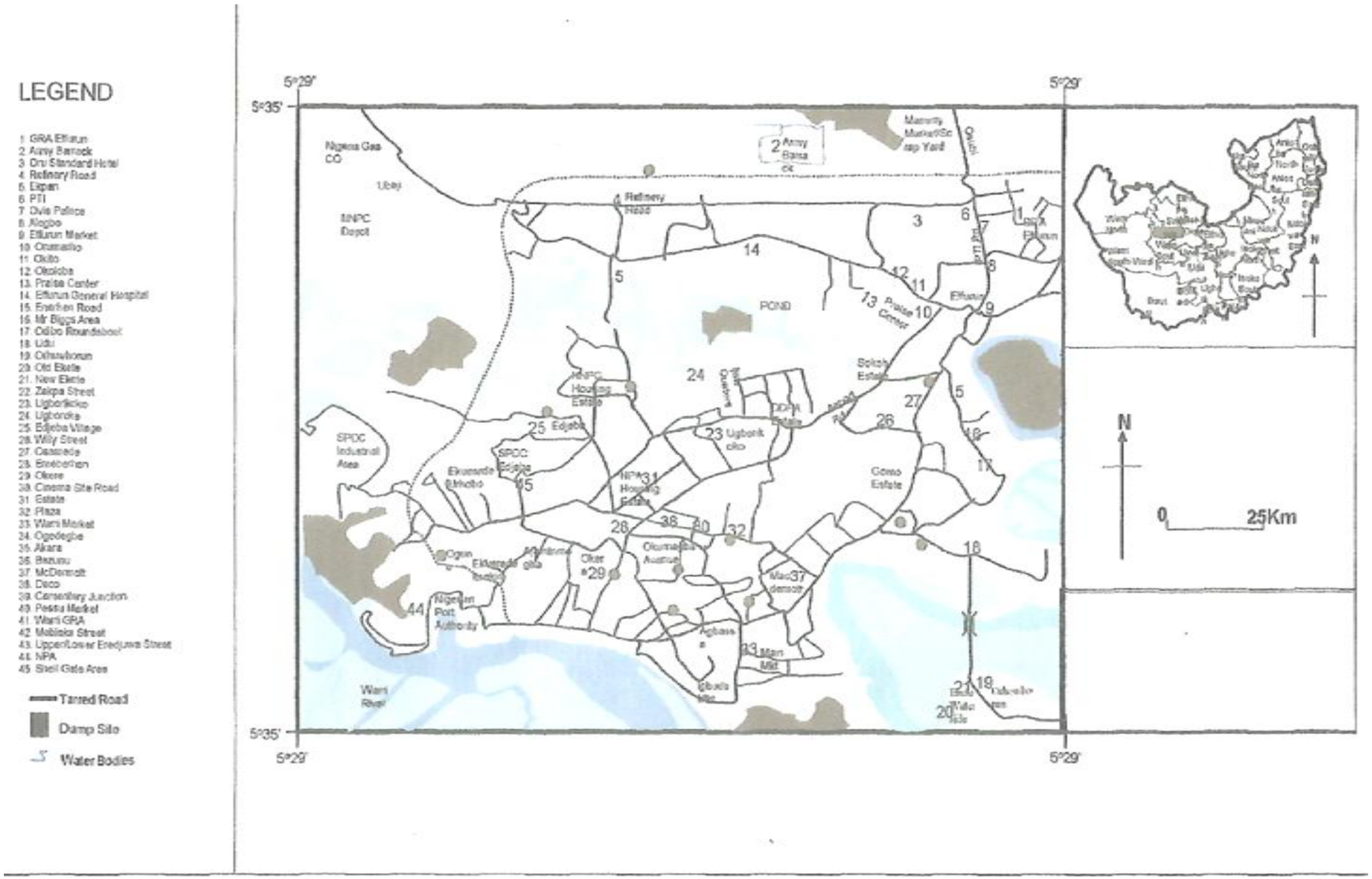

Fig 3.2: Map of Warri Metropolis
Source: Adaped From Efe, 2002a.

3.2 Geology and Soil

Warri metropolis lies within the Agbada, Akata and Benin Formation. The rocks are of sedimentary rock type, having silt, clay and sand as top layer (4-6m) and followed by coarse and pebbly (up to 17m) thick layer (Okoye et al., 1987). The terrain is flat, having an elevation of 6lm above sea level (Barbour et al, 1982) and located at the shores of Warri River. The area is characterized by hydromorphic soils, which is a mixture of coarse alluvial and colluvial deposits (Okoye et al 1987; Efe, 2002b). Thus, the soils are poorly drained and accumulated with water because it is near to the Atlantic coast, having a high water table close to the surface. The Warri River, creeks that lead to Rivers Forcados and Escravos drain the area too. This is as a result of urban heat island that is been experience in the study area.

3.3 Climate

The location of Warri put it firmly within the tropics; as such solar radiation is high all the year round. The area has sunshine duration averaging 4.6 hours and 2.5 hours in January and July respectively. The shorter hours of sunshine over the year are due to dust haze during the dry season and cloud cover in the rainy season; the lower values in July is as a result of the efficiency of cloud cover in reducing isolation.

In the hottest months of February to April, isolation increases with the apparent northward movement of the sun. This period coincides with the beginning of the rainy season, cloud cover is sparse while the influence of the harmattan dust diminishes; all tending to increasing insolation and temperature. Temperature, in these months is typically above 27°C. The second period of high temperature is delayed by the heavy rains of September and October and it only begins to be noticed in November. The second high temperature period is short, with temperature typically above 30^0C.

The coolest month is usually August. It is the middle of the rainy season and cloud cover is thus high, with attendant lower receipt of isolation. Temperatures are typically around 29°C, annual temperature is fairly high over 27^0C. This results in a fairly low annual range of 3^oC.

The area also experiences August hiatus (little dry spells) that lasts 1-2 weeks annually. Dry season is relatively short lived for one or two months with intermittent rainfall in most areas. However areas that border the Atlantic Ocean enjoy slight dry season towards the end of December through January. The occurrence of these seasons is associated with the prevalence of the tropical maritime or southwesterly monsoon air mass, tropical northeasterly air mass and the movement of the inter tropical discontinuity (ITD). The mT air mass which is warm, moist and humid prevails almost throughout the year. The cT on the other hand is dry and dusty and it brings in harmattan (dry) season to the area for one or two months. The ITD marks a boundary zone between the two air masses and its seasonal fluctuation and areal extent marks the limit of these seasons. For instance, the ITD rest at the coast of the Atlantic Ocean in January and the entire state experience dry season during this period and weather type C of Ayoade (1982). Apart from these factors, urbanization and gas flaring has resulted in heat waves in the area (Efe, 2002a). For instance, gas flaring has led to increased temperature, acid rain and low relative humidity at Ugborikoko (Efe, 2002a). These factors have also influence the rainfall, temperature, humidity etc distribution in the area.

Warri metropolis has been experiencing humid and warm climate over the past years with 31°C mean annual temperature and minimum and maximum atmospheric temperature values of 25°C and 35.5°C respectively for the past 71 years. At times temperature could rise as high as 37°C or 38°C between the hours of 1200 and 1600. While morning and evening hours showed temperature values as low as 21°C to 28°C in most places in the state, (Efe, 2002a).

However, areas close to gas flaring sites generally recorded temperature values that range from 35°C to 40°C (Efe, 2002a). These areas include Ugborikoko and Ekpan in the area. On the other hand, spatial distribution of temperature revealed that temperature increases from the coastal areas of Forcados, Bennet Island and Ramos, with 29.5°C, 29.8°C and 30°C respectively. Other communities in the area recorded temperature value that span from 30°C to 30.5°C. The seasonal distribution of temperature showed that the highest and lowest temperature values of 30^{o}C and 32^{o}C were observed during the months of March and November respectively. This indicated a variation of 2°C over the months. Other months had 30.2°C to 31.5°C. Also, the first climatic normal (1936-1966) showed a mean of 29.6°C, while the last cycle (1967-2006) had 31.4^{o}C, indicating the area is warmer with 1.8^{0}C over the last 71 years. (Efe, 2002a)

Moreso, Warri metropolis is generally warm, moist and humid throughout the year, with 83% mean relative humidity and a range of between 70%-95% in most areas. However, values as high as 98% were recorded in the coastal locations of Forcados, during the morning hours and 65% in the afternoon hours. This showed that relative humidity decreases gradually from the coast to the north. The seasonal distribution of relative humidity over Warri revealed a mean value of 83%, and the highest and lowest values of 95% and 72% in the months of July and January respectively. This showed a variation of 23% in relative humidity over the years. Similarly, since all the months had humidity values that are above 70%, it showed that all the months in Warri are generally humid and moist throughout the year.

Warri metropolis belongs to the equatorial climate (Ileoje 1981) and climate region. According to Efe (2006b) where rainy day is 140mm and above and rain in all months is above 25mm in most areas. Warri metropolis experiences heavy and torrential rainfall throughout the year and whenever it rains during the months of June, July and September, it last for hours.

The total annual rainfall is generally above 3000mm. However the spatial distribution of rainfall in the area showed that rainfall decreases from 3466mm in the coast to 2000mm in the hinterland areas. This variation is ascribed to the influence of water bodies, and the effect of continentality amongst others. The mean annual rainfall distribution in Warri for the past 71 years indicated a mean value of 3130mm, with the last climatic cycle (30years) being wetter with 140mm than the previous climatic cycle. This showed that Warri metropolis experienced increased rainfall over the years.

However the seasonal distribution of rainfall in the area showed that the month of July had the highest rainfall with 584mm mean monthly rainfall value, while January recorded the lowest mean monthly rainfall value of 34.3mm. This indicates that there is no marked dry season in the area. Warri also experiences double rainfall mazima during the rainy season. The August hiatus is occasioned by the seasonal withdrawal of the tropical maritime air mass during this period. When this occurs Warri metropolis experiences little dry spells for one or two weeks in the study area.

3.4 Vegetation

Warri metropolis is traversed by a variety of vegetation types. These vegetation types range from the swamp forests along the coast and southern parts of the State, to the tropical rainforests in the central and northern parts of the region.

The main vegetation types of the area include the following:

1. The Mangrove Swamp Forest.
2. The fresh water Swamp Forest
3. The Tropical lowland Rainforest

3.4.1 The Mangrove Swamp forest

The mangrove swamp forest thrives in the saline brackish water of the study area. This forest type can be found in coastal areas of the study area. It is characterized by swampy ground often separated by narrow bodies of water and creeks. The creeks or bodies of water are formed by a mixture of fresh water from rivers and salt water from the ocean.

In some coastal locations, the mangrove swamp has been replaced by the fresh water swamp. This is due likely to the destruction of mangrove vegetation as a result of oil prospecting activities in these areas. The mangrove forest is composed of tall slenderly trees of about 30-50m. Mangroves are highly productive and as such have a vibrant, rich wildlife. The mangrove vegetation is known to play a dual role of shelter as well as provision of food for marine animals especially those that are threatened.

The mangrove swamp forests of the area possess the following dominant economic species namely *Rhizohora racemosa, R. mangle, R. harrisonia and vicennia Africana*. Others include *Mitragyna ciliate* which is found in areas adjoining the mangrove vegetation. The most common mangrove and thereby the most important is the *Rhizophora racemosa*. It is also called the mangrove. The *R. racemosa is* known to reach up to a height of 50m and a girth of 2.5m.

3.4.2 Fresh Water Swamp Forest

This is situated much more inland, than the mangrove swamp vegetation and is therefore free from the contact of ocean water. It normally occurs around Ogbe-Ijoh. This vegetation zone maintains its nature by the consistent supply of fresh water as a result of heavy rainfall as well as the flow of the numerous rivers which crisscross the area. This zone is characterized by two tree layers. These layers include the upper broken layer with trees as high as 45m as well as a lower continuous layer. Perennial logging has however resulted in these layers being indistinguishable.

The species which can be found within this zone include *Raphia sp, Calamussp, Irvingia gabonensis, Termilaniasp, Nauclea didderrichii, Bombax sp, Monodara my-ristica an Piptadeniastrum africanum*. The most common among all these is the raffia Palm. Notable among all these are the *Hookeri and Raphia Vinifera* (Aweto, 2002).

3.4.3 The Tropical Lowland Rainforest

The typical undisturbed lowland rainforest can be found to still occur very sparsely in some parts of the study area. The evergreen tropical rainforest occurs inland from the mangroves with a considerable number of tree species, wood climbers, creepers and undergrowth.

The trees of the typical rainforest are known to be characteristically evergreen. The rainforest is characterized by trees that occur at the three different storeys namely the emergent upper, middle and lower storeys. The emergent upper storey usually stands out on its own above the middle storey. The tree of this storey normally grows to a height of between 50-60m. The boundaries of the trees in the middle storey form a canopy which shields the lower layer and the ground from the effect of sun’s rays. The lower layer comprises mainly of shrubs. At the forest margins or in areas disturbed by human activities, woody lianas usually form an almost impenetrable tangle. The boundaries of the trees in the middle storey form a canopy which shields the lower layer and the ground from the effect of the sun’s rays. The lower layer comprises mainly shrubs. Much of the typical lowland rainforest has been seriously disturbed over the years due to deforestation. This has given rise to the emergence of secondary forests in its place.

3.4.4 The Secondary Forest

The secondary forest is the highest occurring vegetation within the metropolis. The secondary forest is actually an offshoot of the tropical lowland rainforest. The secondary forest is a sub-climax successional stage of the typical rainforest vegetation which once covered the area. The forest type emerged as a result of the destructive activities of man leading to the large scale deforestation of the typical lowland rainforest. The secondary forest is distinguished from the high forest by their smaller height, smaller volume and reduced diversity of species.

This forest type is rich in economic trees such as *Triplochiton scieroxylon, Milicia excelsa, Khaya spp, Mansonia postulata, Piptadeniastrum africanum, Scottelia coriacea, Ricinodendron heudelotii, Pausinystalia jolimbe and throehieum ivorensis. Others include Calamus spp, Monodara myristica, Irvingia gabonensis and Tetrapleutra tetraptera* (EFPA, 2001)

3.4.5 Population

The rapid urban growth which Warri has experienced stemmed from its position as the headquarters of Warri South Local Government Area and the zonal headquarters of federal parastatals as well as the oil and gas industry such as Nigerian National Petroleum Company (NNPC), Shell Petroleum Development Company (SPDC), many shipping and allied companies which have provided employment opportunities. The establishment of Warri refinery and petrochemical company as well as the Aladja steel complex and its associated companies has in no doubt contributed to the rapid population growth as well as the urbanization process.

There has been a tremendous growth in human population; it has grown from being a rural area to an urban area (Oriero, 1998; Efe, 2002a). Warri and environs is one of the rapidly growing cities in Nigeria, with a population rising rapidly from 19.526 in 1933, 55,256 in 1963, 280,000 in 1980, 500,000 in 1991 to 536,023 in 2006 (Annual Abstract of Statistics, 2008). It has a high population density that is concentrated in the core areas of the city. These areas include; Sapele Road, Agbassa, Okere, Okumagba Avenue, Igbudu, lyara, Jakpa and Airport Road, P.T.I. Road, Udu and Ekpan (Efe & Ojoh, 2011). Thus, as population increases so also the urban heat increases as well (Lankao & Gnatz, 2008). According to Cheke (2012) the urban heat warming bias of metropolis is 4.18°C with a population of 536,023.

3.5 Commercial Activities

3.5.1 Manufacturing Industries

The establishment and growth of manufacturing industries in urban areas has been aided by a number of important factors among which are the abundance of agricultural and mineral resources (oil) a well-developed transportation network (road and air), and a high population density which constitutes a source of labour for the manufacturing plants as well as a ready market for their products, important energy resources, and the provision of industrial estates.

However, these manufacturing industries create pockets of high temperature zone around their sites. Thus, contributing to the high temperature trend within the city. These industries use energy for production and produce green house gases (GHG) that influence temperature around their locations.

3.5.2 Transportation

A well developed transportation network in Warri plays a vital role in stimulating manufacturing. Equally, well developed network of roads of various categories connects important centers of trade and industry within and outside the State.

Apart from the movement of raw materials, the various modes of transportation have helped in the evacuation and distribution of finished products. The existence of a well developed distributive trade system in Warri has made the job of marketing of finished products easier. This good transportation network has increase traffic flow in the entire transportation network- road, air and this undoubtedly has increased the concentration of greenhouse gases in the city with their attendant high temperature. This high temperature coming from good network results from low reflectivity of roads, rails and runways as well as the burning of fossil fuels in Warri.

3.5.3 Market

Market size has been acknowledged by the government and foreign investors as the major stimulus to industrial investment in Nigeria (Usoro, 1977). The absence of a market large enough to absorb the products of manufacturing industries could constitute a constraint on industrial development (Teriba and Kayode, 1977). On the other hand, large size of the market which generates a high demand for consumer goods provides the basis for rapid and substantial industrial development.

These large markets accompanied by the population concentration in Warri metropolis have been important in the establishment of pockets of high temperature island compared to their surroundings. This may be attributed mainly to the high population density concentration and other human activities going on in the market.

3.5.4 Settlement and Building Design

The settlement patterns influence the physical environment as well as its history. The patterns of development have continued to change in urban center such that the urban canopy of Warri has witnessed marked transformation. The building pattern has changed from largely bungalows and low single storey building of the 1960's to multiple storey buildings. Zinc and asbestoses roofing sheets are also giving way to aluminum roofing sheets with resultant changes in radiation and temperature characteristics of the surface.

CHAPTER FOUR

RESEARCH METHODOLOGY

4.1 Introduction

This chapter covers the design and methodology of the study under the following headings:

i. Study design

ii. Data needs

iii. Data sources

iv. Study sample and sampling techniques

v. Methods of data collection

vi. Methods of data presentation, processing and analysis

4.2 Study Design

The study adopted empirical research and expost facto design. This design and approach was adopted mainly because the study is an effort geared towards solving a specific existing problem in environmental management, spatial analysis of urban heat island, motivated by the need to solve the specific problem of urban high temperature in an urban area.

4.3 Data Need

The methodologies employed for measuring UHI are:

1. Satellite imageries: broad and visible
2. Historical weather data: long-term recording and;
3. Fixed point survey: observation of given area within a designated period.

4.4 Data Sources

Urban Heat Island measurement through satellite imageries Landsat TM data were downloaded from the NASA website. Landsat TM data of the dry season (Feb/March 1985 - 2014) and rainy season (June/July 1985-2014) were analyzed for studying the Urban Heat Island phenomena.

A Landsat ETM7+ satellite image obtained in February and July 2014 were selected. Satellite image with a thermal band was processed to obtain an instantaneous impression of the UHI. In order to map out the UHI, mapping of land surface temperature (LST) and normalized difference vegetation index (NDVI) were necessary. Its aim was to overlay two imageries (NDVI and LST images) and extract maximum temperature value for both urban and rural areas as well as identify the possible hot spots in the study area. The size and other appropriate information on the built-up areas, paved surfaces, forested, bare surfaces and water bodies were extracted from satellite imagery.

4.4.1 Urban Heat Island Measurement through Historical Weather Data

In order to measure UHI intensity during a 30 year period, this study selected two stations (meteorological station in urban area and Airport station in rural area). The stations were selected from weather station network sources, under the Nigerian Meteorological Agency.

4.4.2 Urban Heat Island measurement through fixed survey

During the study, a network of sensors was set over the urban centre to complement satellite data. These sensors measured air temperature. Measurements were taken every one hour. The study concentrated on the months of February, March, June and July to generate its data. These months represent the dry and rainy season periods. The average diurnal cycle was calculated over every one month period. Temperature data were obtained from several transects done during the study period.

4.5 Study Population

The study population comprised the urban temperature condition, obtained from residential areas, commercial areas, mixed residential/commercial areas as well as open parks.

The choice of the population was informed by the parametric criterion of common interest, which according to Taha (1997) Unger et al,(2001) is the most obvious observed climatic difference between urban centers and rural areas.

4.6 Sample and Sampling Techniques

4.6.1 Site Selection

Two land-use classes (residential and commercial) and two land-cover types (paved and green surfaces) were considered for this study. The permeability of land surfaces to water, role of industry (including automobiles) in the land-use category and the potential for evapotranspiration were the characteristics of distinction used in the selection of the study sites.

Quadrat sampling method and purposive sampling were employed based on the presence or absence of these variables and the degree of vegetation shade available. Thirty (30) sites, with the following land-use/land-cover patterns were selected for the study. The selected sites were a fair representation of the entire city and for a fair coverage of Warri and its environs.

i. High-density, high-rise, non-residential areas with low greenery (DTL).

ii. Low building density, low-rise, residential area with high greenery (HDR).

iii. Medium density, mixed residential (some residential, some commercial institutional) area with a greenery extent between (i) and (ii) above (NW2).

iv. Areas with similar land-use, building density and greenery, one having more fully developed vegetation canopy than the other (LVR and LOR).

A search for locations with these characteristics resulted in the selection of the following sites:

1. DTL = Down Town Location (CBD), accompanied by heavy traffic, high degree of paved areas and little or no greenery.
2. HDR = High-Density Residential Site e.g New Ekete,
3. MFR = Multi-family Residential/Institutional Site e.g Army barrack, Shell Gate area, industrial, residential! commercial areas
4. Substantial parking lots.
5. LVR = Low-density Vegetated Residential Neighborhood e.g Osubi
6. LOR Low-density Open-Canopy Residential Neighborhood. E.g GRA Effurun

4.7 Method of Data Collection

Data were collected using both primary and secondary sources of data collection.

4.7.1 Primary Sources of Data Collection Method

The primary data for this study were obtained from fixed survey using digital thermometers model kT 300 and Satellite imagery.

4.7.2 Secondary Sources of Data Collection

Secondary sources of data were collected from NIMET, journals and other government departments including landuse maps, and on landsat EMT+ satellite images of warm. A political map of warri was also used.

4.7.3 Urban Heat island measurement through historical weather data

Data on several climatic parameters, such as air temperature, humidity, solar radiation, wind speed and global luminance were obtained from meteorological stations in urban areas Airport station in rural areas were used to estimate general climatic characteristics during the study period. Data on several climatic parameters, such as air temperature, humidity, solar radiation, wind speed and global luminance were obtained from NIMET to estimate general climatic characteristics during the period and used for the study as shown in Tables 4.1, 4.2, 4.3, 4.4 and 4.5.

4.7.3.1 Urban Heat Island measurement through fixed survey

Air temperature was measured at each experimental site and a reference station set up for the study at an open area (Western side) of Airport. In close proximity to the reference station is a full-featured weather station maintained by Nigeria Meteorological Agency (NIMET) at the airport.

The reference station is located near a large open grass field on the western side of the, airport. The surrounding area can be classified as low-density institutional land-use, with a stretching plain terrain, significant grass cover and some paved (parking lot) areas. Due to its more or less “rural” like nature, the difference between a location’s air temperature and that at the reference station was considered to be the “effect” due to urbanization at the said location.

Digital thermometer (KT 300) was selected as the measurement probe due to its good performance outdoors. The digital thermometer (KT 300) was placed in a naturally ventilated, insulated place to avoid direct radiation. Probes used at the reference station and other urban sites were shaded similarly. The shielded probe was sited at an open area approximately 1.5m above ground.

Test run was performed by running each shielded probe assembly for three days and comparing the temperature reading against the weather station data at the airport and the result was satisfactory. Site climate data were gathered every hour for the purpose of statistical analysis, the one hour data averaged over a month. Data collection spanned over two seasons (dry and rainy). The essence was to capture the peak periods, frequency, magnitude and seasonality of urban heat Island.

4.7.3.2 Satellite imagery (Land Sat 5 Thematic Mapper Thermal Infrared Imagery)

The Landsat program is a long term corroborative effort between the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA) to gather satellite remotely sensed spectral images of the earth's surface. LandSat has been one of the most successful earth observation missions. LandSat provides almost 30 years of uninterrupted time series of global optical and thermal remote sensing data (*USGS Global Visualization Viewer*, 2012). Thematic Mapper (TM) is a 7 band instrument aboard LandSat 5 mission where each band tracks the reflected radiance of a surface within a portion of visible, infrared or thermal infrared spectrum. Thematic Mapper measures thermal infrared radiance between wavelength range 10.4 to 12.5um called band 6. Thermal infrared band with a spatial resolution of 20 meters was used to estimate the land surface temperature.

4.8 Methods of Data Analysis

The results obtained from the field were analyzed using both descriptive and inferential statistical techniques. Descriptive statistics involved the use of multiple and simple bar charts, histograms, tables, graphs as well as measures of central tendency such as the running mean. Inferential statistics such as paired measurement program, comfort analysis and spearman rank correlation were also employed to obtained the urban heat island characteristics of Warri metropolis.

4.8.1 Paired Measurement Programme

During the study period, transect and fixed point measurements were taken hourly and averaged over a month. All temperature differences were calculated as site temperature minus reference temperature. Thus, a negative (-) temperature difference indicates that the site was cooler than the reference station; and positive (+) indicates the site was warmer than the reference station.

4.8.2 Satellite Data Analysis

Urban heat island studies are generally conducted in one of two ways: measuring the UHI in air temperature through the use of automobile transects and weather station networks, and measuring the UHI in surface (or skin) temperature through the use of airborne or satellite remote sensing in-situ data, have the advantage of a high temporal resolution and a long data record, but have poor spatial resolution. Conversely, remotely sensed data has higher spatial distribution but low temporal resolution and a shorter data record. In recent years, the field of remote sensing has lend itself well to the study of UHI's. Roth, Oke, and Emery (1989) and Gallo (1999) used remote sensing techniques to compare the UHI effect with vegetation index. The study made use of Landsat TM data covering urban area and were analyzed using ENVI 4.5 image processing software and this broadly consists of the following major steps:

1) Multi-date data preparation and geo-referencing,
2) Ahmedabad City Administrative boundary superimposing,
3) Superimposing GPS locations of field data collection points on the registered landsat TM digital data,
4) Generation of temperature values from the Landsat TM thermal data,
5) Generation of Iso-thermal maps of the six administrative zones of the city using Quantum GIS software-I .8.

The geo-referenced image covering urban space and locations of field data collection using digital thermometer model KT 300 were also superimposed on georeferenced satellite imagery.

4.8.3 Satellite Data Analysis of Two Seasons

The LANDSAT-5 TM images were analyzed using ENVI software version 4.5. The images of all the seven bands were stacked using the layer-stacking tool to generate a layer-stacked image having the attributes of all the bands. The Landsat TM data of Feb/March (dry season) and June/July (rainy season) were used in this study.

The Region of Interest (ROI) tool was used to select the ROIs across the city of size 10 x 10 pixels. The DN values of these ROIs were used to derive the surface temperature using Landsat-Temperature Model. This model directly converts spectral radiance to temperature. It is a three steps process:

Step 1: Conversion of the Digital Number (DN) to Spectral Radiance (L)

$L = L_{min} + (L_{max} - L_{min}) \times \frac{DN}{255}$ …………………………………… 1

Were;

L = Spectral Radiance,

L= 1.238 (Spectral radiance of DN value 1).

DN = Digital Number.

L_{max} 15,600 (Spectral radiance of DN value 255).

Step 2: Conversion of Spectral Radiance to Temperature in Kelvin

$$Tb = \frac{K2}{\left(\left(\frac{K1}{L}\right) + 1\right)}$$ …………………………..2

Were;

K1 = Calibration Constant 1 (Landset-5 TM Band 6 value 607.76 W/cm2/sr/μm).

K2 = Calibration Constant 2 (Landset-5 TM Band 6 value 1260.56 W/cm2/sr/pm).

Tb = Surface Temperature.

Step 3: Conversion of Kelvin to Celsius

TC^{o}C) = TCK) – 273.15 ----------------3

Where;

TC^{o}C = Temperature in degree Category

TC^{o}C = Temperature in Kelvin

4.8.4 Generation of Isotherms for Warri metropolis

The generation of isotherms was done using Quantum GIS software version 1.8. The temperature data in the form of delimited text is used for the generation of a shape file. Further, the shape file was used for generation of the isotherms using the Polygonize (Raster to Vector) function in the Raster menu. Based on these temperature ranges, isotherm maps were generated from the Landsat TM data of Feb/March (2014) and June/July (2014) using Quantum GIS software. The steps followed to generate isotherm map for the city are given below:

- Identification of region of interest (ROI) from the layer stacked image,
- Calculation of surface temperature for selected ROI using image processing software ENVI version 4.5,
- Using the ROIs in the stacked image, isotherms are generated using Q-GIS software. 8.0
- Classification of the contours in three different classes, viz.

1) **Class-1**: 18°C - 28°C, 2)

4.8.3.1. Isotherms Based on Landsat TM Data

The isotherms for various zones were generated using the Landsat TM data of 360 months under study. The isotherms were divided into several temperature zones for further analysis. These isotherm maps were used to identify major urban hot spots across the city.

CHAPTER FIVE

PRESENTATION AND ANALYSIS DATA

5.1 Introduction

The assessment of urban heat island characteristics in Warri was carried out using landsat in thermal imagery and field date collected using digital thermometers (KT300). This chapter therefore discusses the field results of data collected from 1985 to 2014 from satellite imageries online, climatic data from NIMET Warri, as well as on site temperature data generation from ground truthing. Extraction of land surface temperature (LSTs) and land use/land cover (LULC) classification from past satellite imageries were made possible in a GLS environment, while further analyses were done with the adoption of inferential statistical techniques are used for the study.

5.2 Land Use Distribution

Classified image representation of land use change of Warri metropolis in 1987 is shown in Figure 5.1. The state of land use converge of Warri metropolis in 1987 was generated from the supervised image classification of landsat ETM of 30m resolution. In 1987, bare surface accounted for 210.7689.km (17.33%), built-up area for 213.99 89km (17.60%), cultivated area for 256.74 km^2 (21.11%), natural vegetation for 309.95 km^2 (25.49%), water bodies for 224.56 km^2 (18 4.7%) (Table 5.1 and Figure 5.1).

Table 5.1: Calculated area for each of the landuse for 1987

Classes	**Area covered (km^2)**	**Percentage area covered**
Bare surface	210.76	17.33
Built up area	213.99	17.60
Cultivated area	256.74	21.11
Natural vegetation	309.95	25.49
Water bodies	2245.56	18.47
Total	**1216**	**100**

Source: Fieldwork, 2016.

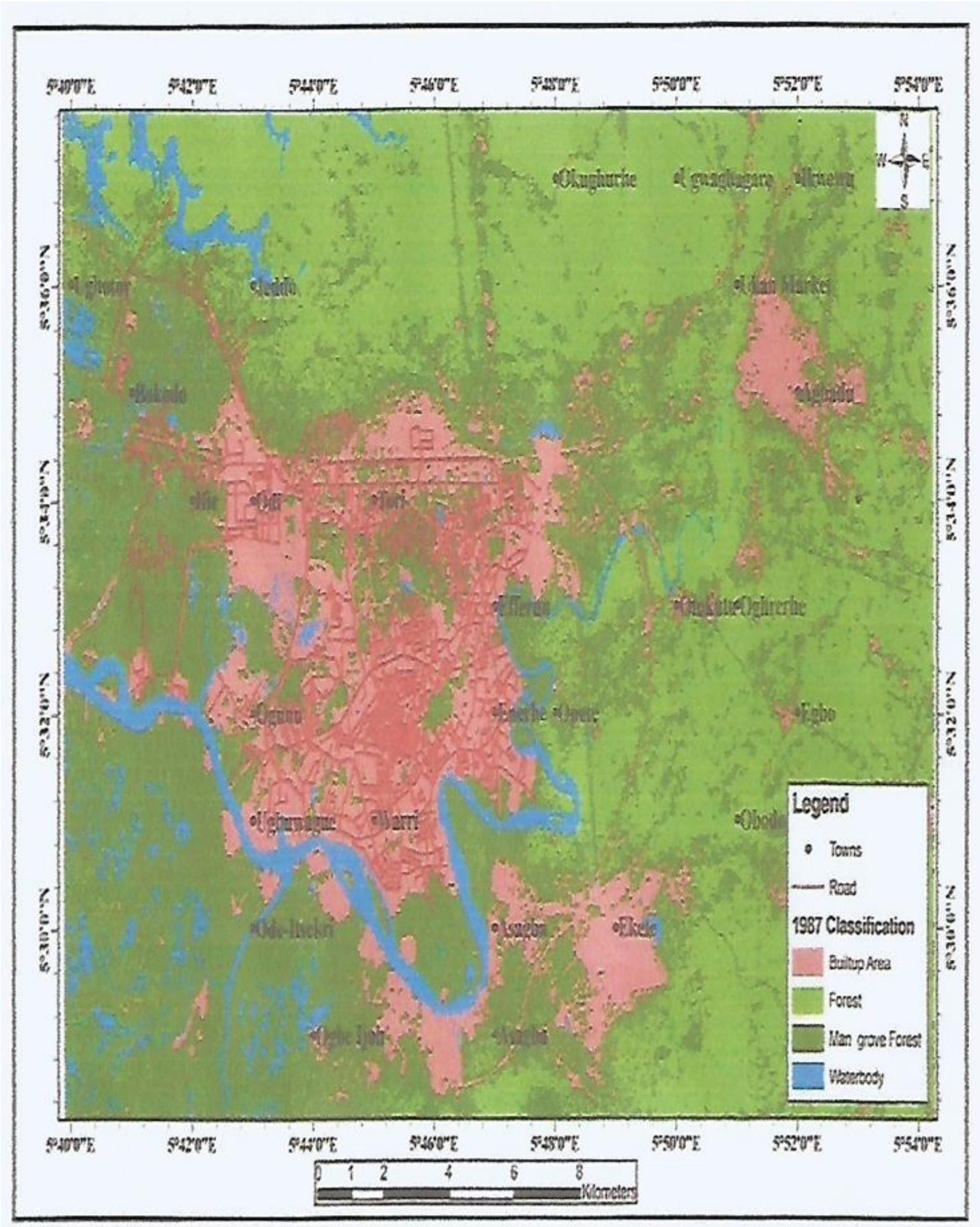

Figure 5.1: Classified Land use Map for Warri Metropolis for 1987

The pattern of landuse distribution in 2002 also follows the pattern in 1987, with bare surface occupying 190.75 km^2 (15.68%), built-up area for 376.96 km^2 (31%), cultivated are 289.74 km^2 (23.83%), natural vegetation for 223.96 (18.5%), water bodies for 133.59 km^2 (10.99%) (Table 5.2 and Figure 5.2). However, there exists an increase in the total built up area by 162.97 km^2 (13.40%) and a decrease in the natural vegetation by 84.99 89km (6.99%) and the water bodies by 90.97 km^2 (7.48%) (Table 5.3)

Table 5.2: Calculated Area for each of the land use for 2002

Classes	**Area covered (km^2)**	**Percentage area covered**
Bare surface	190.75	15.68
Built up area	376.96	31.00
Cultivated area	289.74	23.83
Natural vegetation	224.96	18.5
Water bodies	133.59	10.99
Total	**1216**	**100**

Source: Fieldwork, 2016.

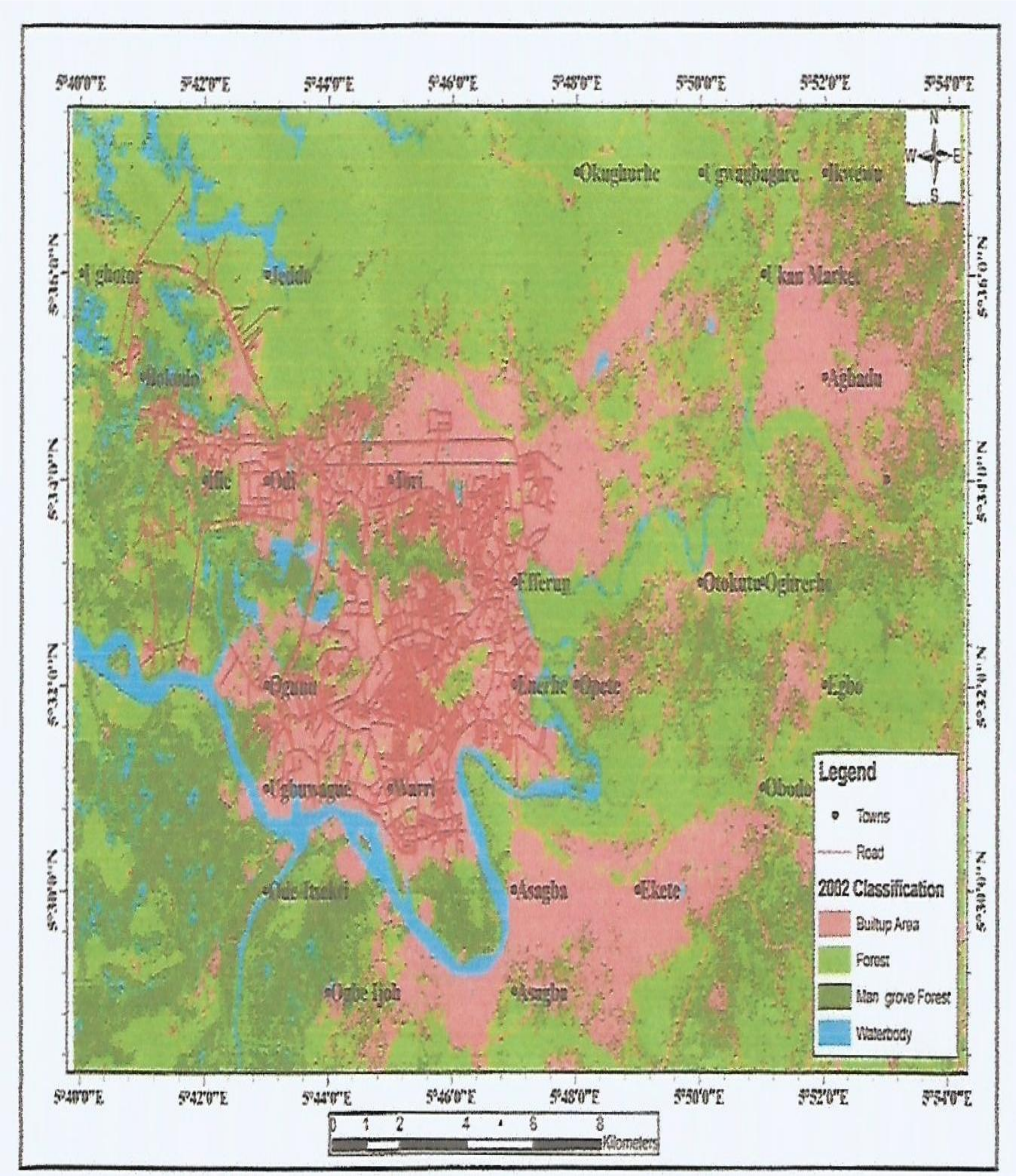

Figure 5.2: Classified Land use Map for Warri Metropolis for 2002.

Table 5.3: Differences in Calculated area for 2002 and 1987 for land uses

Classes	**Area covered (km^2) 2002**	**Area covered (km^2) 1987**	**Difference sqkm**	**Differences %**
Bare surface	190.75	210.76	-20.01	-1.65
Built-up area	376.96	213.99	162.97	13.40
Cultivated area	289.74	256.74	33	2.72
Natural vegetation	224.96	309.95	-84.99	-6.99
Water bodies	133.59	224.56	-90.97	-7.48
Total	**1216**	**1216**	**-**	**-**

Source: Fieldwork, 2016

The increase in the built-up area (table 5.3) was as a result of rapid development in terms of urbanization and urban expansion to meet the economic and social demands of the growing population of Warri. Also, the decrease in natural vegetation in 2002 (224.96 sqkm) as against 309.95sqkm in 1987 points to the fact that there was as increase in land used for urban development and expansion. It is evident that land use coverage changed between 1987 and 2002 was positive for human activities. This development points to the fact that human activities (built-up areas) constitute one of the major factors determining the state of the environment in Warri metropolis. This assertion corroborates the works of Ogidiolu, Ifatimehin and Abu (2012).

The 2009 image situation suggests increase in built-up area accounting for 417.81sq.km (34.36%) of the total land area, bare surface accounted for 199.77sqkm (16.43%), cultivated area accounted

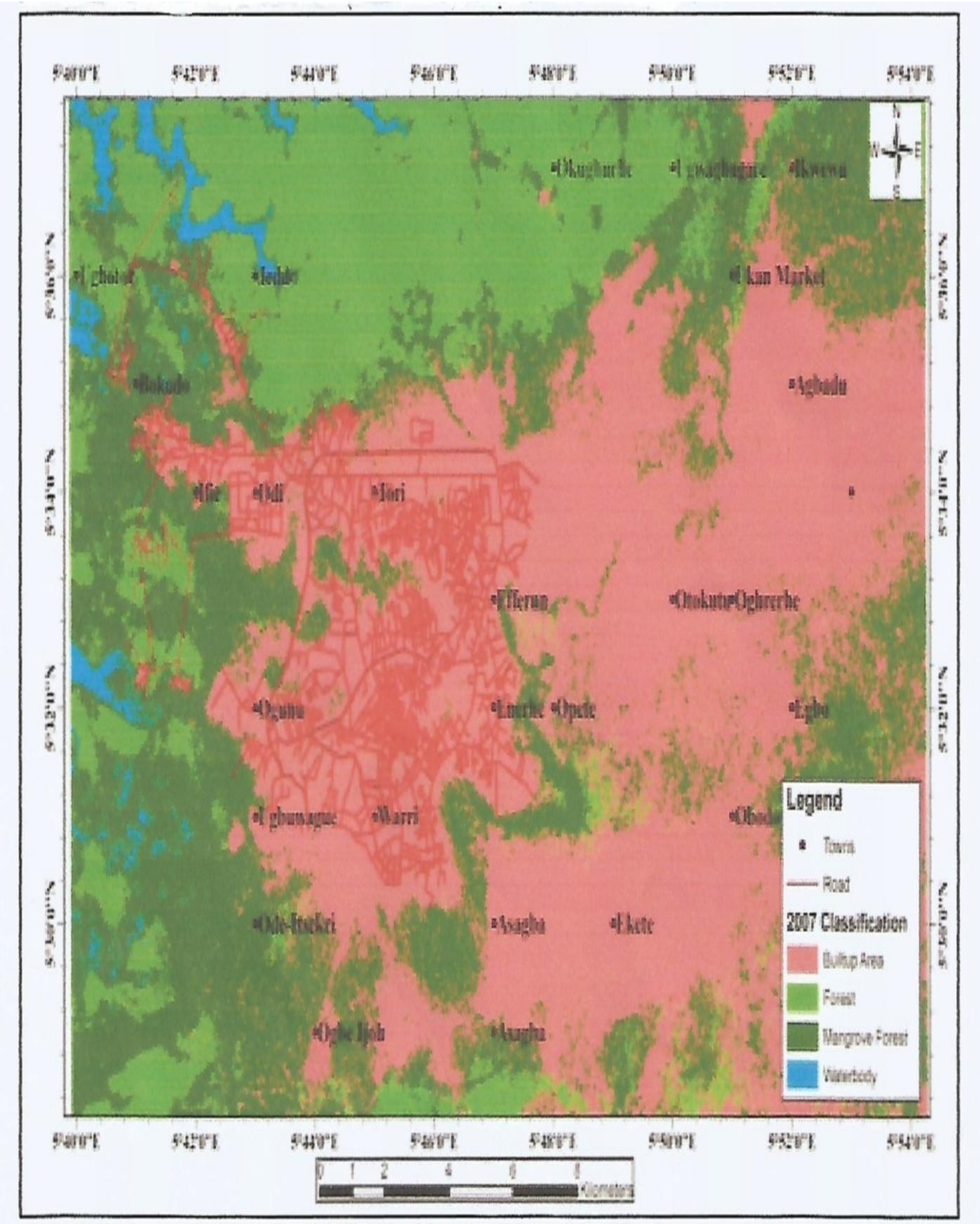

Fig. 5.3: Warri Landsat Image Classification

For 299.08 sqkm (24.60%),while natural vegetation accounted for 174.82 sqkm (14.38%) and water bodies recorded a total of 124.52 sqkm (10.23%) (Table 5.4). This noticeable changes in the various land uses corroborates other scholarly works where much emphases is placed on the growth of urban land at the expanse of natural vegetation (Ifatimehin, Musa and Adeyemi, 2011) (Figrue 5.3).

Table 5.4: Calculated area for each of the landuse for 2009

Classes	**Area covered (km^2)**	**Percentage area covered**
Bare surface	199.77	16.33
Built up area	417.81	34.36
Cultivated area	299.08	24.60
Natural vegetation	174.82	14.38
Water bodies	124.52	10.23
Total	**1216**	**100**

***Source*:** Fieldwork, 2016.

In the same vein, image situation showed drastic increase in built up areas in 2011, accounting for 464.91 (38.23%) of the total calculated area. Bare surface accounted for 284.04 sqkm representing 23.36 percent, while cultivated area accounted for 184,75 sqkm representing 15.19 percent. Natural vegetation and water bodies accounted for 142.76 sqkm and 139.54 sqkm representing 11.74 percent and 11.48 percent respectively (Table 5.5). This increase in land use experienced in land uses corroborates the findings of Ifatimehin, Musa and Adeyemi (2011) on landuse change in Abuja, Nigeria.

Table 5.5: Calculated areas for each of the landuse for 2011

Classes	**Area covered (km^2)**	**Percentage area covered**
Bare surface	284.04	23.36
Built up area	464.91	38.23
Cultivated area	184.75	15.19
Natural vegetation	142.76	11.74
Water bodies	139.54	11.48
Total	**1216**	**100**

Source: Fieldwork, 2016.

The magnitude of change of landuse and land cover between 2002 and 2011 is tremendous as shown in table 5.6.

Table 5.6: Magnitude and Percentage change in land use and land cover between 2002 and 2011

Classes	A Area (km) 2002	B Area (km) 2011	C Magnitude of charge (B-A) KM^2	D Ameliorate of change (c/10) km	E % change C/A x 100
Bare surface	190.75	284.04	93.29	9.33	48.91
Built up area	376.96	464.91	88.31	8.83	23.43
Cultivated area	289.74	184.75	-104.99	-10.50	-36.24
Natural vegetation	224.96	142.76	-82.2	-8.22	-36.54
Water bodies	133.59	139.54	5.95	0.60	4.45
Total	1216	1216	0.36	0.04	4.01

Source: Fieldwork, 2016.

From Table 5.6, the magnitude of change in landuse/land cover for built-up area was 88.31sqkm representing 23.43 percent, while there was a decrease in natural vegetation by -82.20sqkm representing – 36.54 percent. Also, there was a decrease in cultivated areas from 289.74sqkm to 184.75sqkm, with a magnitude change of -104.99sqkm representing -36.24 percent. There was an increase in water bodies by 5.95sqkm (4.45%) most probably as a result of the rainy season and flood experienced in the area (Gobo, Amangabara and Agobie, 2014). However, bare surface areas increased drastically from 190.75sqkm in 2002 to 284.04sqkm in 2011, with a magnitude of change of 93.29sqkm at an annual rate of change of 9.33sqkm representing 48.91percent (Table 5.6). These changes in landuse is as a result of the rapid rate of urbanization and increase in population resulting in the building and construction of more infrastructure such as roads, houses and other commercial activities in the area. This finding also corroborates similar studies carried out by Ogidiolu, Ifatimehin and Abu (2002), Ifatimehin, Ujoh and Magaji (2009) and Ujoh, Ifatimehin and Baba (2011) in Nigeria's Federal Capital, Abuja, lokoja and Umuahia respectively.

5.3 Land Surface Temperatures Distribution

The average values of surface temperature by land use types in 1987, 2002, 2009 and 2011 is shown in table 5.7. An understanding of the impact of land use/land cover on surface temperature, the characteristics of the thermal signatures of each land use type was studied. Thus, built up areas and bare surface areas exhibited the highest temperature of 28.5^{0}C and 25.17^{0}C in 1987, 31.99^{0}C and 28.48^{0}C in 2002, and 34.78^{0}C and 30.96^{0}C in 2011 respectively.

This was followed by cultivated land (26.85^{0}C) and natural vegetation (21.86^{0}C) in 1987, 30.44^{0}C, 22.42^{0}C in 2002 respectively and 31.41^{0}C, 25.68^{0}C respectively in 2011. The lowest surface temperature in 1987, 2002 and 2011 was observed in water bodies (16.87^{0}C and 19.95^{0}C respectively).

Table 5.7: Land surface temperature over different land use categories

	Built up area	Bare surface area	Cultivated area	Natural vegetation	Water bodies
Minimum and maximum LST (1987)	26.84-28.50	23.51-25.17	25.19-26.85	20.20-21.86	15.20-16.87
Minimum and maximum LST (2002)	30.24-31.99	26.73-28.48	28.77-30.44	23.75-25.42	17.42-19.18
Minimum and Maximum LST (2011)	32.87-34.78	29.05-30.96	29.50-31.44	23.77-25.68	18.04-19.95
Change in LST	+6.28	+5.79	+4.56	+3.82	+3.08

Source: Fieldwork, 2016.

From table 5.7, increase in built-up area implies that development and increased population brings about high surface temperature by replacing natural vegetation with non-evaporating surfaces such as tarred surfaces, stores, metals and concrete. The change in land surface temperature (LST) values is high for built-up areas and experience wide variation in surface temperature. The rise in temperature can be attributed to a disruption in the ecosystem provided by the vegetation, buildings and infrastructural development. This finding corroborates the works of Pickett et al (2001), Bonnan, et al; (2002) and Peterson, (2003) in their separate studies of metropolitan areas in parts of the United States.

5.4 Monthly Temperature Distribution

The mean monthly temperature distribution for Warri metropolis from 1985 to 2014 (30years) is as shown in appendixes A to C and summarized in tables 5.8 and 5.9 and discussed.

Table 5.8: Mean maximum and minimum monthly temperature distribution in Warri metropolis (^oC) from 1985 to 2014.

	Months											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Maximum	32.12	33.38	32.60	31.86	31.21	30.18	28.50	28.22	28.95	29.76	30.92	31.61
Minimum	22.83	23.91	23.91	22.80	23.38	23.40	22.56	22.76	22.75	23.08	23.31	23.00
Range	9.29	9.47	8.69	9.06	7.83	6.78	5.94	5.46	6.20	6.68	7.61	8.61

Source: Fieldwork, 2016.

In Warri metropolis, the highest mean maximum temperature recorded for the period 1985 to 2014 was in the month of February with a temperature of 33.38^0C, with a minimum temperature of 23.91^0C while the lowest mean minimum temperature recorded for the period 1985 to 2014 was 22.56^0C in the month of July, with a maximum mean temperature of 28.50^0C. The months of January, March, April, May and June recorded mean maximum temperature of 32.12^0C, 32.60^0C, 31.21^0C and 30.18^0C respectively. While 28.220C, 28.95^0C, 29.76^0C, and 30.18^0C respectively. While the minimum temperature are 28.220C, 28.95^0C, 29.76^0C, 30.92^0C and 31.61^0C were the mean maximum monthly temperature recorded for the months of August, September, October, November and December respectively. However, a minimum temperature of 22.83^0C, 32.91^0C, 22.80^0C, 23.38^0C and 23.40^0C were recorded for the months of January, March, April, May and June respectively. Other mean maximum temperature recorded include 22.76^0C (August), 22.75^0C (September), 23.08^0C (October), 23.31^0C (November) and 23.00^0C (December)

Figure 5.4

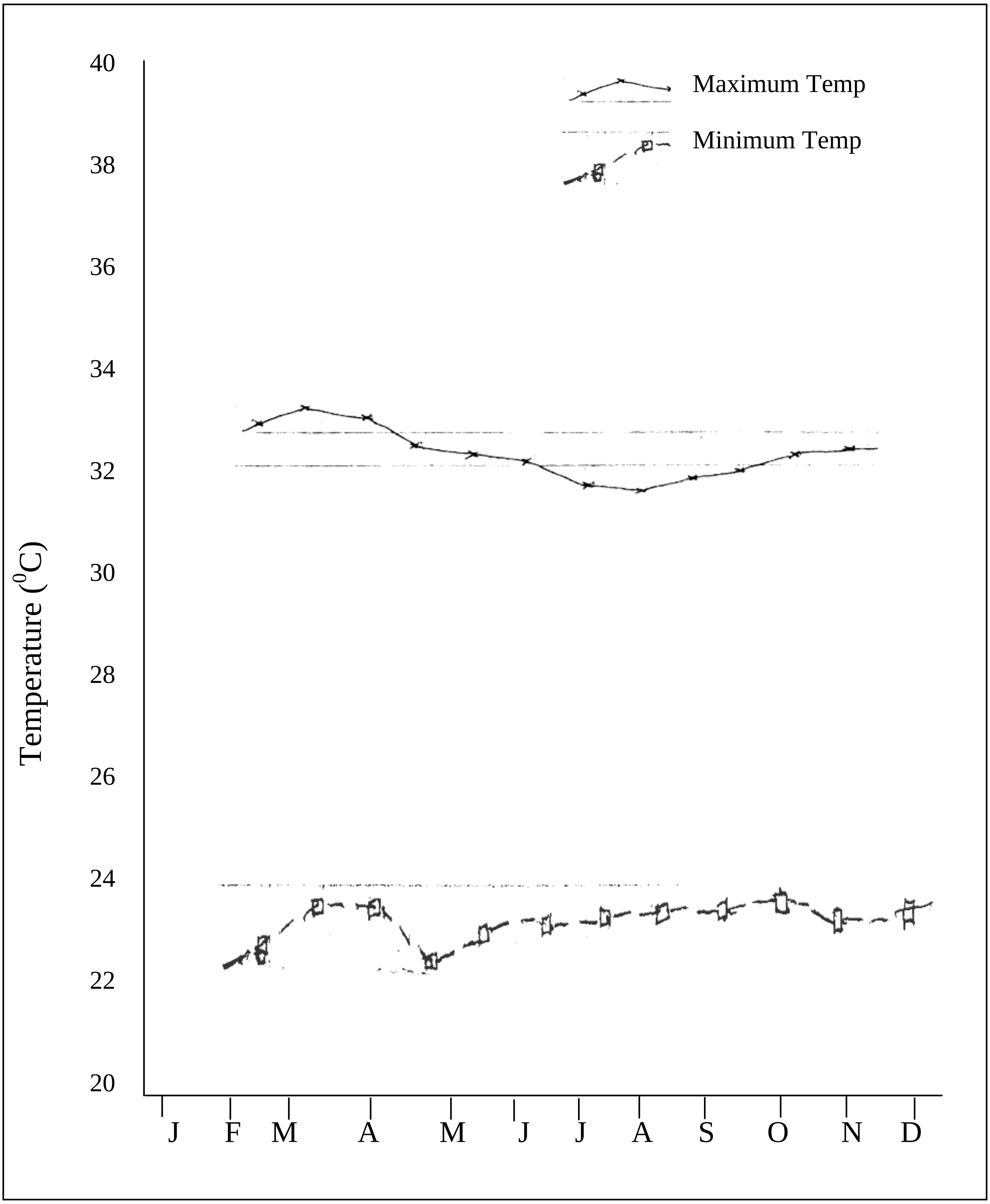

Figure 5.4: Mean Monthly Maximum and Minimum Temperature Distribution in Warri Metropolis from 1985-2014
Source: Fieldwork, 2016.

The implication of this is that the dry months of January, February, March, November and December recorded the highest mean maximum temperature from 1985 to 2014.

This finding is in line with the works of Gobo, Amangabara and Agobie (2014) in their study of flood events in Warri, Delta State, Nigeria.

5.5 Mean Monthly Temperature Distribution

In Warri metropolis, the mean annual temperature of 26.95^{0}C decadal increase in temperature over the last thirty years (1985-2014) was observed (Table 5.9). The highest mean annual temperature of 28.64^{0}C was recorded in February and the lowest mean annual temperature of 25.49^{0}C was recorded in August. Other mean annual temperature of 27.47^{0}C was recorded for the month of January, 28.25^{0}C for March, 27.33^{0}C for April, 27.29^{0}C for May, 26.79^{0}C for June, 25.53^{0}C for July, 25.85^{0}C for September, 26.42^{0}C for October, 27.11^{0}C for November and 27.30^{0}C for December.

Table 5.9: Mean Yearly Maximum and Minimum Temperature Distribution in Warri Metropolis from 1985 to 2014

	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
X	27.47	28.64	28.25	27.33	27.29	26.79	25.53	25.49	25.85	26.42	27.11	27.30

Source: Fieldwork, 2016.

This high temperature variation observed in the area is the main cause of urban heat island. This is best attributed to the modification of the surface by urban development and waste heat generated by energy usage. As population in the metropolis grows, they tend to modify a greater portion of the land use and consequently have a corresponding increase in average temperature and precipitation in the urban canopy. This finding corroborates the works of Santamouris (2001), Fuchs (2005), Efe (2002b) and Oguntoyinbo (1981) in their separate studies of urban heat island in parts of Spain, Britain, Warri and Ibadan respectively.

5.6 Spatial Distribution of Temperature

The spatial distribution of temperature within the Warri metropolis and the various land use types from February to March and from June to July, 2015 during the day and night revealed that there is an increase in temperature during the day in the months of February, March, June and July than during the night in the months of February, March, June and July (table 5.10). This is evident from the ambient mean temperature recorded during the day and night from February to March and from June to July in the area.

Table 5.10: Ambient mean temperature in different landuse types for day and night (Feb. Mar, June, and July 2015).

Parameter	Day (^oC)				Night (^oC)			
	Feb	Mar	June	July	Feb	Mar	June	July
Effurun market	32	32.5	31	28.3	23.3	21	20.5	22
Igbudu market	33.5	32.3	31.3	28.5	23.5	21.5	20.5	21.8
Ogbe-ijaw market	31	31	30	27.5	21.5	20.8	19.5	21.3
Jigbale market	32.5	32.3	31.3	27	21.8	22.3	21.3	22
NNPE ekpan	34.3	31.8	29.8	29.5	23	22	22.8	22
Express road edjeba	33.3	32.3	29.5	28	24	21.3	21.8	22.3
Dsc ovwian-aladja	33.5	33	30.3	28.8	23.8	22.3	21.3	21.5
Deco road	33	32.3	29.3	29	23	21	21	22
Agbassa	31	32.3	29.3	28.8	20.5	21.3	22.3	22.8
Range	3.3	1.5	2	2	2.2	1.5	3.3	1.5

Source: Fieldwork, 2016.

Table 5.10 revealed that the different landuse types in Warri metropolis recorded different temperature during the day and at night. For example, the high density areas, such as Effurun market, Igbudu market, Ogbe-ijaw market and Jigbale market recorded mean temperature of 32^0c, 33.5^0C, 31^0C and 32.5^0C during the day respectively. These areas also served as commercial nerve centres of Warri metropolis including the NNPC Ekpan area with mean temperature of 34.3^0C recorded during the day. The medium residential areas denoted by Express Road, Edjeba, DSC Ovwian Aladja, Deco road and Agbassa have mean temperature of 33.3^0C, 33.5^0C, 33^0C and 31^0C respectively. The commercial areas have temperature variation of 1.5^0C, while the industrial area of NNPC Ekpan has a variation of 3.3^0C; while the residential areas have a temperature variation of 0.5^0C. This implies that the industrial areas are warmer than the commercial areas, and the commercial areas are warmer than the residential areas. These increase in temperature in the high density/industrial areas, commercial areas and the residential areas over their surrounding rural areas could be attributed to the high population density of those areas, green house gases effect from waste incineration, fumes of generating sets, fumes from industrial machines/plants, vehicular movement, low wind velocity that characterized the urban canopy and the turning of landscape to townscape (Efe and Eyefia, 2014). In fact, as population in these areas increases, they tend to modify a greater areas of landuse and consequently have a corresponding increase in average temperature. These temperature increases corroborate the work of Omogbai (1985) on the urban climate of Benin-City, Nigeria, Ojo (1981) on energy balance in metropolitan Lagos and Ayoade (1993) while writing on the climate of Ibadan, Nigeria affirmed urban heat island effect of 2^0C-4^0C in the zone of dense traffic and main corridors of Mushin and Oshodi areas of Lagos metropolis at noon (Ojo, 1981).

It was also observed from table 5.10 that the mean day temperature for the month of March, 2015 also recorded increase from 33^0C at DSC Ovwian-Aladja to 31^0C at Ogbe-Ijaw market with a range of 1.5^0C. While commercial centers such as Effurun market, Igbudu markets, Jigbale market recorded ambient mean temperature of 32.5^0C, 32.3^0C aad 32.3^0C for the month of March, 2015 respectively. While in June and July (rainy season), there was a slight decrease in temperature as against the dry months of February and

March with Effurun market recording 31^0C and 28.3^0C for the months of June and July respectively. Igbudu market recorded 31.3^0C (June) and 28.5^0C (July). Others include Ogbe-Ijaw market, 27.5^0C (June), 27^0C (July), while the industrial nerve of NNPC Ekpan recorded 29.8^0C (June) and 29.5^0C (July) and DSC Ovwian-Aladja recorded 30.3^0C for June and 28.8^0C for July. The residential areas of Deco Road recorded for June 29.3^0C and 29^0C for July and Agbassa recorded 29.3^0C for June and 28.8^0C for July. (Figures 5.5-5.8).

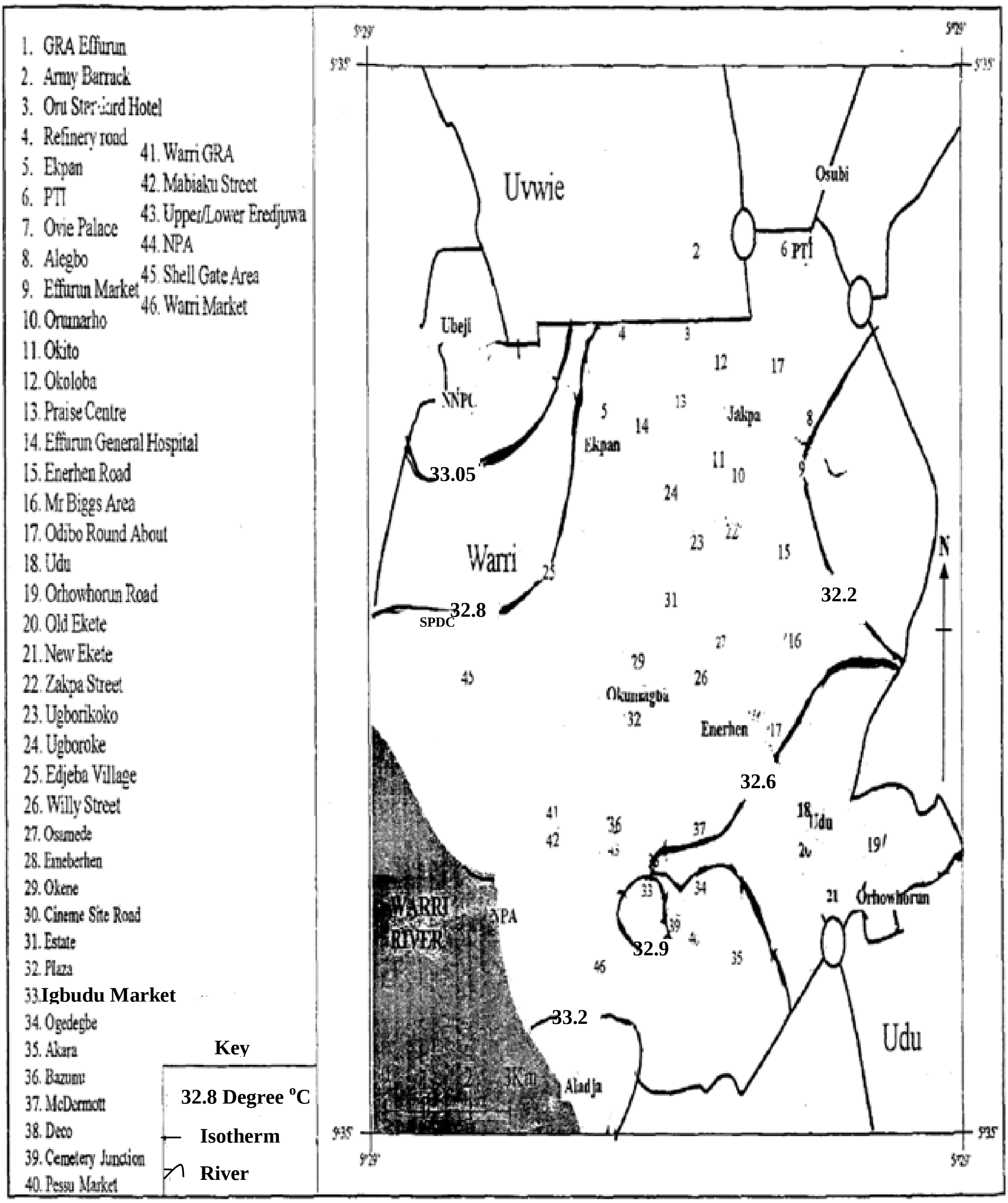

Figure 5.5: Isotherm Map During Daytime in the Dry Season in Warri Metropolis

Source: Fieldwork, 2016.

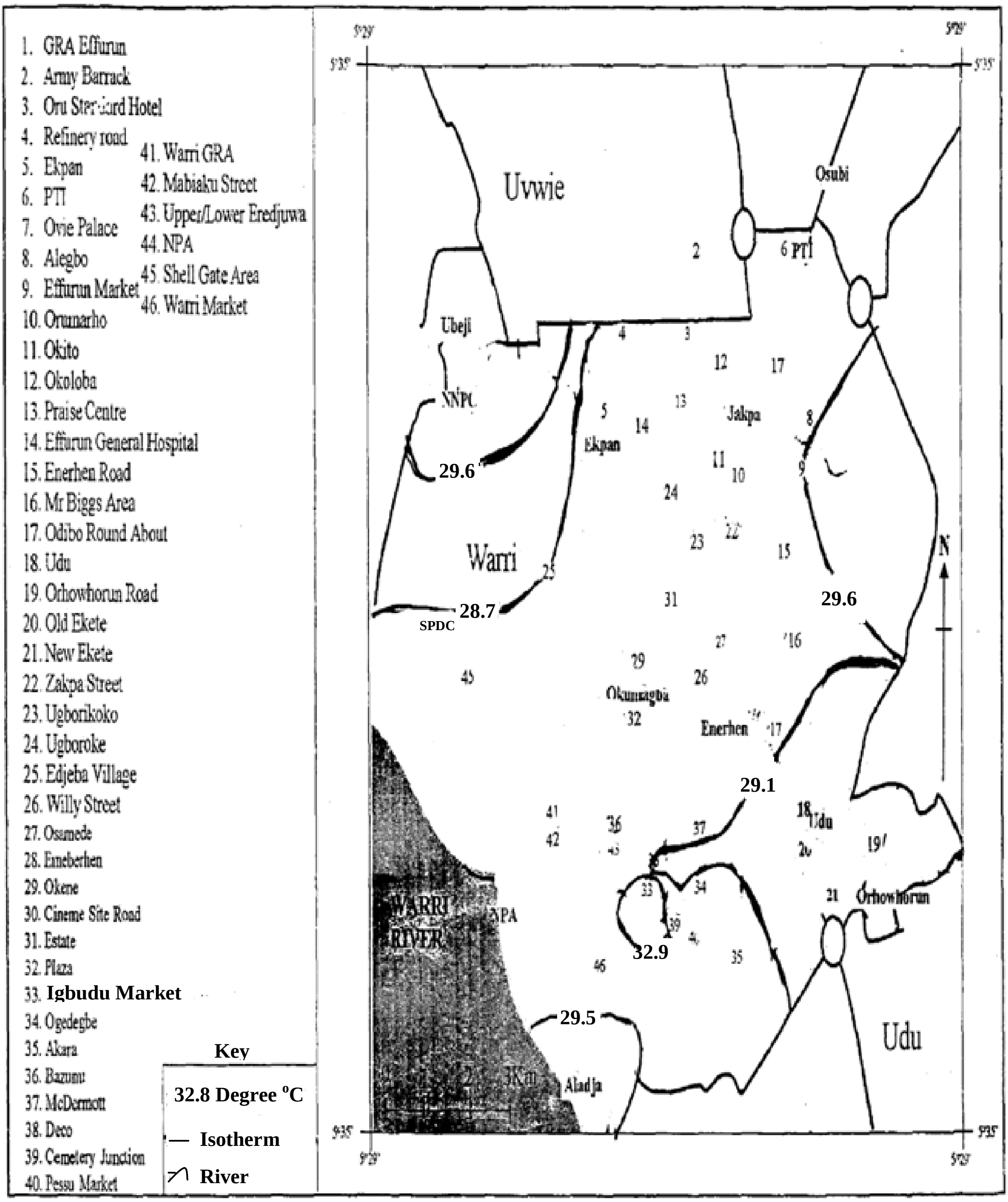

Figure 5.6: Isotherm Map During Daytime in the Rainy Season in Warri Metropolis

Source: Fieldwork, 2016.

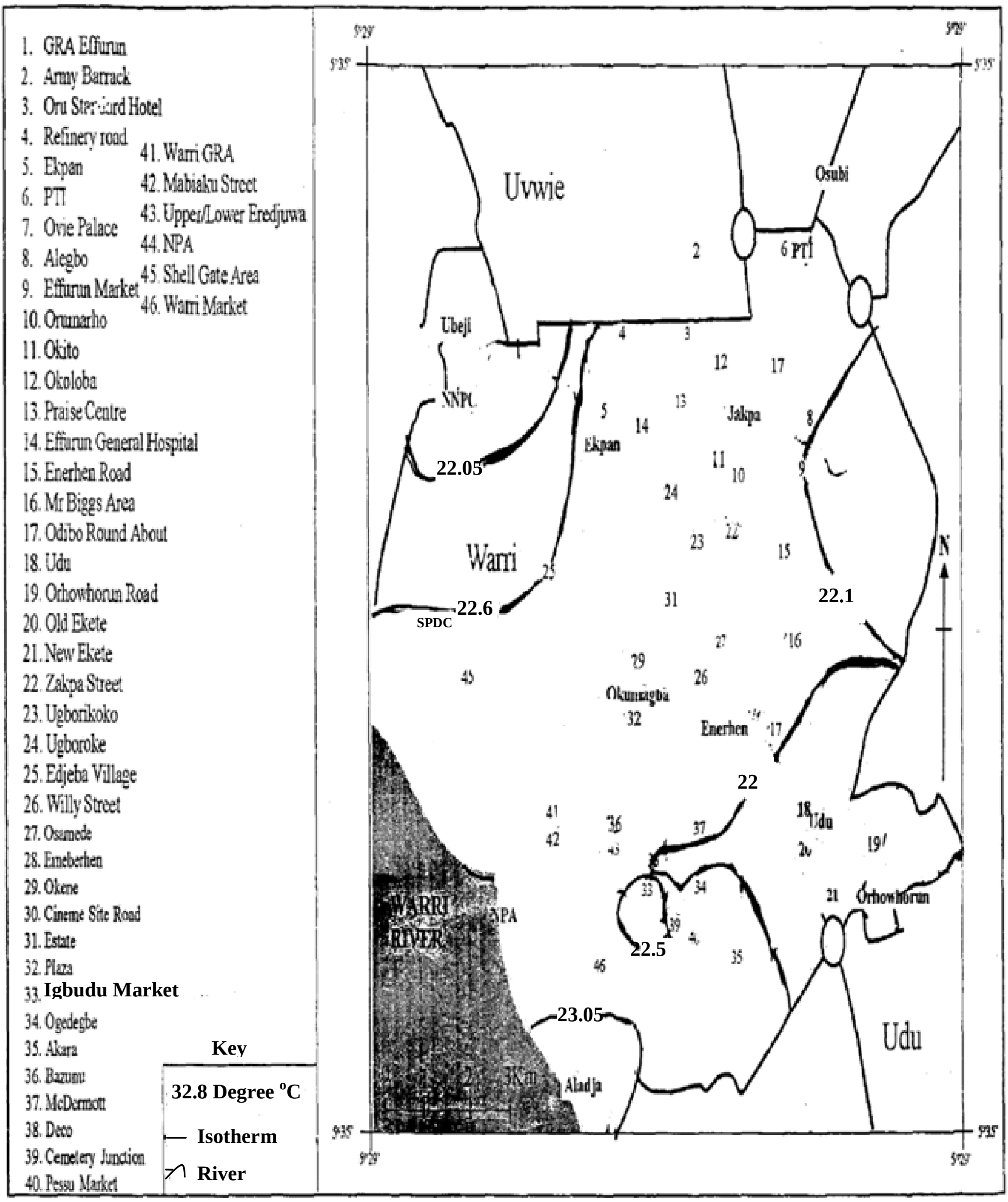

Figure 5.7: Isotherm Map During Night Time in the Dry Season in Warri Metropolis

Source: Fieldwork, 2016.

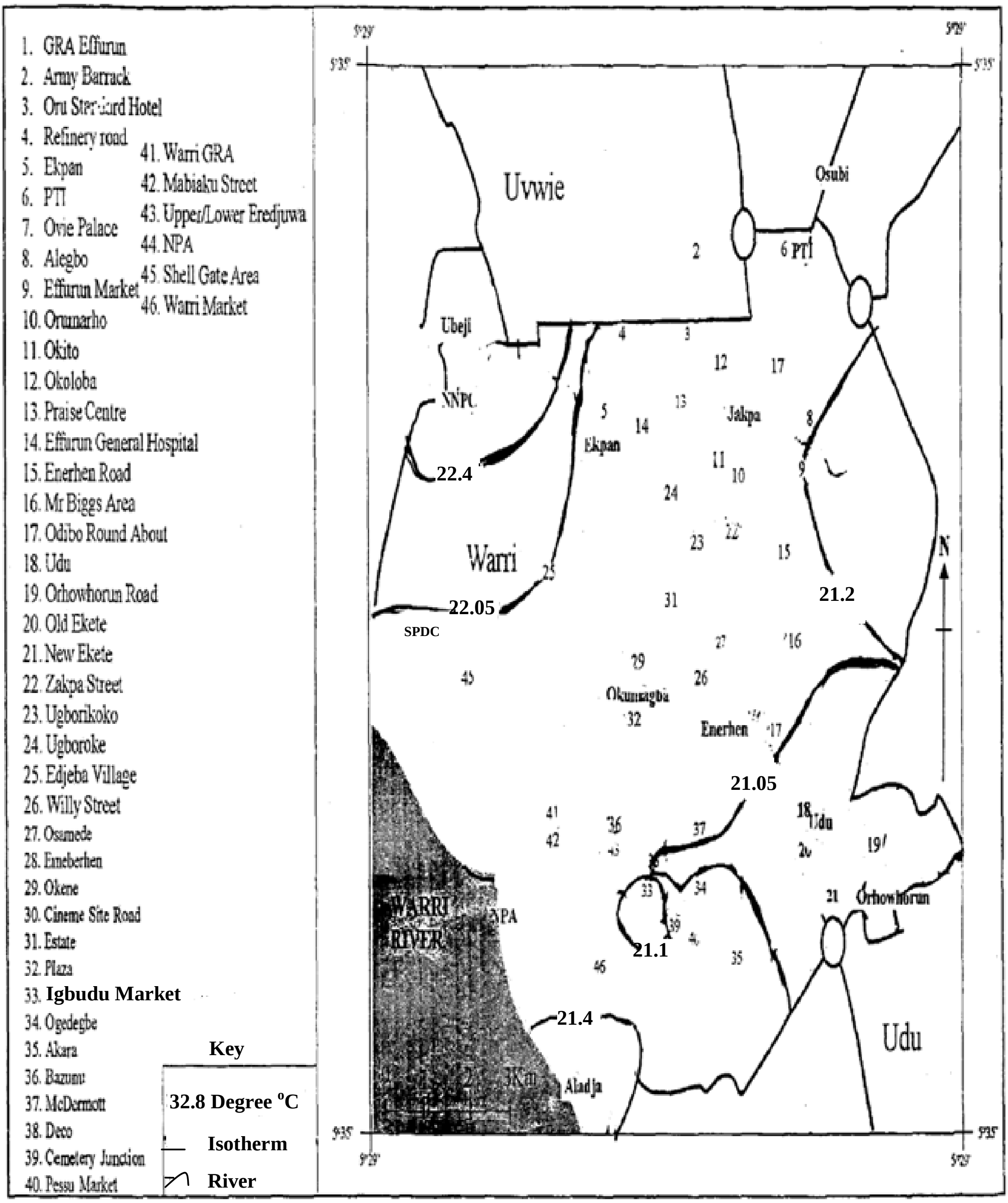

Figure 5.8: Isotherm Map During Nighttime in the Rainy Season in Warri Metropolis

However, the night temperature was much lower but higher in the months of February and March than the months of June and July. For instance, a mean night temperature of 23.3^0C and 21^0C were recorded for February and March and 20.5^0C and 22^0C for June and July respectively (table 5.10). Thus, the commercial centres of Igbudu market, Ogbe-Ijaw market and Jigbale market recorded temperature that varied between 32.5^0C and 21.5^0C with a range of 27^0C.

5.7 Test of Hypothesis 1

The hypothesis one which states that, "there is no significant variation in temperature within Warri metropolis and emergence of urban heat islands in Warri", was tested using the analysis of variance (ANOVA) statistical technique. The data for this test are presented in appendices A and B.

Thus, the hypothesis was posited as follows;

Ho: There is no significant variation in temperature within Warri metropolis and emergence of urban heat islands in Warri.

Table 5.11: Anova table showing variation in temperature within Warri metropolis

Model	**Sum of squares**	**Df**	**Mean square**	**F**	**Critical f**
Between groups	246.586	5	49.317	49.370	2.21
Within groups	177.808	187	0.946		
Total	**424.394**	**183**			

Source: Fieldwork, 2016.

Conclusively, H = 49.370 and table value = 2.21. Thus, the calculated F – value of 49.370 at 0.05 significant level is greater than the critical F-value of 2.21. Therefore, there is a significant variation in the distribution of temperature within the Warri metropolis. This further confirms the 3.3^0C temperature variation for February, 1.5^0C for March, 2^0C for June and 2^0C for July for daytime temperature and 2.2^0C for February, 1.5^0C for March,

3.3^0C for June and 1.5^0C for July for night temperature for various landuses in Warri metropolis. The implication of this assessment is that there are pockets of heat islands in Warri metropolis. According to the fourth assessment of the intergovernmental panel on Climate Change (2007), Urban Heat Island (UHI) has some environmental and health implications on the residents. UHI provokes physical traumas such as natural disasters like storms, flood and heat wave which increases human problems and cause ill health in children and the elderly. It equally results in climate anomaly that lead to food insecurity, reduces air and water quality and creates infectious diseases that affect the life of man.

5.8 Landuse Change and Land Surface Temperature Prediction

The rate of change in land use types as presented in table 5.12 reveals evidence that urban development is expanding. Built-up area and water bodies all had a consistent increase in 1987-2002, 2002-2009 and 2002-2011. Therefore, there was a positive change for built structures and water bodies (x 10.19 and x5.69 square kilometers per year) from 1987 to 2002 and x5.84 and x1.30 square kilometers per year from 2002 to 2009; while an increase of x8.83 and x0.60 square kilometers per year was recorded from 2002 to 2011.

Table 5.12: Magnitude and percentage change in land use and land cover between 1987 and 2002

Classes	**A**	**B**	**C**	**D**	**E**
	2002 area (km^2)	2009 area (km^2)	Magnitude of change (B-A)km^2	Annual rate of change c/7 (km^2)	% change C/A x 100
Bare surface	210.76	190.75	-20.01	-1.25	-9.49
Build up area	213.99	376.74	162.97	10.19	76.16
Cultivated area	256.74	289.74	33.04	2.07	12.87
Natural vegetation	309.95	224.96	-84.99	-5.31	-27.42
Water bodies	224.56	133.59	-90.97	-5.69	40.51
Total	**1216**	**1216**	**0.04**	**0.01**	**92.63**

Source: Fieldwork, 2016.

Bare surface and natural vegetation showed loss as a result of seasonal variations and therefore showed a negative change of -20.01 and -84.99 square kilometers per year from 1987 to 2002 and negative change from 2002-2009 (-7.1689km/year) for natural vegetation and a negative change of -104.99 and -82.2 for cultivated area and natural vegetation respectively in 2002 and 2011 (tables 5.13 and 5.14).

Table 5.13: Magnitude and percentage change in land use and land cover between 2002 and 2009

Classes	**A**	**B**	**C**	**D**	**E**
	2002 area (km^2)	2009 area (km^2)	Magnitude of change (B-A)km^2	Annual rate of change c/7 (km^2)	% change C/A x 100
Bare surface	190.75	199.77	9.02	1.29	4.73
Build up area	376.96	417.81	40.85	5.84	10.84
Cultivated area	289.74	299.08	9.34	1.33	3.22
Natural vegetation	224.96	174.82	-50.14	-7.16	-22.29
Water bodies	133.59	124.52	-9.07	-1.30	6.79
Total	**1216**	**1216**	**0**	**0**	**3.29**

Source: Fieldwork, 2016.

Table 5.14: Magnitude and percentage change in land use and land cover between 2002 and 2011

Classes	**A**	**B**	**C**	**D**	**E**
	2002 area (km^2)	2009 area (km^2)	Magnitude of change (B-A)km^2	Annual rate of change c/7 (km^2)	% change C/A x 100
Bare surface	190.75	284.04	93.29	9.33	48.91
Build up area	376.96	464.91	88.33	8.83	23.43
Cultivated area	289.74	184.75	-104.99	-10.50	-36.24
Natural vegetation	224.96	142.76	-82.2	-8.22	-36.54
Water bodies	133.59	139.54	5.95	0.60	4.45
Total	1216	1216	0.36	0.04	4.01

Source: Fieldwork, 2016.

It was observed from tables 5.12, 5.13 and 5.14 that built-up area, a non-evaporative and use type increases more than the other land uses. This accounts for the noticeable increase of land surface temperature of the land use and also in the generation and emission of heat flux through human activities (Ogidiolu, Ifatimehin and Abu, 2012). In totality, the non-evaporative land use types increased by 13.50 square kilometer per year (table 5.15) at the expense of the evaporative land use types, which decreased at the rate of 22.76 square kilometer per year (Table 5.16).

Table 5.15: Gain in non-evaporative land use types of the study area between 1987 and 2002, 2002 and 2009 and 2002 and 2011.

Year	Built up area (sqkm)	Gain in the non-evaporative land use types (km^2)	Time in years	Mean gain per year
1987	424.75	-	-	-
2002	567.71	142.87	15	9.15
2009	617.58	49.37	7	7.12
2011	748.95	131.37	2	65.685
Total	**-**	**324.20**	**24**	**13.50**

Source: Fieldwork, 2016.

The non-evaporative land use types are very good conductors of heat and emitters of latent heat fluxes which are known to increase the temperature of the surrounding environment. Their increase is shown in their capacity to accumulate more heat and also in the emission of the stored heat. The changes in the mass of each land use components of the non-evaporative land use types is indicated in the varying increase in land surface temperature of each land use types (Table 5.16).

Table 5.16: Loss in evaporative land use types of the study area between 1987 and 2002, 2002 and 2009 and 2002 and 2011.

Year	Built up area (sqkm)	Gain in the non-evaporative land use types (km^2)	Time in years	Mean gain per year
1987	791.25	-	-	-
2002	648.29	-49.87	15	-9.53
2009	598.42	-49.87	7	-7.12
2011	467.05	-131.37	2	-65.68
Total		**-324.20**	**24**	**-13.50**

Source: Fieldwork, 2016.

The charge rates of the major land surface temperature, pattern for 1987, 2002, 2009 and 2011 in Warri metropolis are shown in table 5.17. The rate of land surface temperature charge to land use types has increased from 1987 to 2011 by 0.2617^oC, 0.2413 ^oC, 0.1900 ^oC, 0.1592 ^oC and 0.1293 ^oC for built up area, bare surface, cultivated area natural vegetation and water bodies respectively.

Table 5.17: The rate of land surface temperature charge to land use types has incased in Warri Metropolis between 1987 to 2011

Time in years (24)	Non-Evaporative land types		Evaporative land types		
Change in LST	X6.28	X5.79	X4.56	X3.82	X3.08
Rate of change in LST	0.2617	0.2413	0.1900	0.1592	0.1283

Source: Fieldwork, 2016.

The increase in temperature (LST) in built-up area (0.2617 ^oc) can be attributed to increase in population propelled by increase in houses for the people and increases in land transportation resulting in the emission of greenhouse gases into the environment. These findings show that there exist a relationship between land use and land surface temperature. This relationship is direct between the two variables (built-up area and temperature), as an increase in built-up, area will certainly lead to an increase in the capacity to which this body accumulates and emits heat, which invariably leads to the increases in land surface temperature. This finding corroborates the works of EI- Sayoad (2012), Aniello, Devadas (2005), Oke (1982), Sundra Udaya and Padmakumari (2012) and

Ifatimetin, Musa and Adeyemi (2011) in separate research on urban heat island is different parts of the world.

In predicting the land use and land surface temperature, little change in the classes between 2011 and 2015 can be observed as shown in table 5.18.

Table 5.18: Land use/land cove[r projection for 2025.

Land use/land cover classes	Bare surface	Built up area	Cultivated area	Natural vegetation	Water bodies
2025 Area in sakm	414 .66	588.53	37.75	27.68	147.94
Area in percentage	34.09	48.38	3.10	2.27	12.16

Source: Fieldwork, 2016.

From table 5.18, built-up area still maintains the highest position in the classes whilst natural vegetation has the least position. Bare surface takes the second position, followed by water bodies and cultivated area. The implication of this is that there is likely to be compactness in development of built up land in Warri metropolis by 2025 as a result of dense population. There is going to be a remarkable growth, which will be brought by increased land consumption and alteration in the status of land use /land cover as well as changes in land surface temperature in Warri metropolis by 2025. This situation will have negative implications in the area because of the associated problems of urban heat Island, malaria infestation, easy spread of diseases crime and increased in the temperature of local climate. The finding corroborates the works of Ifatimehiri (2007) and Zhao and Wang (2001).

5.8.1 **Test of hypothesis II**

The hypothesis which states that, "there is no relationship in land use changes and surface temperature characteristics in Warri metropolis, "was tested using the analysis of variance (ANOVA) statistical technique. The hypothesis posited thus:

Ho: There is no significant relationship in land use change and surface temperature characteristics in Warri metropolis.

The test was conducted using the one way ANOVA analysis on the change of land use and temperature. The calculated values are shown in table 5.19.

Table 5.19: ANOVA calculation

	SS	**DF**	**MS**	**F**	**P**
Between	35.514	4	8.878	223.976	0.000
Within	0.793	20	0.040		
Total	36.306	24			

Source: Fieldwork, 2016.

Table 5.19 shows that calculated F (223.976) is greater than the critical table value (2.78) at p=0.05 and thus the model is significant. Therefore, we accept the alternative hypothesis which states that there is a significant relationship in land use change and surface temperature characteristics in Warri metropolis.

Thus, change in land use leads to increase in temperature especially in built up areas. This finding corroborates our earlier result as shown in table 5.17 of this section. This finding also validates the works of El-sayad (2012) and Hatimehm, Musa and Adeyemi (2011).

5.9 Seasonality of Temperature in Warri Metropolis

5.9.1 Dry Season (Day-time)

In the study, the months of February and March were used as good examples of dry season months. These months show variability in temperature. 4.33 millimeters of rainfall was recorded on average for a period of 120 days that this section covered. The dry season temperature during the day is as shown in table 5.20.

Table 5.20: Dry season temperature variation during the day

Site	Location name	Temperature (^oc)
DTL	NNPC EKPAN	-8.95
LOR	DSC Ovwian-Aladja	-8.55
LVR	Express Road, Edjeba	-9.45
HDR	Ogbe-Ijaw Market	+3.05

Source: Fieldwork, 2016.

The high density, high rise, residential areas with low greenery (HDR) representing Ogbe-Ijaw market site was the warmest (+3.05^{0}C). The heavily, vegetated urban residential site of Edjeba (LUR) with developed vegetation canopy was the coolest (-9.45^{o}C). The hour-to-hour variation in air temperature during day time was significant. Also the magnitude of the temperature differences decrease as climate becomes hotter. During the day, very few cool inlands were observed. The thick vegetation along DSC Ovwian-Aladja and Express Road, Edjeba recorded few days of urban cool islands (UCI). The peak temperature value was recorded between 1300 hours and 1500 hours of the day.

5.9.2 Dry Season (Night-Time)

The nighttime dry season showed a remarkable increase in temperature. This variation is depicted in table 5.21.

Table 5.21: Night time temperature variation during the dry season

Site	Location name	Temperature ^{o}c
DTL	NNPC Ekpan	+0.3
LOR	DSC Ovwian-Aladja	+1.4
LVR	Express Road Edjeba	+0.6
HDR	Ogbe-Ijaw Market	-2.4

Source: Fieldwork, 2016.

All the residential sites (NNPC Ekapn, DSC Ovwian-Aladja, Express Road Edjeba) were warmer than the non-residential (Ogbe-Ijaw Market) area. The downtown location was up to 1.4^{0}C warmer. This leads to a maximum nighttime air temperature heat island of about 1.4^{0}C in the study area. The implication of this is that urban heat island in Warri metropolis has a close link to the diurnal cycle of human activities as well as the atmospheric conditions characterizing day and night. Thus, extensive free canopy produced some cooling effect during the day results in warm micro-climate at night in the area.

5.9.3 Rainy Season (Day-time)

The months of June and July are regarded as rainy months in the study area. These months show variations in temperature and rainfall . The day time rainy season temperature is as shown in Table 5.22.

Table 5.22: Rainy Season Temperature Variation during day time

Site	**Location name**	**Temperature ^{o}c**
DTL	NNPC Ekpan	+1.0
LOR	DSC Ovwian-Aladja	+8.8
LVR	Express Road Edjeba	-0.8
HDR	Ogbe-Ijaw Market	-0.8

Source: Fieldwork, 2016.

As shown in table 5.22, the high density, high rise, residential areas of NNPC Ekpan recorded the highest temperature of +1.0^{0}C variation during the rainy season at daytime, while the lowest variation in temperature was recorded by the LVR (-0.8^{0}C) respectively. This implies that areas of low population recorded the lowest amount of temperature, an indication of urban influence on temperature variability in the area.

5.9.4 Rainy season (night time)

Table 5.23: Shows the variation in night time temperature during the rainy season.

Site	**Location Name**	**Temperature ^{o}c**
DTL	NNPC Ekpan	+173
LOR	DSC Ovwian-Aladja	-0.3
LVR	Express Road Edjeba	+1.0
HDR	Ogbe-Ijaw Market	-2.3

Source: Fieldwork, 2016.

From table 5.23, the high density residential area recorded the highest night time temperature variation (+1.7^{0}C) in the area. While the lowest night time temperature was recorded in the Ogbe-Ijew market (-2.3^{0}C) and DSC Ovwian-Aladja (-0.3^{0}C) respectively. The implication of this is that there is a relationship between the dry season night time temperature and the rainy season night time temperature in the area.

CHAPTER SIX

SUMMARY OF FINDINGS, RECOMMENDATIONS AND CONCLUSION

6.1 Summary of Findings

This study examined the characteristics of urban heat island in Warri metropolis of Delta State, Nigeria. In achieving this aim, the study focused on urban heat island measurement through satellite imageries, and landsat ETM data downloaded from NASA website. These landsat data were obtained during the dry season (February to March, 1985 to 2014) and the rainy season (June to July, 1985 to 2014). The data were analysed in order to identify the urban heat island characteristics in Warri metropolis, investigate the emergence of urban heat island through the examination of meteorological records of diurnal temperature ranges and the impact of urban heat on socio-economic activities in the area.

The study also tested the two posited hypotheses using the analysis of variance (ANOVA) statistical technique as the most reliable tool for the data collected. The study also provided answers to research questions posited in the course of the study.

Based on the above, the following findings emerged:

There was an increase in landuse from 1987-2011 in the area. Thus, increases were recorded in built-up areas and bare surface. This was attributed to increase in population as a result of pressure on the available land for more houses for human habitation. This equally led to increase in transportation network and road construction in the area.

The study discovered that from 1987 to 2011 that there was a decrease in cultivated land and natural vegetation as a result of urbanization. This is as a result of the demand for more houses to accommodate the people. This led to the destruction of natural vegetation and use of cultivated land for house construction, roads and industrial development in such areas as Ovwian-Aladja, Edjeba and Ekpan.

The study also found an increase in temperature in the built-up areas. This is as a result of increased land consumption by the people for development purposes such as residential. This led to the creation of urban heat islands in parts of Warri metropolis.

In the resulting analysis as carried out in this study, land surface temperature changes witnessed in Warri metropolis and used to estimate the land surface temperature for 2025 showed that built-up area gave rise to increase in surface radiant temperature. The implication therefore is that the rate of increase of the built-up surface radiant temperature will be on the increase and this may create an environment for urban heat island and heat waves when all the regulatory land use types decline unchecked to a minimal, which may in the long run reduce ecosystem services of these land uses.

In the course of this study, urban heat island has been found to occur throughout the day and night, especially in residential areas. Weak daytime heat island exists throughout the rainy season (June and July) and extremely weak during the dry season accounting for reduced energy demand for cooling, but higher frequency of intense heat island at night time during the dry season. This is an indication of warmer nights, capable of increasing the energy required for cooling. This result ascertained that the UHI is more of a nocturnal phenomena in Warri metropolis, as the highest UHI intensity occurs at night, and also higher in the dry season than the wet season.

The study established from the test results of the posited hypothesis one that there are significant variations in the distribution of temperature within the Warri metropolis. Thus, 3.3^0C temperature variation was recorded in February, 1.5^0C recorded in March among others in the study area. This confirms pockets of heat islands in Warri metropolis.

The test result from hypothesis two revealed that there is a relationship between land use change and surface temperature characteristics in Warri metropolis. The implication of this is that changes in landuse especially in built-up areas lead to changes in temperature.

Findings from observation in the course of this study here shown that although urban heat island exists in Warri metropolis, thermal levels vary considerably within the metropolis with a direct relationship to land use (built-up area and natural vegetation changes).

The study also found that extensive tree canopy produced some cooling effect during the day time, but results in warm climate at night time.

6.2 Contribution to Knowledge

The study has been able to contribute to meteorological and environmental studies by revealing the urban heat island characteristics of Warri metropolis. The relationship between land use types and urban heat island characteristics in Warri metropolis was well established, thereby making the study of importance to town planners and urban development.

The study also established that urbanization processes here contributed immensely to urban heat island in the area through population increase, transportation networks, emission of gases from cars, industrial fumes, thus making the study of relevance to the ministry of urban development.

6.3 Recommendations

The following are recommendations, strategies and policy implications presented as additional precautionary measures for mitigating and improving on the present status of urban heat island characteristics in Warri metropolis in order to safeguard human health and improve on the environment for the sustenance of man.

Firstly, it should be noted that the area of expansion of Warri metropolis is now over $100km^2$ with an ever increasing population. There is the need to control urban sprawl and land use change. Small towns around Warri metropolis should be developed in order to absorb the excess population of the city; thus reducing spatial expansion of the city to adjoining marginal lands.

Secondly, development and legislative measures should be adopted as to regulate growth in Warri metropolis by urban planners, town administrators, ministries and parastatals.

Thirdly, street trees should be planted as cooling potentials than planting open-surface trees, because the temperature differential between trees and impervious surfaces is greater than that between trees and grasses. Also, the cooling effect of open-space trees tends to be localized (Enete and Alabi, 2012).

Fourthly, light-coloured materials should be used for roofing as this will improve the reflectivity of pavements within the urban centre and the adjoining suburbs could minimize the impact of urban heat islands in Warri metropolis.

Fifthly, government should embark on the contraction of housing estates and recreational centres away from the city centres. This will encourage massive urban drift to the suburbs and hence reduce the urban heat island.

Sixthly, weather stations should be scattered around the metropolis to monitor temperature and other weather parameters. This will enable meteorologists to forecast temperature elevation and predict consequent effects on the microclimate.

In addition, urban forestry concept should be introduced around each urban centre in the Warri metropolis, else tree planting campaign should be intensified in the area.

Finally, preservation and conservation of the present state of both vegetal and water bodies to enhance sustainable resource utilization be encouraged including efficient use of land resources, and environmental protection.

6.4 Conclusion

Urban areas are centres of economic activity with vital infrastructural development which needs to be protected. These infrastructures have been the bane of rural-urban drift in Nigeria. Rapid urbanization, particularly the growth of metropolis and the associated problems of environmental degradation pose a formidable challenge in Nigeria and other developing countries of the world. Thus, more than half of the world's population live in urban centres. The question that arises is whether the current trend in urban growth is sustainable, considering the accompanying urban challenges of temperature variability.

Warri metropolis has experienced accelerated growth in its urban space from about $83.15km^2$ in 1987 to $236.76km^2$ today. This urban growth has led to the unregulated development of marginal areas which has affected with the land cover/land use and by extension increased the total impervious cover of the area on the one hand urban heat island variability on the other. Thus, the high rate of depletion of the vegetal resources at the expense of non-evaporative land uses such as concrete, asphalt and other impervious materials are seriously responsible for the rise in the land surface temperature in Warri metropolis. The heat experience in the built-up areas is more than the surroundings.

Therefore, the overall analysis concludes that warming during the period under study was because of the conversion of water bodies, natural vegetation to bare surfaces and dense forest to open forest. It was also predicted that by 2025 about 50 percent of the total land mass of Warri metropolis will be built-up area and this suggest land surface temperature increase and devastating impact on the inhabitants of the metropolis. There is therefore the need to protect the environment through sustainable resource utilization and prudent management.

6.5 Limitation of the Study

A major constraint of this study was the large amount of capital required for the analysis of data collected. This affected the number of isotherm maps produced for the area. More importantly, moving from one weather station to another collecting data was time consuming; hence some weather stations designated for study were left out. Also, some improvised weather stations were destroyed by the inhabitants of the area, hence the researcher had to look for alternative areas to mount them before data were collected and used for the study.

6.6 Suggestion for Further Study

This study focused on the examination of the spatial characteristics of urban heat island in Warri metropolis, Delta State, Nigeria. Thus, other towns and cities in Nigeria may be studied to make this study all embracing for the benefit of people in Delta State and Nigeria in general. Such studies should cover the macro, micro and meso scale climatic characteristics of urban areas in Nigeria.

Researchers are also needed to carryout a detailed study of other climatic elements such as rainfall, humidity, wind and sunshine in the area. Coupled with the above, the impact of these elements on man, particularly on his health, be researched upon in order to make this study all embracing for the survival of man on the earth's surface.

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Appendix A

Average Monthly Minimum Temperature from 1985 to 2014 for Warri Metropolis

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	MEAN
1985	23.8	23.6	24.7	23.5	22.8	22.3	22.3	22.6	22.3	22.7	23.3	22.9	23.1
1986	23.8	23.6	24.7	23.5	22.8	22.3	22.3	22.6	22.3	22.7	23.3	22.9	23
1987	23	23.9	24	24.4	23.9	23.1	23.2	23.2	23.1	23	23.8	23.6	23.5
1988	23.1	25	24	22.1	22.1	22.9	22.5	22.8	22.4	22.7	23.1	22.1	22.9
1989	20.4	22.6	23.5	23.2	22.5	22.6	22.1	22.2	22.2	22.4	23	22.4	22.4
1990	23.5	23.7	25.2	24.7	23.8	23.6	22.9	23.3	23.1	23.2	23.7	24.3	23.8
1991	23.5	25.3	24.8	23.9	24.1	24.2	23.3	23	23.1	22.7	23.6	22.9	23.7
1992	21.5	24.1	24.5	24.5	23.9	22.8	22.7	22.3	22.4	22.7	22.2	22.8	23
1993	22.2	24.1	23.5	23.9	24.2	23.5	22.9	23	22.8	22.9	23.2	23.3	40
1994	22.6	24.1	23.5	23	22.4	21.9	21.5	22.7	22.8	22.6	22.6	21.1	22.6
1995	21.9	23.1	22.6	23.1	22.6	22	21.6	21.7	21.6	21	22.5	21.9	22.1
1996	21.9	23.7	23.2	22.6	22.9	22	21.5	21.4	21.4	21.1	22.4	22.7	22.2
1997	22.5	21.6	22.9	22.1	22	21.7	21.1	22.6	23.2	22.8	22.8	22.6	22.3
1998	21.5	24.7	24.3	23.8	23.3	23.2	22.6	22.3	22.3	22.3	22.6	21.9	22.9
1999	22	22.5	22.2	22.3	22.2	21.9	21.1	21.4	22.6	22.7	22.9	22.6	22.2
2000	23.9	23.2	24.3	23.6	23.7	23.1	22.8	22.5	23	23	23.4	22.5	23.3
2001	22.4	23.4	23.7	23.7	23.7	23	22.8	22.6	22.8	23.2	23.7	24.1	23.3
2002	22.5	23.5	24.3	24	23.6	23.4	23.5	22.9	23.3	23.1	23.4	23.3	23.4
2003	23.4	24.4	24.4	23.6	23.6	23.3	23	23.1	22.9	23.4	23.6	23.3	23.5
2004	24	25	24	24	23	23	23	23	22.7	23	23	23.4	23.4
2005	21.7	25.2	24.0	24.6	23.8	23.7	23.0	22.9	23.3	23.1	23.8	23.3	23.5
2006	24.6	24.3	23.6	24.3	23.6	23.2	23.2	23.3	23.2	23.3	23.6	23.1	23.6
2007	22.9	23.7	23.7	23.9	23.9	23.3	22.8	22.9	22.9	22.9	23.2	23.3	23.3
2008	23.6	24.1	23.8	23.4	23.3	23	22.3	22.4	22.7	22.8	23.2	23.1	23.1
2009	22.6	22.7	23.3	22.9	24.6	22.5	22.2	22	22.5	22.6	22.6	23.3	22.8
2010	23.3	22.4	24.1	23.5	23.6	22.8	22.4	22.7	22.4	22.6	22.8	21.8	22.9
2011	22.2	23.8	23.8	23.9	23.9	23.4	22.5	23	23.1	23.1	23.5	23.1	39.9
2012	22.5	23.6	25.1	23.9	23.4	23.4	23.1	22.9	22.9	24.2	23.7	23.4	23.5
2013	23.7	26.2	24.0	24.6	23.8	23.7	23.0	22.9	24.3	25.1	24.8	26.3	24.4
2014	24.6	26.3	23.6	24.3	24.6	23.2	24.2	26.7	23.2	24.3	25.9	24.1	24.6
	22.8	**23.1**	**23.9**	**23.6**	**22.4**	**23**	**226**	**22.8**	**22.8**	**22.9**	**23.3**	**23.0**	**728.2**

***Source*: NIMET (2014).**

Appendix B

Average Monthly Maximum Temperature from 1985 to 2014 for Warri metropolis

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	MEAN
1985	32.3	33.6	33	31.4	31.2	29.6	29.2	28.5	29.3	29.7	30.7	30.7	30.8
1986	32.6	33.1	31.8	32.5	31.5	29.9	26.9	28.1	2S.5	29.4	30.6	31.4	30.5
1987	32.9	33.3	32.4	32.6	31.5	30	29.3	28.7	29.1	29.7	31.3	31.7	31.0
1988	31.2	33.7	32.5	29.9	30.2	30.3	28.3	27.8	28.5	29.1	30.8	30.1	30.2
1989	31.6	33.4	32.4	31.5	30.8	29.7	28.2	27.9	28.5	29.7	30.9	31.7	30.5
1990	31.7	33.5	35.2	32.9	31.1	29.7	26.6	27.7	28.5	29.5	30.4	30.8	30.6
1991	32.2	33.3	32.6	31.3	30.9	30.5	28.3	28	29	29	30.5	30.8	33.0
1992	31.5	34.2	32.3	31.6	30.9	28.8	27.9	26.2	27.8	29.4	30.5	32.2	30.3
1993	31.4	33.3	31.7	31.6	31.2	29.7	28.4	28	29.4	30.1	30.1	30.9	30.8
1994	31.7	33.2	32.6	32.1	31.2	29.8	27.5	27.4	28.8	29.7	30.9	32.5	30.6
1995	32.7	34.1	32.6	32.4	31.5	30.9	29.4	29.3	30.3	30.1	30.5	31.5	31.3
1996	32.6	33.8	31.7	32.1	31.9	29.8	28.3	27.3	28.1	29.3	31.5	32.5	30.7
1997	31.9	33.6	32.7	30.8	31	29.4	28.7	28	29.9	30.7	31.4	32.3	30.9
1998	32.9	35	34.2	33.1	32.5	31.1	29.5	28	29.2	30.3	31.5	31.1	31.5
1999	31.9	32.3	32.3	31.1	30.8	30.1	29.3	29.2	28.7	29.3	30.4	32.3	30.6
2000	32.7	33.8	34.3	32.2	31.6	30.5	29	28.2	28.7	29.8	31.3	32	31.2
2001	32.4	34.3	32.5	32	31.6	30.1	28.5	27.1	28.2	30.2	31.3	32.2	30.9
2002	32.5	34.3	32	32	31.9	30.2	29.6	28.2	29.6	29.7	31.2	32.1	31.1
2003	33.1	34.2	33.3	32.1	31.4	30.2	30.2	28.7	31	29.8	31.5	31.6	31.4
2004	32.4	34	32	31	30	30	28	30	30.2	30	32	31.9	31.0
2005	32.6	34.0	32.4	32.5	31.2	29.1	28.0	26.7	29.0	29.5	31.3	30.8	30.6
2006	31.8	32.6	30.2	31.7	30.2	28.2	28.2	27.8	28.2	30.1	30.6	32.0	30.1
2007	29.9	32.1	30.8	31.4	30.9	29.8	28.4	27.9	28.7	29.6	30.4	30.8	30.1
2008	30.4	31.9	32.6	31.5	31.3	29.2	27.8	28.4	28.4	29.4	30.2	30.3	30.1
2009	30.8	31.9	32.2	31.8	30.6	29	27.2	28.1	28.8	29.2	30	30.5	30.0
2010	30.9	31.7	32.3	31.6	30.8	30.2	27.8	27.8	29.1	29.7	30.5	30	30.2
2011	32.2	32	33	32	31.6	29.6	28	27.6	29.1	29.8	31.7	32.7	30.8
2012	32	31.5	33.7	32.1	31.7	30.3	28	28.4	29.1	30.9	31	32.1	30.9
2013	33.4	34.3	32.5	32.9	31.6	34.1	315	30.8	28.2	30.2	31.3	32.9	32.0
2014	35.5	35.3	32	32	31.9	35.2	29.6	32.2	29.6	29.7	31.2	34.1	32.4
	32.1	**33.4**	**32.5**	**31.9**	**31.2**	**30.2**	**28.5**	**28.3**	**28.9**	**29.8**	**30.9**	**31.6**	**926.1**

***Source*: NIMET (2014).**

Appendix C

Ambient Temperature mean of Day and Night in June/July 2014 and February/March 2015

S/n	Parameter	DAY				NIGHT			
		June	July	Feb.	March	June	July	Feb.	March
1.	Effurun market	31	28.3	32	32.5	20.5	22	23.3	21
2.	Igbudu market	31.3	28.5	33.5	32.3	20.5	21.8	23.5	21.5
3.	Ogbe-ijaw market	30	27.5	31	31	19.5	21.3	21.5	20.8
4.	Pessu market	29.8	26.8	31	30.8	19	21.8	21.5	21
5.	Jigbale market	31.3	27	32.5	32.3	21.3	22	21.8	22.3
6.	NNPC Ekpan	29.8	29.5	34.3	31.8	22.8	22	23	22
7.	Gramen petro-serve Nigerian limited express road Edjeba	29.5	28	33.3	32.3	21.8	22.3	24	21.3
8.	Delta steel company Ovwian/Aladja	30.3	28.8	33.5	33	21.3	21.5	23.8	22.3
9.	Bariodni greia limited deco road	29.3	29	33	32.3	21	22	23	21
10.	Raycon Nigerian limited deco road	29	29.3	33	32	22.5	21.8	23.8	23
11.	Edjeba	29.3	28.3	33	32	22	23.3	20.8	22
12.	Agbassa	29.3	28.8	31	32.3	22.3	22.8	20.5	21.3
13.	Igbudu	29.8	29	34	31.8	21.5	22.5	20.8	22
14.	Ekapn	29.8	29.3	33	33.3	22.3	23.3	20.3	22
15.	Ovwian	29.5	29.5	34	32.5	22.5	23.3	21.5	22

Appendix D

Maximum and Minimum Temperature Range from 1985-2014 for Warri Metropolis

Yrs	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1985												
Max	32.3	33.6	33	31.4	31.2	29.6	29.2	28.5	29.3	29.7	30.7	30.8
Min	23.8	23.6	24.7	23.5	22.8	22.3	22.3	22.6	22.3	22.7	23.3	22.9
Range	8.5	10	8.3	7.9	8.4	6.9	6.9	5.9	7	7	7.4	7.9
1986												
Max	32.6	33.1	31.8	32.5	31.5	29.9	26.9	28	28.5	29.4	30.6	31.4
Min	23.8	23.6	24.5	23.5	22.8	22.3	22.3	22.6	22.3	22.7	23.3	22.9
Range	8.8	9.5	7.1	9	8.7	7.6	4.6	5.5	6.2	6.7	7.3	8.5
1987												
Max	32.9	33.3	32.4	32.6	31.5	30	29.3	28.7	29.1	29.7	31.3	31.7
Min	23	23.9	24	24.4	23.9	23.1	23.2	23.2	23.1	23	23.8	23.6
Range	9.9	9.4	8.4	8.2	7.6	6.9	6.1	5.5	6	6.7	7.5	8.1
1988												
Max	31.2	33.7	32.5	29.9	30.2	30.3	28.3	27.8	28.5	29.1	30.8	30.1
Min	23.1	25	24	22.1	22.1	22.9	22.5	22.8	22.4	227	23.1	22.1
Range	8	87	8.5	7.8	8.1	7.4	5.8	5	6.1	6.4	7.7	8
1989												
Max	31.6	33.4	32.4	31.5	30.8	29.7	28.2	27.9	28.5	29.7	30.9	31.7
Min	20.4	22.6	23.5	23.2	22.5	22.6	22.1	22.2	22.2	22.4	22.4	22.4
Range	11.2	8.9	8.9	8.3	8.3	7.1	6.1	5.7	6.3	7.3	7.9	9.3
1990												
Max	31.7	33.5	35.2	32.9	31.1	29.7	26.6	27.7	28.5	29.5	30.4	30.8
Min	23.5	23.7	25.2	24.7	23.8	23.6	22.9	23.3	23.1	23.2	23.7	24.2
Range	8.2	9.8	10	8.2	7.3	6.1	3.7	4.4	5.4	6.3	6.7	6.5
1991												
Max	32.2	33.3	32.6	31.3	30.9	30.5	28.3	28	29	29	30.5	30.8
Min	23.4	25.3	24.8	23.9	24.1	24.2	23.3	23	23.1	22.7	23.6	22.9
Range	8.7	8	7.8	7.4	6.8	6.3	5	5	5.9	6.3	6.9	7.9
1992												
Max	31.5	34.2	32.3	31.6	30.9	28.8	27.9	26.2	27.8	29.4	30.5	32.2
Min	21.5	24.1	24.5	24.5	23.9	22.8	22.7	22.3	22.4	22.7	22.2	22.8
Range	10	10.1	7.8	7.1	7	6	5.2	3.9	5.4	6.7	8.3	9.4
1993												
Max	31.4	33.3	31.7	31.6	31.2	29.7	28.4	28	29.4	30.1	30.1	30.9
Min	22.2	24.1	23.5	23.9	24.2	23.5	22.9	23	22.8	22.9	23.2	23.3
Range	9.2	L9.2	8.2	7.7	7	6.2	5.5	5	6.6	7.2	6.9	7.6
1994												
Max	31.7	33.2	32.6	32.1	31.2	29.8	27.5	27.4	28.8	29.7	30.9	32.5
Min	22.6	24.1	23.5	23	22.4	21.9	21.5	22.7	22.8	22.6	22.6	21.1
Range	9.1	9.1	9.1	9.1	8.8	7.9	6	4.7	6	7.1	8.3	11.4
1995												
Max	32.7	34.1	32.6	32.4	31.5	30.9	29.4	29.3	30.3	30.1	30.5	31.5
Min	21.9	23.1	22.6	23.1	22.6	22	21.6	21.7	21.6	21	22.5	21.9
Range	10.8	11	10	9.3	8.9	8.9	7.8	7.6	8.7	9.1	8	9.6

1996												
Max	32.6	33.8	31.7	32.1	31.9	29.8	28.3	27.3	28.1	29.3	31.5	32.5
Min	21.9	23.7	23.2	22.6	22.9	22	21.5	21.4	21.4	21.1	22.4	22.7
Range	10.7	10.7	8.5	9.5	9	7.8	6.8	5.9	6.7	8.2	9.1	9.8
1997												
Max	31.9	33.6	32.7	30.8	31	29.4	28.7	28	29.9	30.7	31.4	32.3
Min	22.5	21.6	22.9	22.1.	22	21.7	21.1	22.6	23.2	2.8	22.8	22.6
Range	9.4	12	9.8	8.7	9	7.7	7.6	5.4	6.7	7.9	8.6	9.7
1998												
Max	32.9	35	34.2	33.1	32.5	31.1	29.5	28	29.2	30.3	31.5	31.1
Min	21.5	24.7	24.3	23.8	23.3	23.2	22.6	22.3	22.3	22.3	22.6	21.9
Range	11.4	10.3	9.9	9.3	9.2	7.9	6.9	5.7	6.9	8	8.9	9.2
1999												
Max	31.9	32.3	32.3	31.1	30.8	30.1	29.3	29.2	28.7	29.3	30.4	32.3
Min	22	22.5	22.2	22.3	21.9	29.9	21.1	21.4	22.6	22.7	22.9	22.6
Range	9.9	9.8	10.1	8.8	8.2	8.2	8.2	7.8	6.1	6.6	7.5	9.7
2000												
Max	32.7	33.8	34.3	32.2	31.6	30.5	29	28.2	28.7	29.8	31.3	32
Min	23.9	23.2	24.3	23.6	23.7	23.1	22.8	22.5	23	23	23.4	22.5
Range	8.8	10.6	10	8.6	7.9	7.4	6.2	5.7	5.7	6.8	7.9	9.5
2001												
Max	32.4	34.3	34.3	32.2	31.6	30.5	29	28.2	28.7	29.8	31.3	32
Min	22.4	23.4	24.3	23.6	23.7	23.1	22.8	22.5	23	23	23.4	22.5
Range	10	10.9	10	8.6	7.9	7.4	6.2	5.7	5.7	6.8	7.9	9.5
2002												
Max	32.4	34.3	32.5	32	31.6	30.1	28.5	27.1	28.2	30.2	31.3	32.1
Min	22.4	23.4	23.7	23.7	23.7	23	22.8	22.6	22.8	23.2	23.4	23.3
Range	10	10.9	8.8	8.3	7.9	7.1	5.7	4.5	5.4	7	7.8	8.8
2003												
Max	33.1	34.2	33.3	32.1	31.4	30.2	30.2	28.7	31	29.8	31.5	31.6
Min	23.4	24.4	24.4	23.6	23.6	23.3	23	23.1	22.9	23.4	23.6	23.3
Range	9.7	98	8.9	8.9	7.8	6.9	7.2	5.6	8.1	6.4	7.9	8.3
2004												
Max	32.4	34	32	31	30	30	28	30	30.2	30	32	31.9
Min	24	25	24	24	23	23	23	23	22.7	23	23	23.4
Range	8.4	9	8	7	7	7	5	7	7.5	7	9	8.5
20051												
Max	32.6	34.0	32.4	32.5	31.2	29.1	28.0	26.7	29.0	29.5	31.3	30.8
Min	21.7	25.2	24.0	24.6	23.7	23.7	23.0	22.9	23.3	23.1	23.8	23.3
Range	10.9	8.8	8.4	7.9	7.4	5.4	5	3.8	5.7	6.4	7.5	7.5
2006												
Max	31.8	32.6	30.2	31.7	30.2	28.2	28.2	27.8	28.2	30.1	30.6	32.0
Min	24.6	24.3	23.6	24.3	23.6	23.2	23.2	23.3	23.2	23.3	23.6	23. 1
Range	7.2	8.3	6.6	7.4	6.6	5	5	4.5	5	6.3	7	8.9
2007												
Max	29.9	32.1	30.8	31.4	30.9	29.8	28.4	27.9	28.7	29.6	30.4	30.8
Min	22.9	23.7	23.7	23.9	23.9	23.3	22.8	22.9	22.9	22.9	23.2	23.3
Range	7	8.4	7.1	7.5	7	6.5	5.6	5	5.8	6.7	7.2	7.5
2008												
Max	30.4	31.9	32.6	31.5	31.3	29.2	27.8	28.4	28.4	29.4	30.2	30.3

Min	23.6	24.1	23.8	23.4	23.3	23	22.3	22.4	22.7	22.8	23.2	23.1
Range	6.8	7.8	8.8	8.1	8	6.2	5.5	6	5.7	6.6	7	7.2
2009												
Max	30.8	31.9	32.2	31.8	30.6	29	27.2	27.2	28.8	29.2	30	30.5
Min	22.6	22.7	23.3	22.9	24.6	22.5	22.2	22.2	22.5	22.6	22.6	23.5
Range	8.2	9.2	8.9	8.9	6	6.5	5	6.1	6.3	6.6	7.4	7.2
2010												
Max	30.9	31.7	32.3	31.6	30.8	30.2	27.8	27.8	29.1	29.7	30.5	30
Min	23.3	22.4	24.1	23.5	23.6	22.8	22.4	22.7	22.4	22.6	22.8	21.8
Range	7.6	9.3	8.2	8.1	7.2	7.4	5.4	5.1	6.7	7.1	7.7	8.2
2011												
Max	32.2	32	33	32	31.6	29.6	28	27.6	29.1	29.8	31.7	32.7
Min	22.2	23.8	23.8	23.9	23.9	23.4	22.5	23	23.1	23.1	23.5	23.1
Range	10	8.2	9.2	8.1	7.7	6.2	5.5	4.6	6	67	8.2	9.6
2012												
Max	32	31.5	33.7	32.1	31.7	30.3	28	28.4	29.1	30.9	31	32.1
Min	22.5	23.6	25.1	23.9	23.4	23.4	23.1	22.9	22.9	24.2	23.7	23.4
Range	9.5	7.9	8.6	8.2	8.3	6.9	4.9	5.5	6.2	6.7	7.3	8.7
2013												
Max	33.4	34.3	32.5	32.9	31.6	34.1	31.5	30.5	28.2	30.2	31.3	32.9
Min	23.7	26.2	241	24.6	23.8	23.7	23.0	22.9	24.3	25.1	25.9	26.3
Range	9.7	8.1	8.5	8.3	7.8	10.4	8.5	7.9	3.9	5.1	5.3	6.6
2014												
Max	35.5	35.3	32	32	31.9	35.2	29.6	32.2	29.6	29.7	31.2	34.1
Min	24.6	26.3	23.6	24.3	24.6	23.2	24.2	26.7	23.2	24.3	25.9	24.1
Range	10.9	9	8.4	7.7	7.3	12	5.4	5.5	6.4	5.4	5.3	10

Source: Fieldwork, 2016.