CHAPTER ONE

INTRODUCTION

1.1. Background to the Study

Physiologic climatology is an aspect of the study of the climate that is focused on the understanding of the climate-human relationship at different spatial (micro-, meso- and macro-scales) and temporal scales (Lucarini, 2002). Physiologic climatology as a field of scientific study has been described by Lee (1953) as that which commonly deals with the direct effects of climatic elements and patterns on the physiologic behaviour of man and other warm blooded animals. Terjung (1966) described the field of physiologic climatology as that which is concerned with the classification or regionalisation of climatic environments based on measurable human psychological and physiologic reactions. Physiologic climate is the average condition of certain physio-climatic variables in relation to human comfort (Terjung, 1967; Ayoade, 1978). It involves climate classification based on human physiologic and psychological sensations created by climate. The concept of physiologic climatology emphasises the effects of 'heat elements' (temperature, humidity, air movement and radiant energy) in the understanding of adaptation, strain and productivity of man and animals in the environment. Its scope includes a 'humanisation' of geographical climatology as a step towards research on interrelations of physio-climatic features, health, mortality, economy, social habits, military tactics, clothing and shelter needs (Kalkstein, 1991; Comrie, 2007).

Indices of physiologic climate have long been of interest to researchers. For example, application of indices (called comfort or discomfort indices) to the study of the effects of combined atmospheric factors (especially temperature, humidity and air movement) on human bodies and their spatial variations have been widely studied at city, national, country, regional and even global scales (Mieczkowski, 1985; Kalkstein and Valimont,1986; Jauregui, 1993; Jendritzky et al., 2001). Most of these studies showed the relevance of climate and meteorological factors to human health, migration patterns, retirement decisions, tourism development, and energy requirements, among others. Subsequent studies have focused on either the specific or general effects of physiologic climate on man, and the coping strategies especially as relevant to North American and European cities, where increased heat stress, heat stroke or heat waves have resulted in increased mortality and forced migration (Jones et al., 1982; Kunkel et al., 1999; McGeehin and Mirabelli, 2001).

Information on climate comfort or discomfort indices in any area has been described to (a) help victims of diseases, that can be intensified by climatic conditions, make decisions about where to live or where not to go, in order not to aggravate their sickness; (b) simplify knowledge about housing needs, building materials, and heating or cooling requirements; (c) assist in regional analysis, especially in gauging the environmental potential of an area; and (d) assist in developing and strengthening disease control (McMichael and Kovats, 2000; McMichael et al., 2006). Physiologic climate has become an issue of global concern with highlighted variables for national and international discourse shown in Figure 1.1, and perhaps more serious for developing countries where the vulnerability of the people to the effects of climate change is known to be severe (Boko et al., 2007).

Recently, the rate of mortality resulting from meningitis has reportedly increased in the middle belt and northern Nigeria (Greenwood, 1999; Mohammed et al., 2000; Greenwood, 2006). Sawa and Buhari (2011) showed that meningitis and measles would increase by 6 and 19 persons per thousand, respectively for every 1ºC increase in temperature in Zaria, for example. More people in the tropics now prefer air conditioners in homes and offices to suppress the effect of increased heat (Chappells and Shove, 2004). Temperature related diseases increase as urbanisation (a feature of most developing countries) increases (Matzarakis, 2001). Proper physiologic functioning of the human body is, however, obtainable only within a range of favourable weather.

Despite the increased tendency of foreseeable severe effects of climate in the tropics, and particularly in a developing country such as Nigeria; where adaptation and coping strategies of the people to climate stress have been an issue of concern, there are still many misconceptions in international reports. For example, the Intergovernmental Panel on Climate Change (IPCC)'s discussions (e.g. Githeko and Woodward, 2003; Boko et al., 2007) have demonstrated that the main direct weather-related health concerns are malaria and meningitis, and reported increase in temperatures in most part of Nigeria suggests increase in vulnerability of the population to extreme heat.

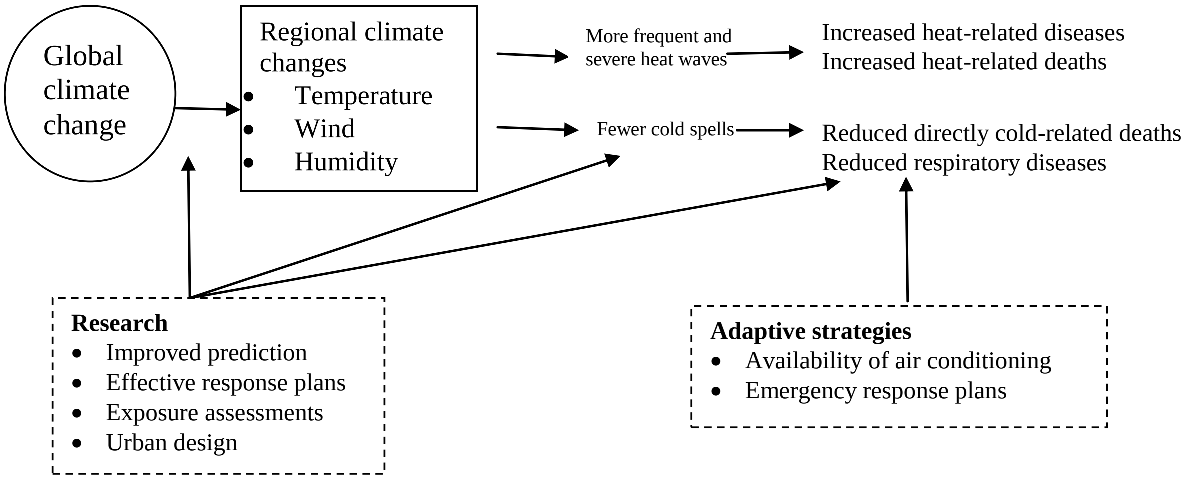

Figure 1.1. Variables associated with climate change, its health consequences and adaptation plans

(Source: McGeehin and Mirabelli, 2001)

In addition, while the Fourth Assessment Report on Europe (Alcamo et al., 2007) reported that cold mortality is a problem in mid-latitudes, with its major determinants including respiratory infections (this is rarely considered for low latitudes since they are classified as hot), studies (e.g. David-West and Cooke, 1974; Omonijo et al., 2011) have shown that some cold-related respiratory infections occur in Nigeria, and could occur irrespective of the latitudinal locations. David-West and Cooke (1974) noted that outbreaks of influenza and other respiratory infections have been diagnosed clinically in Nigeria. The yearly periodicity of its major outbreaks coincides with the onset of the harmattan season (i.e. when cold winds and dust blow south from across the Sahara desert). Although there are so far no accurate statistics on morbidity and mortality, it is generally suspected that these outbreaks claim many lives and many more people are usually unable to work.

1.2. Statement of the Problem

The research problems that are of interest to this study are essentially related to issues of vulnerability of the people to extreme weather conditions, climate variability, and population increase that cannot be supported by the available infrastructure. The first identified research problem is linked with the Fourth Assessment Reports (FAR) of the Intergovernmental Panel on Climate Change, IPCC (Solomon, 2007) which projected that most people in Africa and Asia are vulnerable to the effects of extreme climate conditions as a result of poor health and social infrastructure and poor warning systems. Studies have also shown that the understanding of the climate in relation to health and welfare of the people is relatively poor in Africa when compared to the rest of the world (Bypass, 2009). The poor understanding of the implication of climate variability for human health is known to have stemmed from paucity of investigation in physiologic climatology, and this is an important gap that this study is intended to fill.

Secondly, the increasing urbanisation in Nigeria and many other parts of Africa has resulted to explosions in urban population that are often not matched by a commensurate infrastructural change (United Nations population Fund, UNFPA, 2007; World Health Organisation, WHO, 2011). While it has been hypothesised by many studies that climate variability occurs in spatial and temporal dimensions, and that the available infrastructure for adaptation can affect the severity of the effect of climate on the affected people (Collins, 1993; Davis et al, 2004), information about the situation of the physiologic climate, which can be used to suggest the health impact situation of the climate in Africa is less known, especially at national scale (Terjung, 1967). One characteristic of large tropical countries such as Nigeria is climatic complexity and varying influence on the comfort of the humans in different locations.

A consequence of the poor understanding of the climate-human relations in Africa is a general lack of consensus in the climate zoning of many African countries, especially the large ones such as Nigeria (Garnier, 1967; Ayoade, 1978; Ileoje, 2001; Ogunsote and Prucnal-Ogunsote, 2002). While the popular approach is to consider rainfall distribution and vegetation index as a major parameter for climate zonation (e.g. Koppen, 1936, Olaniran, 1986), other scholars have considered the use of rainfall and vegetation index as limited, especially as they are not related to thermal comfort (Lee, 1953; Terjung, 1967; Kovats and Hajat, 2008). Figure 1.2a-e shows some examples of attempts to classify Nigeria into different climate regions by different scholars, probably because the delineated zone in each classification system often vary with purpose and parameters, including moisture, thermal, and ecological indices. For simplicity, this study hypothesises that the Nigerian climate regions comprises the 'Tropical Rainforest' and 'Tropical Savanna' climate zones as guided by Ayoade (2004). The Tropical Rainforest zones consist of the 'Tropical wet' (characterised by high air temperature and rainfall) and 'Tropical wet and dry' (characterised by hot climate, with distinct wet and dry seasons) (Olaniran, 1986). The Tropical Savanna, on the other hand, is divided into Guinea, Sudan and Sahel climates (Dada et al., 2008). Montane climate characterises areas with distinctly high altitudes.

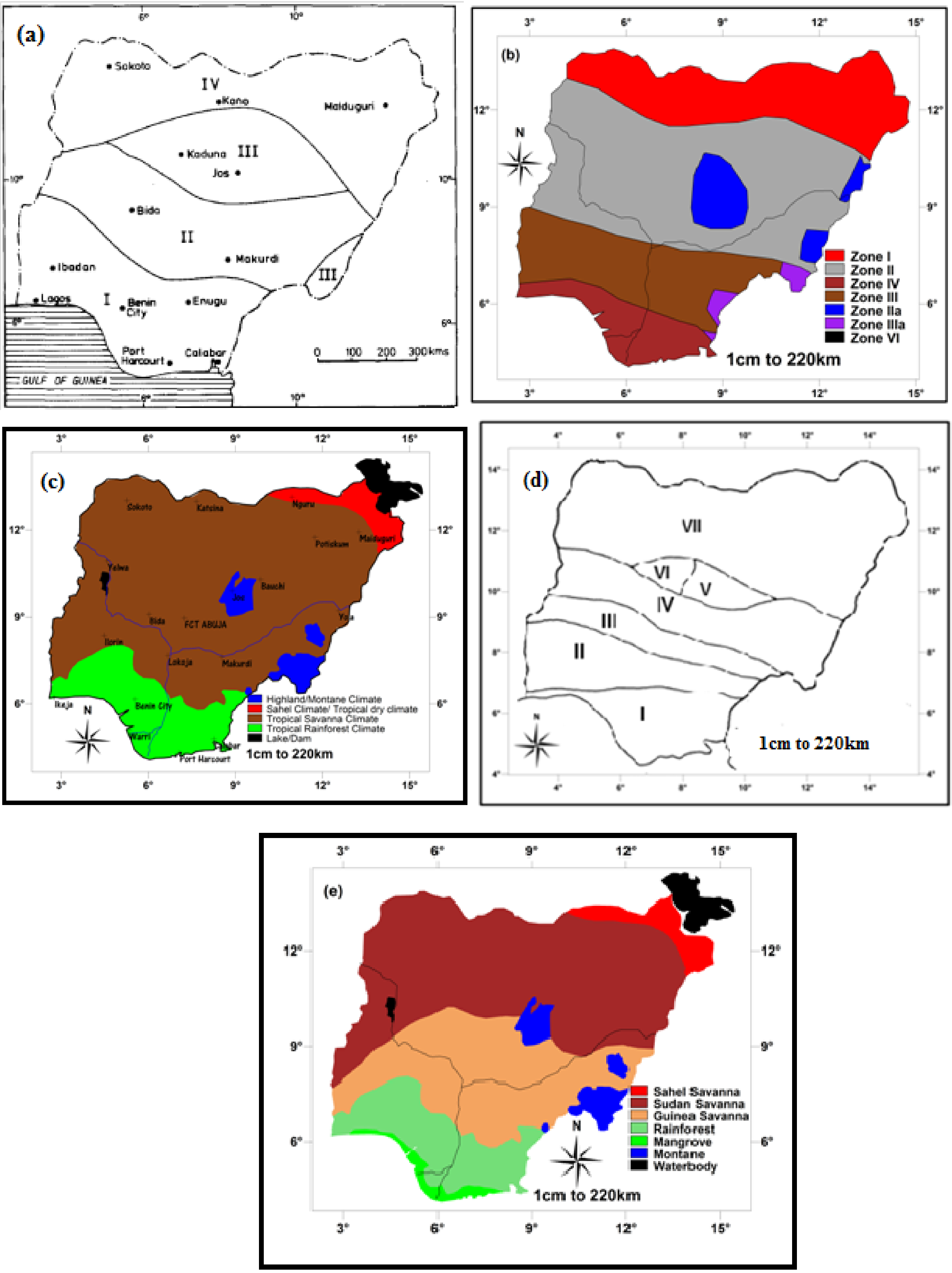

Figure 1.2: Some Climate Zoning of the Nigerian Climate from Literature (a) Ayoade (1978) derived from Effective Temperature Index (b) Generic Classification by Ileoje (2001), (c) Zoning based on Ecology (Olaniran, 1986) and (d) Zoning based on Rainfall Distribution (Olaniran, 1986) (e) Simplified Eco-Climatic Regional Classification Adopted in this Study

1.3. Aim and Objectives

The aim of this study is to examine the spatial and temporal variations in physiologic climate of Nigeria, with the view of assessing existing changes and predict future patterns.

To achieve the aim, the objectives of the study are to:

i. examine the physiologic climate over Nigeria in terms of the selected indices- Effective Temperature Index (ETI), Temperature- Humidity Index (THI) and Relative Strain Index (RSI) between 1951 and 2009;

ii. examine the temporal (hourly, monthly, seasonal, decadal, and 1951-1980 and 1981-2009 periods) variations of selected indices of physiologic comfort in (1) above;

iii. compare ETI, THI and RSI as indices of physiologic comfort in Nigeria; and

iv. examine the perception of sampled Nigerians on physiologic climates and adaptive strategies to extreme conditions.

1.4. Justification for the Study

Investigations into the spatial and temporal dynamics in the physiologic climates of a region are justified by the recent concerns for climate change, climate uncertainties and their implications to the global ecosystem, including human existence (Jauregui, 1993; Wolkoff and Kjaergaard, 2007; Lin et al., 2011; White-Newsome et al., 2011). Several scholars have sought explanations to climate variability, its implications on humans systems, and adaptation strategies in different environments (Parish and Putnam, 1977; Jauregui, 1997; Jonsson, 2004). Changes in certain elements of climate, such as temperature and humidity have been linked with increase

1cm to 220km

in mortality and hospital admissions (Ostro et al., 2011). The global temperature has also increased, especially from the 19th century and it is projected to continue to increase because of natural and anthropogenic causes (Figure 1.3, Le Treut et al.,

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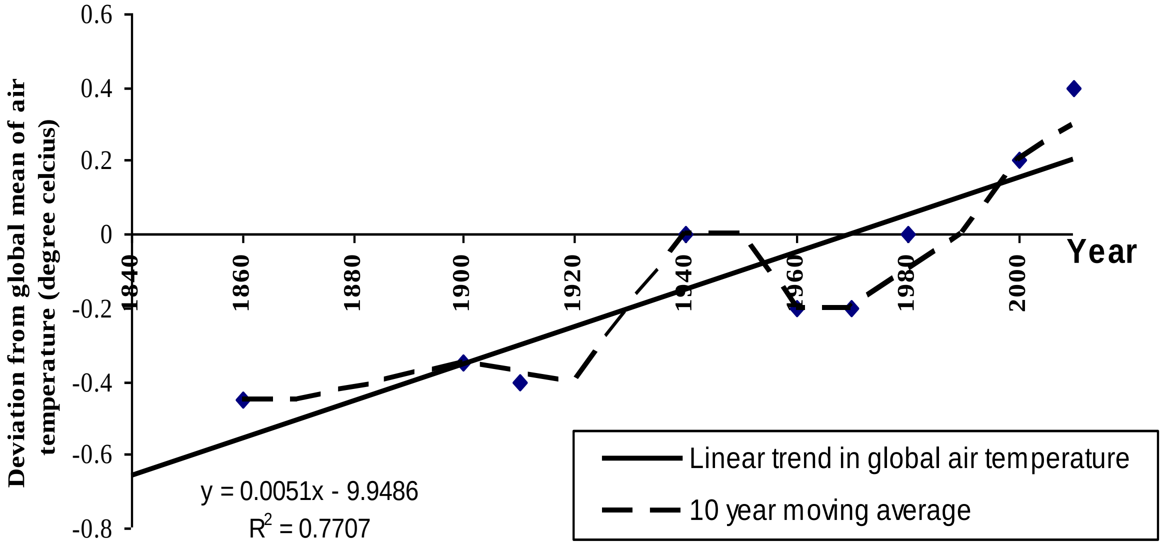


Figure 1.3. Trend of the global mean air temperature showing an increasing pattern from 1840

(Source: Le Treut et al., 2007)

The anthropogenic causes of temperature change are linked with urban growths and population increases, and the investigation of these causes have become important priority in the programme of the World Meteorological Organisation (WMO) (Jauregui, 1997). Studies such as Jonsson (2004) have also argued that the accelerated growth of urbanisation in African countries in the recent decades has led to certain environmental problems, including those related to poor health, caused by automobile pollutions, industrialisation and urbanisation, causing local climate change. The hypothesis of increasing temperature and urbanisation is important to the investigation on climate variability and change since studies have shown that temperature exhibits different patterns of relationship (U-, V- or J-shapes) with rate of deaths in different regions. Old people, children and pregnant women are also known to be vulnerable to extreme heat and cold, causing cardio-respiratory and skin diseases in many regions (Huynen et al., 2001; Curriero et al., 2002; Lin et al., 2011). Furthermore, information on spatial and temporal variations in human physiologic comfort or discomfort for any region is useful in planning for health facilities, holiday and tourism, understanding some issues in migration studies and building needs (Gregorczuk and Cena, 1961; Brager and de Dear, 1998; Matzarakis and Mayer, 2000; Ajibola, 2001; Ahmed, 2003).

1.5. Limitation of the Study

This study is limited to the scope of temporal and spatial variability of the physiologic climate in Nigeria (with regards to temperature, relative humidity as well as effective temperature, temperature-humidity and relative strain indices), for the period of 1951 to 2009. Data used for the determination of mean values were means of monthly values for 1951-2009, for 18 stations, at 2 X 2^o grids. The hourly variations in the physiologic climates in this study were also determined using the means for 5 hours (i.e. 0600, 0900, 1200, 1500 and 2100) for 1971 and 2001 because of limitations in data availability.

Despite the use of a relatively unbiased gridding system, the medium (2 X 2^o) spatial resolution chosen for this study is however a source of uncertainty in the adoption of this study at face value, for decision making. Hence, a higher resolution (more dense and well-unbiased distributed network of functioning synoptic systems) may improve further studies. The limited hourly dataset used for this study (1971 and 2001), notwithstanding will provide sufficient interpretation of the average diurnal information on physiologic climate situation of the past and present times. Comparing

1971 with 2001 is also expected to reflect cases of significant changes, if any, in the recent decade. It is also necessary to note that aggregation of the annual datasets for their means could also reflect a significant level of uncertainty.

Questionnaire administration was also limited to tertiary institution because the institutions could easily be tracked and administration organised within the available financial and time constraints. Issues of security, especially in the Northern Nigeria and Niger-Delta regions were also considered as important before the decision for tertiary institutions were made. Despite the identified uncertainties, the present study is believed to be able to make significant contributions to the study of physiologic climate in Nigeria.

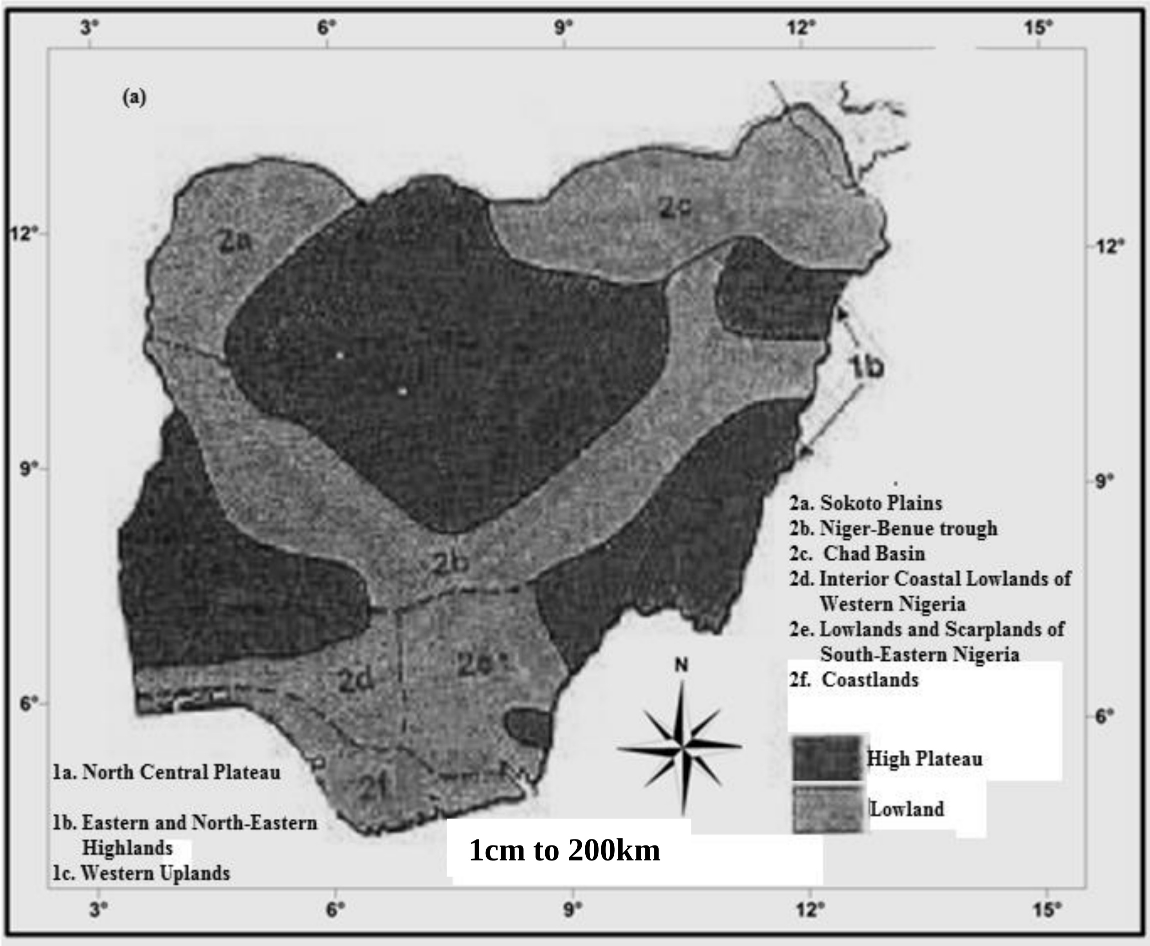
1.6. Study Area

1.6.1. Description

The study area, Nigeria, lies between 4-14^{o}N and 3-15^{o}E in the southeastern edge of the West African region. Nigerian land area is about 923 800 km^2, and is about 14% of West Africa. The country is bordered in the north, east, and west by the Francophone countries of Niger, Cameroon and Benin Republic respectively. The Atlantic Ocean forms the southern boundary with the total length of about 850 km.

1.6.2. Relief

Relief is one of the factors that affect the climate of an area; hence it is discussed in relevance to the present study. The relief of Nigeria can be generally divided into two groups; the high plateau; and the lowlands (Iloeje, 2001; Aregheore, 2009). The Niger-Benue river system cut across the highland to form three blocks, i.e. the central Plateau in the north; the Eastern and North-Eastern highlands in the east; and the western Uplands in the west (Figure 1.4a). The highlands correspond roughly with the areas of volcanic rocks and uplifted areas of basement complex rocks, and are therefore initially high and resistant. The high plateau consists of the north-central plateau, eastern and northeast highlands and western uplands (Figure 1.4a). The north-central plateau occupies the centre of northern Nigeria and covers nearly one-fifth of the area of the country. The plateau is made up of two distinct platforms that lie at different levels, including the high plains of the northern region with approximate elevation of 750 m; and the Jos plateau, which varies from 1500 to 1800 m. It is on this plateau that the synoptic station representing the montane climate is located.



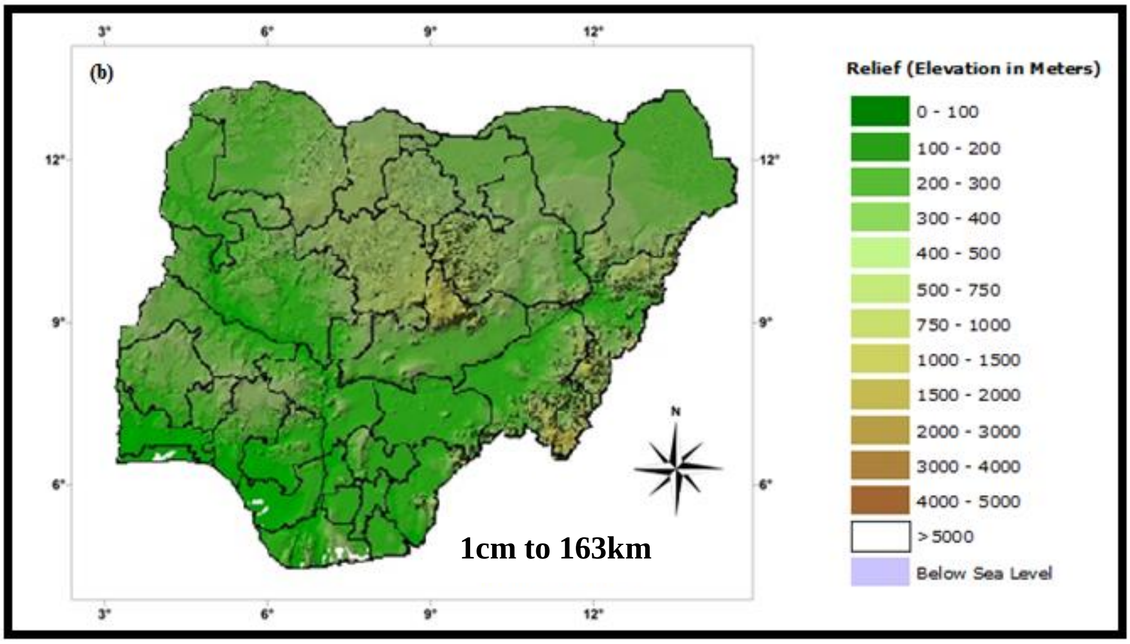


Figure 1.4: Relief of Nigeria. (a) Distribution of Highlands and Lowlands, and (b) General Description of the Topography

The eastern and north-eastern highlands comprise the Mandara Mountains (1200-1500 m) and the Biu Plateau (600-900 m) that are of complex exposure and basaltic nature, respectively. The range of eastern highlands also include Obudu Plateau (about 1200 m) and Oban Hills (1200 m), which are described as granitic spurs of western prolongations of the Cameroon mountains into the Cross River plain in Nigeria (Ileoje, 2001). In addition, the Western uplands comprise a distinctly high Idanre hills (1000m) and the rest region which varies from 300 to 600 m, above sea level.

On the other hand, lowlands occur in the basins of the major rivers (Rivers Niger and Benue), within the areas of sedimentary rocks, and include the Sokoto plains, River-Niger-Benue trough, Chad Basin, coastal lowlands and south-eastern scarp lands and lowlands (Figure 1.4b). Sokoto plains occur in the north-west, with an average altitude of 150 m, and drain some major streams, including the Sokoto, Rima and Zamfara rivers. Many areas in the Sokoto plains are cultivated by irrigation caused by the seasonal flood event, supporting 'Fadama' agricultural practices. In addition, Niger-Benue trough, which lies below 300m, exists around the north-central plateau, and it extends from the Sokoto plains through Lokoja, and towards the north-east. At the north-east of the extension of the Niger-Benue trough is the Chad Basin, with an average elevation of about 45-60 m. Towards the south of the Niger-Benue trough is the interior coastal lowlands whose boundary is marked in the north by the ridge of the basement complex of the western uplands, and in the south by quaternary deposits of the coastal margin. The altitude is below 300m and highly dissected by draining streams.

In the south eastern Nigeria are lowlands and scarps from sedimentary materials such as sandstones, shales, clays and coal. They include the Cross River plains, Enugu scarp lands and the south-east coastal plains. In the coastal region are coastal margins and swamps, which exist adjacent to the seas, from eastern coast to west in a strip of land below 30 m. They include the lagoon coast, in the west, Niger delta, and stretch of the south-south to the eastern coastlines.

1.6.3. Climate

Considering the latitudes, Nigeria (4-14^{o}N) is in the Tropics ($23\frac{1}{2}^{0}$N-$23\frac{1}{2}^{0}$S). The country is therefore characterised by two main seasons; dry and rainy seasons. The dry season is accompanied by a dust laden wind from the Sahara desert, known as harmattan, which is brought by the Tropical Continental (cT) air mass, while the rainy season is heavily influenced by the Tropical Maritime (mT) air mass from the Atlantic Ocean (Figure 1.5). The front between these air masses is known as the Inter-Tropical Front (ITF) (Miller, 1952), Inter Tropical Convergence Zone (ITCZ) (Barry and Chorley, 1992) or the Inter Tropical Discontinuity (ITD) (Church, 1968).

1.6.3.1. Rainy or Wet Season

The principal rain-producing conditions include orographic; which occurs (a) where the coast is crossed most obliquely, (b) on the edge of the Eastern highlands, (c) on the southwest side of the Jos plateau and to a lesser extent on the slopes up to it from the River Niger, and (d) around Biu plateau, and a corresponding rain-shadow effect in Borno and possibly in the Benue valley (Miller, 1952). The rainy season causes the weather to 'cool' as a result of an increased cloud cover that acts as a blockage to the intense sunshine of the tropics by blocking much of the sun's rays. This consequently brings a cooling effect though afternoons could be hot and humid as it is characteristically a feature of tropical climates.

Adelekan (1998) classified Nigeria, based on the distribution of thunderstorm rainfall into (a) coastal region, with double maxima in May/June and October, i.e. Region I, (b) transition zone in the middle belt zone, with single maximum of rainfall at certain locations, and double maxima at the other, i.e. Region II, and (c) regions with single maximum at other months of the year, i.e. August (Region III), July/August/September (Region IV-VI) (Figure 1.6a). Other forms are squall line rainfall and ordinary monsoon rainfall due to large scale convergence (Adelekan, 1998). In addition, Acheampong (1990) showed from 1941-1980 data that the annual rainfall decreased from the south east towards the west and the north (Figure 1.6b). The areas of high annual rainfall overlap the hilly and mountainous regions as well as the south east lowland areas while the driest parts are the extreme north and north east.

1.6.3.2. Dry Season

According to Adefolalu (1985), the dry season occurs between November and March (i.e. November, December, January, February and March). This period is generally drier (in terms of precipitation amounts) in Nigeria. It is the period when the sub-tropical anticyclone of the northern hemisphere attains its maximum intensity and the harmattan dominates flow in the lowest layers.

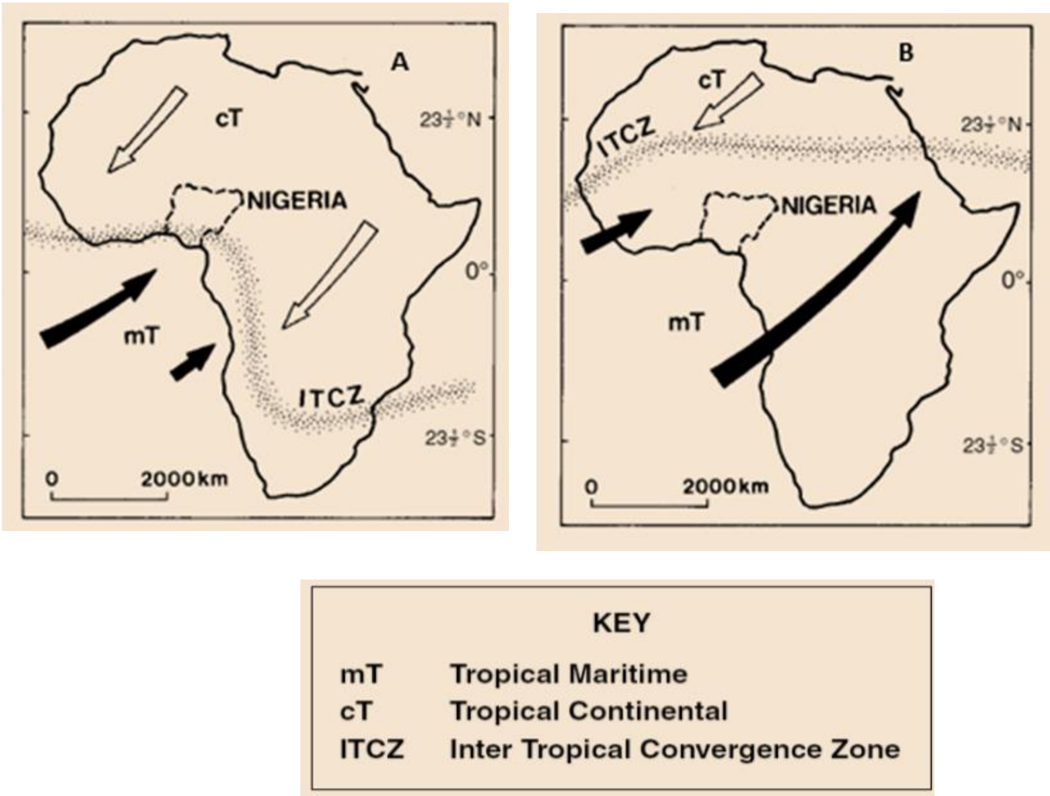


Figure 1.5: Direction and Movement of Air Masses and the ITCZ across Africa, in Dry (A) and Rainy (B) Seasons

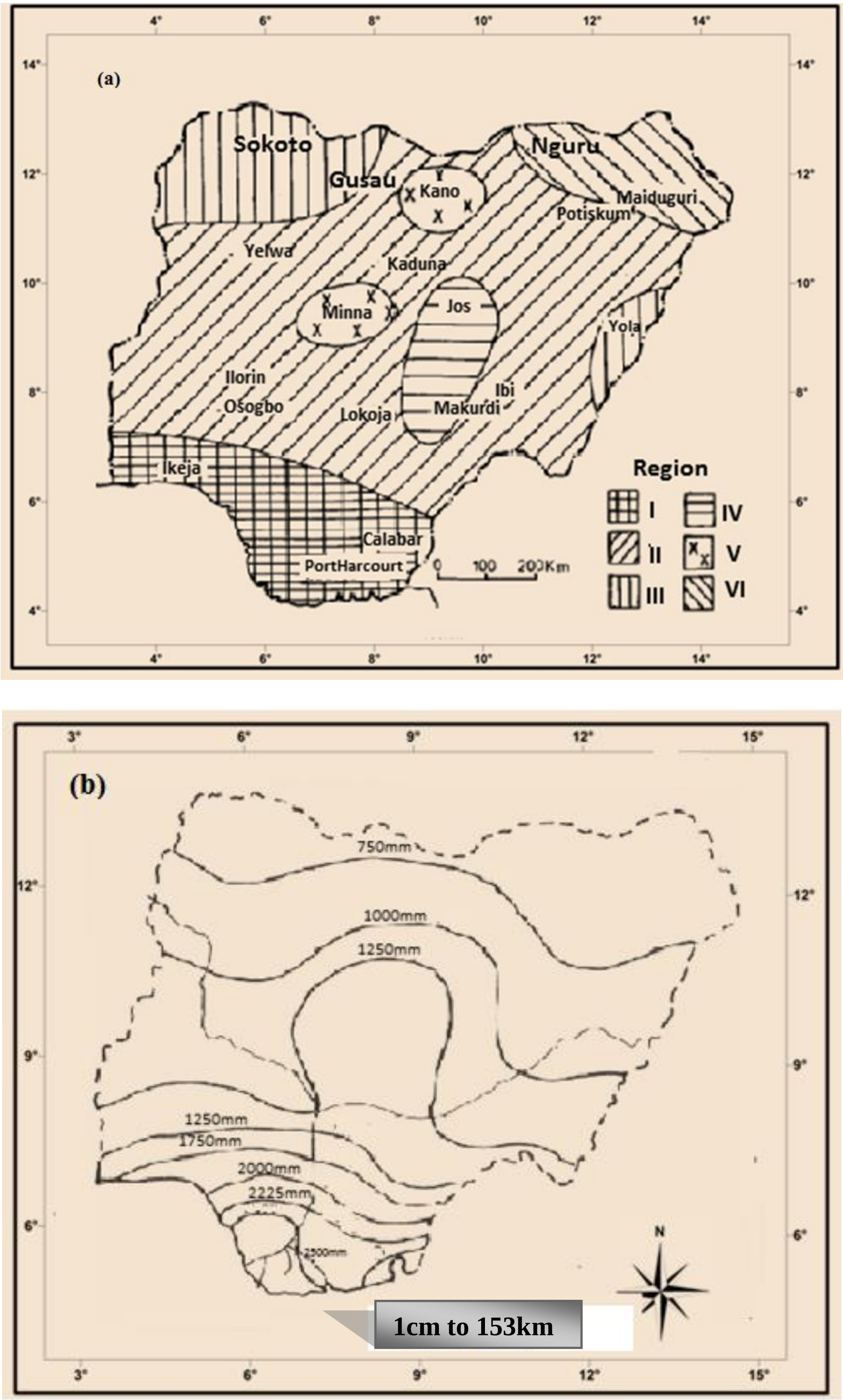


Figure 1.6: Rainfall Distribution in Nigeria – (a) Regional Classification of Rainfall by Acheampong (1990) and (b) Classification of Mean Annual Rainfall Distribution by Adelekan (1998).

The dry season is also a period of little cloud cover in the southern part of Nigeria, and virtually no cloud cover in the northern part of Nigeria. The sun shines through the atmosphere with little obstructions from the clear skies making the dry season in Nigeria a period of warm weather conditions. During these five months, the ITCZ is very close to the coast of Nigeria. In February, when it reaches its most southern position, it is located at about 6°N. During these months, parts of Nigeria around 7-14^0N is primarily dust-laden harmattan zone while the rest of the country below the latitudes is dominated by a mixture of the characteristic harmattan and early morning fog or mist. The movement of the harmattan dusts is shown in Figure 1.7.

1.6.3.3. Harmattan

The harmattan is often described as the redeeming feature in the climate of Nigeria, and West Africa (Miller, 1952). In the middle of the dry season around December, a dusty wind from the Sahara desert, ‘the harmattan’, prevails, blocking sun rays partially from shining and also creating haze in the atmosphere. This effect of the wind lowers temperatures considerably saving inhabitants for some time, from the scorching heat that would have occurred as a result of clearer skies during the dry season. But with the withdrawal of this wind around February to March following the onset of the rainy season, temperatures can go as high as 44 °C in some parts of Nigeria (Miller, 1952; Adefolalu, 1984). It brings cool nights but the air can often feel just as cool in rainy weather. It is also characterised by excessively low humidity, which is often described as uncomfortable (Miller, 1952; Adefolalu, 1984); first attacking the mucus of the nose and throat and in some people may cause a catarrh which usually persists ‘until the air recovers its humidity’ (Miller, 1952). In addition, Miller (1952) reported that the load of dust associated with the harmattan causes filthiness, as well as dull and oppressive atmospheric condition. A heavy season of harmattan was also characterised with outbreak of cerebro-spinal meningitis which kills and maims thousands of young people.

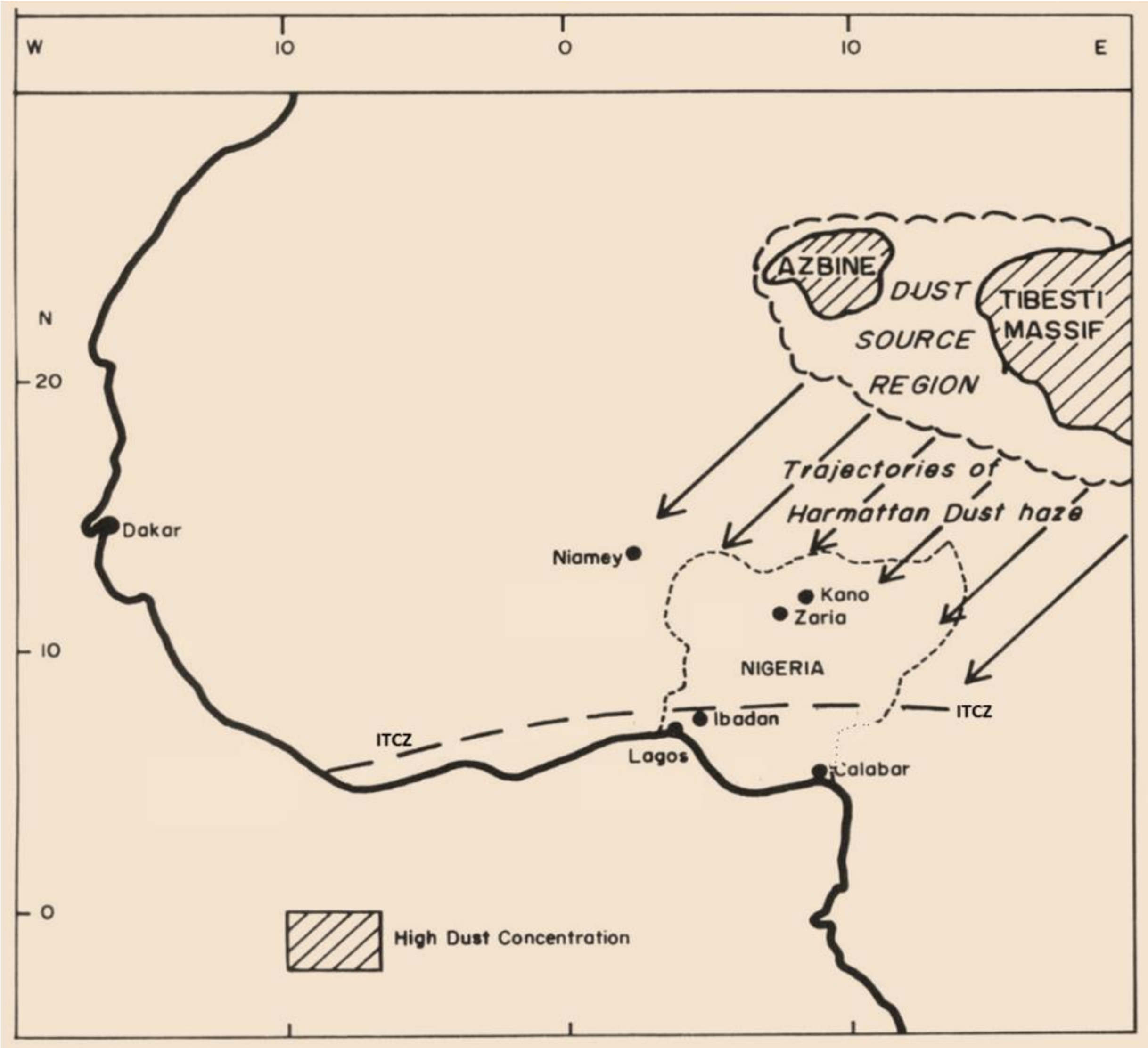


Figure 1.7: Dry Season Condition in Nigeria (Source: Adefolalu, 1985)

1.6.4. Climate Types in Nigeria

Nigeria is affected by three main climate types (Garnier, 1967; Koppen, 1936):

1.6.4.1. The tropical rainforest climate

This climate type is designated by the Köppen climate classification as 'Af', occurs in the southern part. This climate is influenced by mT airmass. Its warmth and high humidity gives it a strong tendency to ascend and produce copious rainfall, which is a result of the condensation of water vapour in the rapidly rising air. The Tropical rainforest is sub-grouped into the tropical wet and tropical wet and dry climates as mapped by Dada et al. (2008).

The tropical rainforest climate exhibits a very small temperature range, which are almost constant throughout the year and also experiences heavy and abundant rainfall. These storms are usually convectional in nature due to the regions proximity to the equatorial belt. The annual rainfall received in this region is very high, usually above the 2000 mm rainfall totals. Over 4000 mm of rainfall is received in the coastal region of Nigeria around the Niger delta area. The rest of the southeast receives between 2000 and 3000 mm of rain per year. The southern region of Nigeria experiences a double rainfall maxima characterised by two high rainfall peaks, with a short dry season and a longer dry season falling between and after each peaks. The first rainy season begins around March and last to the end of July with a peak in June, this rainy season is followed by a short dry 'August break' which is a short dry season lasting for two to three weeks in August. This break is shortened by the short rainy season starting around early September and lasting to mid October with a peak period at the end of September. The ending of the short rainy season in October is followed by long dry season. This period starts from late October and lasts till early March with peak dry conditions between early December and late February.

1.6.4.2. The tropical savanna climate

This consists of the guinea, sudan and sahel savanna which covers most of the central and northern Nigeria. Beginning from the Tropical rainforest climate boundary in southern Nigeria to the central part of Nigeria is the guinea savanna while the Northern fringes of Nigeria experiences the sudan savanna climate. The north-eastern fringes exhibit the sahel climate. The tropical savanna climate exhibits a well-marked rainy season and a dry season with a single peak. Temperatures are above 18 °C throughout the year. Abuja, Nigeria's capital city found in central Nigeria, has a temperature varying from 18.5 to 36.1 °C, and an annual rainfall of about 1500 mm with a single rainfall maximum in September. The single dry season experienced in this climate, spanning from December to March, is hot and dry with the harmattan wind, prevailing throughout this period.

With the Inter Tropical Convergence Zone (ITCZ) swinging northward over West Africa from the southern hemisphere in April, heavy showers coming from pre-monsoonal convective clouds mainly in the form of squall lines are formed mainly as a result of the interactions of the two dominant air masses. This situation begins in central Nigeria with the arrival of the mT air mass in July, bringing with it humidity, heavy cloud cover and heavy rainfall, till September when the monsoons gradually begin retreating southward. Rainfall totals in central Nigeria vary from 1100 mm in the lowlands of the river Niger Benue trough to more than 2000 mm along the south western escarpment of the Jos Plateau and the southern Kaduna highlands which extends into Abuja, due to orographic activities in central Nigeria. The Sahel savanna climate is the predominant climate type in north-eastern Nigeria. Annual rainfall totals are less than the southern and central parts. The rainy season in the northern part of Nigeria lasts for only 3 to 4 months (June-September). The rest of the year is hot and dry with temperatures climbing as high as 40 °C.

1.6.4.3. Highland or montane climate

This climate type occurs on highlands regions in Nigeria. Due to their location in the tropics, settlements on very high altitude (above 1200m) could observe the cool montane climate, even in the tropics (Ileoje, 2001). This is the climate that has been adjudged to exhibit the highest level of physiologic comfort in Nigeria (Ayoade, 1978; Ajibola, 2001), and elsewhere (e.g. Emmanuel, 2005). Temperature in high altitude is known to reduce by 1 ^{o}C for every increase 164 m or 0.6^{o}C for 100 m, otherwise known also as the Environmental Lapse Rate (Strahler and Strahler, 1994).

1.6.5. Population and Land Use

With a population of more than 140 million spread over an area of 924 square kilometres (National Population Commission, 2006), Nigeria is one of the most populated countries in the world. High population densities (greater than 1000 people per square kilometre) exist in all the 36 States’ administrative cities, and Abuja, the

Federal Capital Territory. There are also high population densities in the northern Nigerian cities, including Sokoto and Nguru that participated vigorously in the worldwide commercial activities in the medieval period, and pre-colonial towns, such as Iwo and Ogbomoso in the Southwest (Onakerhoraye and Omuta, 1994). Many of the cities which were classified to exist within the medium population densities (500-1000 people per kilometre), especially in the middle belt, the Niger delta region, the Chad basin and the Cross River region, where some physical barriers such as mountains and rivers are previously known to prevent structural and population growth are in the recent times also witnessing increasing population growth, especially as urbanisation spreads to the hitherto rural regions. In general, except few towns which have been engulfed in severe inter-communal crisis, there have been general population and urbanisation increase in Nigeria.

Table 1.1 shows some details about Nigeria which indicate significant urbanisation issues. For example, Table 1.1 shows an imbalance rate of deforestation and reforestation, about 3990 sq km of excess rate of deforestation, increasing population density (about 30 persons per sq. km in 5 years), increasing urban population and high carbon emissions. Adebayo (1982) suggested that although there is no such clear-cut towards a single land use system, landuse in Nigeria can be correlated with the major ecological and climate zones. Climate zones in Nigeria are grouped into humid forest region (in the South), sub-humid Sudan savanna belt (in the North), and the Guinea savanna zone in the middle belt. Within each of these broad zones, landcover varies with land use, including commercial, industrial, residential, agricultural, recreational, and wastelands (such as landfills). Increased population growth, urbanisation and fuel emission are significant causes of thermal stress (Tukur et al., 2005), and these are of importance in Nigeria (Table 1.1).

Table 1.1: Some Urbanisation Variables about Nigeria

Variables	Specifics	Rate
Landuse	Deforestation	4000 sq. km per year
	Reforestation	10 sq. km per year
	Forested area (2008)	10.8%
Urban Population	Annual growth	3.8%
	Urban Population in 2004, 2010	45%, 48.9%
Rural Population	Annual growth	1.8%
Total population	Population density in 2004, 2009	137.6, 167.5 persons per km
	Annual growth	2.5%
Total fossil fuels emission	1951	460’000 metric tons
	1980	18,586’000 metric tons
	2008	26113’000 metric tons

Sources: 2011World Statistics Pocketbook Country Profile: Nigeria; National CO_2 Emission from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751-2008

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1. Introduction

De Freitas (2003), among others, argued that human response to climate is largely a matter of an individual's perception and sensitivity; while some climatic variables were considered entirely physical (environmental), some are either physiologic or aesthetic. The concept of man-climate relations has assumed a central issue of discourse in geography. This section therefore reviews relevant framework and literature in physiologic climatology. The advantages provided by modern technologies to monitor changes for sustainable development are also highlighted.

2.2. Conceptual Framework

2.2.1. Man-Climate Relationship

Man-climate relationship is reciprocal. The realisation of this fact has become imperative that several attempts have been made to understand climate in order to ensure the sustenance of the earth (Jendritzky et al., 2001; Ahmed, 2003; Bernardi, 2008). Thermal comfort has been the subject of study since the start of 20^{th} century, when improvements of building techniques and introduction of central heating and air conditioning systems led to the consideration of improving comfort conditions in indoor environment (Collins, 1993; Brager and de Dear, 1998). A number of comfort indices and mathematical models to predict thermal comfort and discomfort were subsequently developed (Gómez et al., 2004; Watkinson et al., 2004). For indoor conditions, most studies, described the efficiency of a person or group of people as being bound up in the climatic conditions in which they work and live (e.g. Huntington, 2008). Han et al. (2007) argued that buildings are designed to suit the climate within which they are located and the functions for which they are intended. One of the models which link human comfort with the atmospheric condition is the Multinode Comfort Model (MCM). A version of the MCM is the Stolwijk model of human thermal regulation, while another is that of University of California, Berkley

Multinode Comfort Model (Rees et al., 2008). These models explain that the body is divided into 19 elements consisting of multiple tissue layers, and each element of the body is subdivided into multiple sectors, e.g. the upper leg is divided into interior, anterior, exterior and posterior sectors and the body as a whole has many of such sectors (Figure 2.1). An application of the MCM was demonstrated in the prediction of the effects of transient and spatially asymmetric conditions in the whole-body as evaluating the thermal comfort in spaces with asymmetric or transient thermal environments; indoor or outdoor.

According to Jendritzky et al. (2001), human-biometeorology deals with the effects of the atmospheric environment on the human organism. Matzarakis (2001) noted the thermal effective complex as one of the main human-climate indices. Thermal effective complex comprises the meteorological factors including air humidity, air temperature, wind velocity, short and long-wave radiation that thermo-physically affect humans in indoor and outdoor climate. It is primarily concerned with the quantitative assessment of heat stress caused by intense solar radiation and high air temperatures and cold stress caused by low air temperatures and high wind velocity. Studies however showed that the thermo-physically relevant assessment of complex atmospheric conditions on the heat transfer of human beings may not be sufficiently described by singular treatment or consideration of heat elements (e.g. Jauregui, 1997; Matzarakis and Alcoforado, 2007), hence the development of more integrative indices, including the Effective Temperature Index (ETI), Temperature-Humidity Index (THI) and Relative Strain Index (RSI), among others (Figure 2.2).

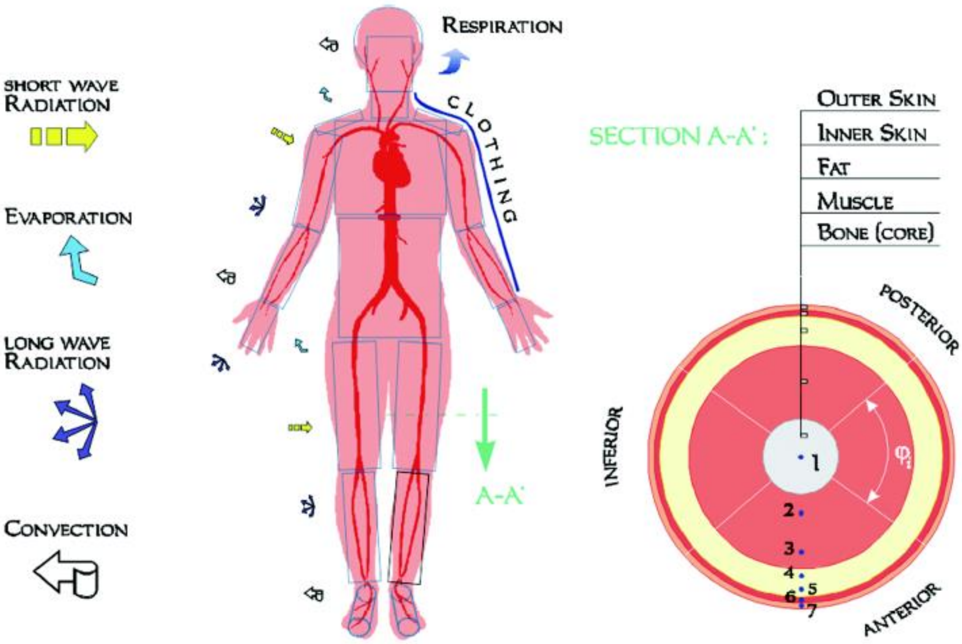


Figure 2.1: A Conceptual Representation of the Comfort Elements based on Multinode Thermo-physiological Model
(Source: Rees et al., 2008)

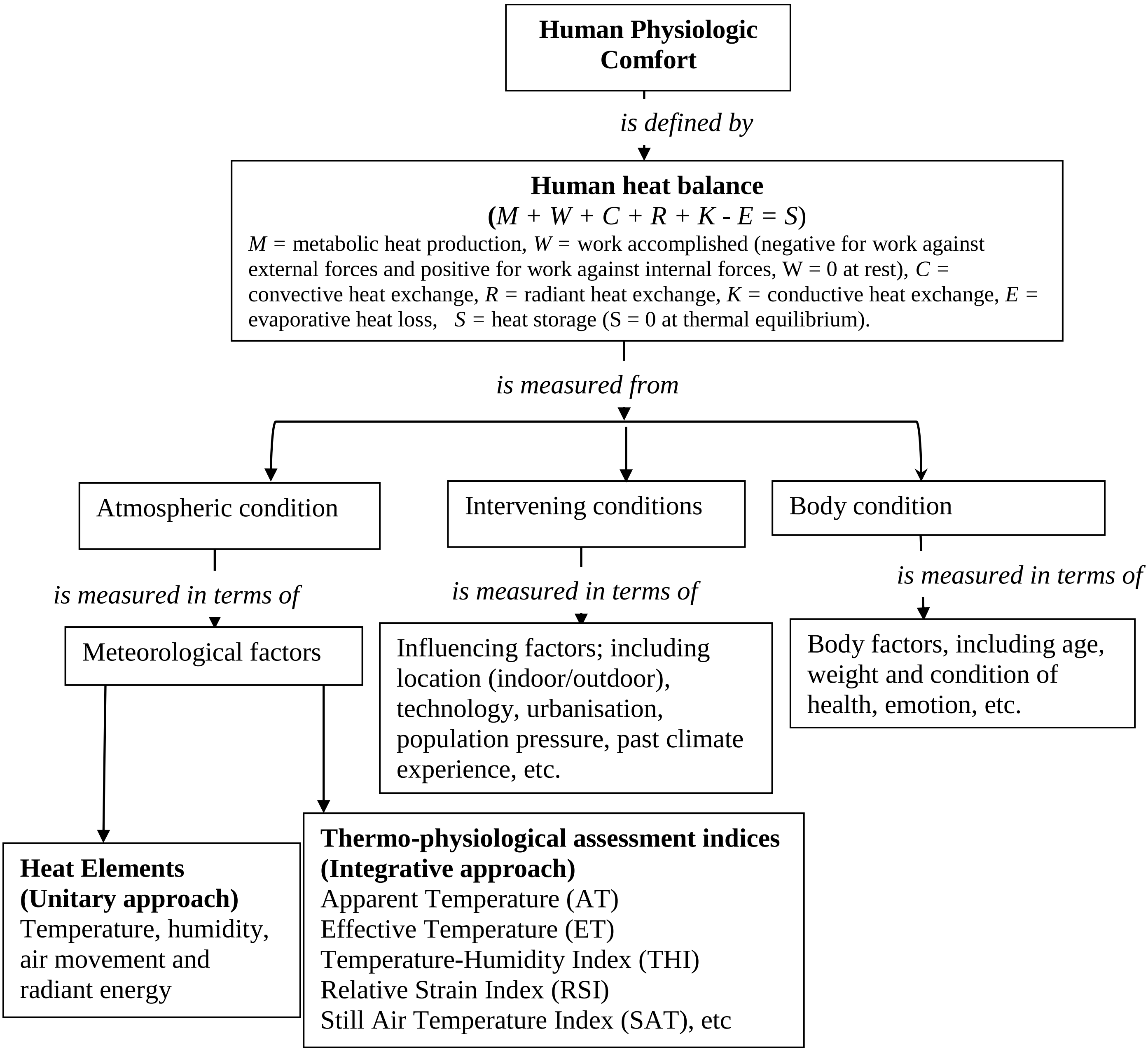


Figure 2.2: Conceptualisation of Physiologic Climate Study from the Synopsis of Past Studies

2.2.2. The Concept of Physiologic Comfort

The term 'comfort' describes a feeling of contentment, a sense of cosiness, or a state of physical and mental well-being (Chappells and Shove, 2004). Comfort is associated with human health defined in terms of a total sense of physical, mental and social well-being. Morgan and Baskett (1974) described physiologic comfort as the state of pleasantness defined by the degree of relationship between skin temperature and wetness and the degree of magnitude of each term of the energy balance of man under a given set of conditions. The interest in 'comfort' is inspired by concerns over climate change, which has been aided by activities that aim at improving comfort. For example, Cooper (1982) argued that creating habitable spaces has become synonymous with the consumption of fossil fuels, partly as a result of the drive for optimal indoor conditions. Kalnay and Cai (2003) examined the possible impact of climate change on comfort conditions under various land use managements. One of the concerns raised is that rising temperatures and more humid environments will increase the risk of air-borne infection. Studies of extreme events, like heat waves, also highlight some of the health implications and social and technical adjustments that might be required to cope with climate change and suggest that changes at the institutional and infrastructural level will be required (Klinenberg, 1999; Bernard and McGeehin, 2004; Kovats and Kristie, 2006; Kovats and Hajat, 2008).

Some studies examining the meanings and perceptions of thermal comfort in various cultures and climates have also disputed conventional methods for measuring and recording thermal comfort. It is argued that people of different cultures consider themselves comfortable across a wide range of temperatures. Nicol and Roaf (1996) and Nicol et al. (1999) found Pakistani office workers comfortable at about 31^{o}C, and that preferred indoor temperatures varied with climate and season. Office workers in Thailand were also found to be comfortable at higher indoor temperatures than those working in more temperate regions (Busch 1992).

Studies (e.g. Brager and de Dear, 2000; de Dear and Brager, 2002; Laschewski and Jendritzky, 2002) have shown that universal methods for measuring and calculating comfort are inadequate because they fail to account for cultural or climatic variation in peoples' interpretations of comfort. Gunn and Adams (1981) showed significant variations in cultural expectations and climates of respondents living in artificially and naturally ventilated buildings. de Dear and Brager (1998) also reported significant differences in benchmarks of comfort between those in air-conditioned and passively ventilated buildings. They argued that people with no experience of air-conditioned offices preferred passively ventilated environments even in a hot condition.

2.2.3. The Concepts of Stress and Thermal Equilibrium

Heat stress is the aggregate of total heat factors, both internal and external, upon the body (Lahey, 1984). Internal factors include metabolic heat, degree of acclimatization, and body temperature while external factors are air temperature, radiant heat, air velocity and humidity. Heat stress is, therefore, the overall effect of excessively high temperature that disturbs the body's thermal comfort. On the other hand, cold stress (cold-related injury and illness) occurs as a result of the condition marked by abnormally low, internal body temperature which develops when the body loses heat faster than it produces it. For steady exposure to cold and warm environments, thermal comfort and neutral temperature sensations lie in the range for physiologic thermal neutrality (28°-30°C), in which there is no physiologic temperature regulatory effort. Discomfort increases more rapidly below 28°C than above 30°C, while thermal sensation for both heat and cold increases rapidly on each side of the neutral. Discomfort correlates best with lowering average skin temperature towards cold environments and with increased sweating towards hot environments. In general, discomfort is associated with a change of average body temperature from 36.5°C. The same conclusion follows for transient changes when the subject goes from comfortable to uncomfortable, neutral to cold, and neutral to warm. However, cold stress would actually occur in cold environment just as heat stress would occur in hot environment. If a body cannot maintain thermal equilibrium, the amount of heat gained by the metabolism cannot offset the amount of heat lost from the body to the environment. If the equilibrium of the body's core temperature is maintained, heat or cold stress will not accumulate. However, the body seldom maintains a precise thermal equilibrium. Heat exchanges between the body and its environment can be represented by the heat balance equation

$$M + W + C + R + K - E = S \qquad 2.1$$

Where

M = metabolic heat production

W = work accomplished (negative for work against external forces and positive for work against internal forces, W = 0 at rest)
C = convective heat exchange
R = radiant heat exchange
K = conductive heat exchange
E = evaporative heat loss
S = heat storage (S = 0 at thermal equilibrium).

The ability of a person to tolerate short heat pulses at temperatures above 5^{o}C depends on other factors. If a significant radiant-heat load is present, pain and burning of the skin can prevent a person from working in heat that he or she could theoretically tolerate on the basis of the heat balance equation. Radiant energy burns can result from exposure to ambient temperatures that raise the skin temperature to 45^{o}C. Lind (1963) indicated noteworthy differences of great significance in man's ability to maintain thermal balance despite widely varying environmental conditions, including (a) the continuous and variable production of heat from the biochemical processes involved in metabolic activity; and (b) physiologically, the body can react dynamically through the cardiovascular and sweating mechanism to changes in the overall heat load, modifying the rate of heat transfer from the body's core tissues to its peripheral tissues while altering the physical state of the skin's surface and directly affecting the amount of heat exchanged through the various channels. The regulation of heat balance is however considered complex and difficult to understand (Benzinger, 1969; Havenith, 2005).

2.3. Literature Review

2.3.1. Approaches to Indexing Physiologic Climate

Generally, two classes of approaches have been identified with the field of physiologic climatology; unitary and integrative. The first approach, according to Lee (1953), is relevant as long as heat is considered a material substance that could be represented by temperature alone. This concept was however challenged by the observations that ‘heat elements’ in climate comprises temperature, humidity, air movement and radiant energy, hence the integrative approach (Mayer and Höppe, 1987; de Dear and Fountain, 1994; Gan, 1994; Wong and Khoo, 2003). Studies (e.g. Unger, 1999; Smoyer et al., 2000) have suggested that the integrative indices may provide more realistic description of the human physiologic climate than the unitary approach. Terjung (1966) developed two integrative indices for defining physiologic climate for any area: the comfort index (CI, an integration of dry bulb temperature and relative humidity) and wind effect index (WEI, a combination of solar radiation and wind chill). WEI was considered to be complementary to CI in conditions of little or no wind effect. Using the WEI and CI, Terjung (1967) zoned Nigeria within the 'extremely hot', 'hot', and 'sultry' weather conditions. In Nigeria, and some other countries where problems with environmental data still persist, application of WEI is limited by general poor or inadequate data, especially on wind chill and radiation (see also Ayoade, 1978).

Studies in the tropics have adopted different indices all of which have been noted to operate within the integrative context. One of the most adopted for the tropical region is the Effective Temperature Index (ETI). The ETI is considered the most widely used index for assessing the effect of climate on man. Computation of ETI has possibly originated from the Missernard (1933) hypothetical formula which subsequent studies (e.g. Ayoade, 1978; Olaniran, 1982; Ogbonna and Harris, 2008) have revised or updated for bioclimate studies in Nigeria, depending on available temperature and humidity data. Ayoade (1978) has classified the country based on the effective temperature index into the Southern, Middle Belt, Plateau/Kaduna and Northern zones, and revealed that temporal variations occur in the pattern. Effective temperature index has also been described to be comparable to the Temperature-Humidity Index (THI) (Olaniran, 1982).

2.3.2. Characteristics of Studies on Physiologic Comfort

Although much research has dealt with comfort climates of the middle latitudes, far fewer studies have been reported for the tropical latitudes (Terjung, 1967; Emmanuel, 2003; Emmanuel, 2005; Johansson and Emmanuel, 2006; Nonomura and Kitahara, 2009). Lee (1953) noted that the disparity in the number and approach of studies in comfort climatology may have accounted for the more accessible 'medical judgment' of a medical biased researcher or the 'empathy' of a sociologist than studies with spatio-temporal approach of a geographer. Moreover, results of the studies are not easy to generalize because of the climate differences (Analitis et al., 2008). Even within the tropics, the effect of physiologic comfort could vary significantly among the races based on diet, social customs, psychological attitudes and coping strategies. For instance, Taylor (2006) argued that a tropical man could sweat more rapidly and have a higher body temperatures than his temperate counterpart; but lower heart rates. Comfort climatology was also conceptualized as changing with the process and intensity of urbanization in contrast to its rural surrounding (Matzarakis, 2001; Emmanuel, 2005). The modification to a city's climate in contrast to its rural surrounding, otherwise known as the Urban Heat Island (UHI) suggests greater discomfort among urban dwellers than the rural dwellers as a result of temperature rise (Watkins et al., 2007). Early studies (Terjung, 1966; Terjung, 1967) have considered two major indices, namely the ETI and Wind Effect Indices (WEI). Further studies have also shown integrative indices that are applicable to the study of comfort climatology in the tropics. Table 2.1 highlights some examples of studies on physiologic climate and popular indices used for its assessment in different climate regions. Dimensions of existing studies related to physiologic climate range vary with the scope of scales, ranging from the small, office, town or city to region or country. Results of these studies are related to design of office or house units (e.g. Aggelakoudis and Athanasious, 2005) or development of regional or national warning systems as in the case of the Southern Ontario (e.g. Smoyer et al., 2000). Table 2.1 also reveals the adoption of effective temperature index (ETI), temperature-humidity index (THI) and relative strain index (RSI) in most studies in the tropics, and Nigeria in particular.

Table 2.1: Examples of Previous Studies on Physiologic Climate (Literature Review, 2012)

Scope	Indices/ variables	Comment	Reference
Office occupants in the University of Patras, Greece	PMV-PPD	The index option (PMV-PPD) involved administration of questionnaire to determine the degree of sensation of some samples of people. This was correlated with the temporal analysis of temperature of the day. The study concluded that it is difficult to design offices that could satisfy all people.	Aggelakoudis and Athanasiou (2005)
Europe	Temperature, heat waves	Heat waves of the summer 2003 bore a phenomological resemblance to model predicted summers of the late 21st century. The temporal phenomenon of heat wave was detected by considering the temperature extreme. The analysis of this was based purely on temperature data	Zaitchik et al. (2006)
St Louis, Missouri, USA	Apparent Temperature Index (ATI)	AT was calculated from the Steadman (1979)'s equation and correlated with the mortality figures of the study period. The relationship was found to be significant. The approach of the study used both temperature data and records of mortality	Smoyer (1998); Rainham and Smoyer-Tomic (2003)
Southern Ontario	Apparent Temperature	The approach of this study is same with Smoyer (1998), howbeit with difference in study area. The target of these two studies, and some others, is to develop a combination of watch or warming systems and focused policies for the monitoring of heat related problems in the States.	Smoyer et al. (2000)
USA	Temperature variables (day and night time temperatures)	Temporal patterns of violence were compared to the pattern of the period with temperature extremes. The study showed that hormonal discharge is a function of body temperature. For this study, temperature data were analysed and compared with crime records of the study area.	Simister and Cooper (2005)
Sweden	Predicted Mean Vote (PMV)	Temperatures at the skin surface are perceived independent of environmental condition. More studies are required to reveal the complex interaction of perception and heat exchange	Holmér (2004)
Bulgaria Black Seaside	THI, PET and PMV	THI was used to estimate the combined influence of air temperature and humidity on human sensation for comfort	Iordache and Cebuc (2009)
General application	Temperature-Humidity Index (THI)	Remote Sensing and GIS application to analysis and prediction of THI was successful	Beck et al. (2000), Kiang et al. (2006)

Table 2.1: Examples of Previous Studies on Physiologic Climate (Literature Review, 2012)

Scope	**Indices/ variables**	**Comment**	**Reference**
Nigeria	Temperature, relative humidity and radiation	The study analysed climate (temperature) data in reference to building design. Spatial dimension of temperature, radiation and relative humidity of the country were related to housing structure and design type	Ajibola (1997); Ajibola (2001))
Ilorin, Nigeria	Effective Temperature Index (ETI), Temperature – Humidity Index (THI), wet bulb temperature, air temperature, dry bulb temperature, P4SR, Vapour Pressure	Air temperature, wet bulb temperature and THI when employed separately produce comparable results, except in terms of minor details. This study essentially considered its results with the use of some locations around Ilorin	Olaniran (1982)
Nigeria	Effective Temperature Index (ETI), relative humidity, temperature	Nigeria was divided into four ETI comfort zones (i.e. southern, middle belt, Plateau / Kaduna, and the northern zone). The study used hourly data for 1951-1965. It considered the ETI as the most widely used measure of physiologic comfort in the Tropics	Ayoade (1978)
Northern Nigeria	ETI (used on selected dwellers of mud houses in the northern Nigeria, and a group of college students)	Comfort level based on thermal sensation and ETI was put at 18-21^{o} ETI. The study made use of calculated ETI values and sensations on some selected people.	Peel (1958), Peel (1961)
Africa	Comfort Index and Wind Effect Index	Higher elevations ameliorate the lowland conditions of human comfort	Terjung (1967a), Terjung (1967b)
World	ETI	Warmest ETI was put at less than 26-27.7^{o} ETI between 5 and 25^{o}S in January and 10 - 30^{0}N in July. ETI was plotted using isoesteses; i.e. lines joining places of equal sensations based on the recognition that the index was used for bioclimatographic analysis of the USA, USSR, Poland and parts of Germany.	Gregorczuk and Cena (1967)
Argentina	RSI	Wave of crimes increased in period of higher temperatures. This study made use of temperature variations and records of violence obtained from the Criminal Records Office for the study area	Alessandro and de Garín (2003)
Szeged, Hungary	RSI, THI	This study used THI and RSI to compare the bioclimatological conditions of rural and urban environment of a medium-sized city in Hungary. The study used the RSI results to complement the THI, and both revealed similar results.	Unger (1999)

2.3.3. Measures of Physiologic Comfort

A number of the most widely used indices are described below with their strengths and limitations:

2.3.3.1. Apparent Temperature Index (ATI)

The apparent temperature index (ATI) is a measure of relative discomfort from combined heat and high humidity. It was developed by Steadman (1979) and is based on physiologic studies of evaporative skin cooling for various combinations of ambient temperature and humidity. The ATI equals the actual air temperature when the dew-point temperature is 14°C. At higher dew-points, ATI exceeds the actual temperature, and measures the increased physiologic heat stress and discomfort associated with humidity; when the dew-point is less than 14 °C, ATI is less than the actual air temperature and measures the reduced stress and increased comfort associated with lower humidity and greater evaporative skin cooling. The index is quantified as a function of the ambient temperature and moisture. It includes environmental and physiologic variables important in determining human response to environmental stresses. It is given as

$$\mathrm{T_{api}} = 2.719 + 0.994 * t_{air} + 0.016 * (t_{dew})^2 \qquad 2.2$$

where

T_{api} =Apparent temperature,
t_{air} =maximum air temperature, and
t_{dew} = maximum dew temperature (°C).

Days with ATI higher than 32°C are considered heat stress days. Steadman (1994) applied ATI to a range of Australian climate data to analyse the diurnal and annual pattern of normal effects of some weather elements and to combine this into maps and charts of ATI. Also, studies have computed ATI for the United States of America (Kalkstein and Valimont, 1986; Smoyer-Tomic and Rainham, 2001) and have found the index to be more relevant to the climate of North America.

2.3.3.2. Effective Temperature Index (ETI)

The effective temperature index (ETI) is one of the oldest physiologic comfort indices identified to be applicable to Africa (Ayoade, 1978). It is defined as the temperature at which saturated air would induce in a normal person wearing ordinary indoor clothing, the same sensation of comfort as that induced by the actual conditions of temperature, humidity and air movement. It was originally intended for indoor conditions in industry and mines and not for open air conditions (Gregorczuk and Cena, 1967) but has later gained wider applications in comfort and climatological analyses in north America and Europe. The results of ETI represent the thermal sensations of a man insulated from air movement and from solar radiation. An approximation of the ETI is given in either of equations 2.3a or 2.3b.

$$T_{eti} = t - 0.4(t-10)(1-\frac{H_{rh}}{100}) \quad 2.3a$$

$$T_{eti} = 0.4(t_{dry} + t_{wet}) + 4.8 \quad 2.3b$$

Where

T_{eti} = effective temperature
t = air temperature,
H_{rh} = relative humidity
t_{dry} = dry bulb temperature
t_{wet} = wet bulb temperature

The ETI appears to be the most widely used measure of physiologic comfort in tropical and temperate regions (Gregorczuk and Cena, 1967; Ayoade, 1978; Matzarakis, 2001; Emmanuel, 2005). Ayoade (1978) mapped and classified Nigeria into four physiologic comfort zones while Gregorczuk and Cena (1967) described the distribution of mean ETI over the world in charts. Table 2.2 highlights some of the geographical variations of human comfort using ETI within the tropics.

Table 2.2: Some Comfort Zones Classification as Derived from Effective Temperature Index

Location	**Comfort Zone (ºC)**
Northern Nigeria	18 – 21
England	14 – 19
Malaysia	21 – 26
Indonesia	20 – 26
Continental Europe	20 – 26
Northern USA	20 – 22
Southern USA	21 – 25
India	21 – 26

Source: Ayoade (1978)

Uncomfortable situations due to cold stress occur with ETI ≤ 18.9°C and heat stress > 25.6°C (Ayoade 1978). Despite the wide application of this index, Terjung (1967) identified some errors with the original version of the index; (a) the basic observations were made on a specific group of subjects; healthy young white men and women living under American conditions of climate, housing and clothing, (b) the observation relate only to sedentary conditions, (c) the index does not apply at air movements below 7.62 m per minute, (d) it is not reliable at the upper end of the scale; and (e) the index in its original form gives too much weight to changes in humidity at the lower end of the Comfort index scale. Observations of the Gregorczuk and Cena (1967)'s distribution of ETI over the earth's surface showed that the areas within 10 and 30°N are the warmest in July and that the space distribution of ETI values is similar to that of the air temperature, but modified by the influence of humidity. Areas with large difference in air temperature and ETI values are those with high temperature and low humidity.

2.3.3.3. Temperature-Humidity Index (THI)

The THI was developed by Thom (1959) for providing a broad approximation of stress changes in a city over time and for developing useful design guidelines for cities (Jáuregui and Soto, 1967; Tout, 1980; Kalkstein, 1991). It combines the wet and dry bulb temperatures into a scale that imitates the thermal sensation of a human being. The original index, which combined the wet and dry bulb temperatures to produce the THI, has been modified by McGregor and Nieuwolt (1998) to use air temperature and relative humidity. THI is calculated by

$$\mathrm{T_{thi}} = 0.8 * t + \frac{H_{rh} * t}{500} \qquad 2.4$$

where

T_{thi} = Temperature-humidity index
t *is* the air temperature (°C) and
H_{rh} *is* the relative humidity (%)

Thom (1959) argued that, although no discomfort is experienced at THI value less than 21.1°C but an increasing proportion of a population would experience discomfort at values above it. Half of the people tested in Thom (1959) were uncomfortable at an index value of 23.9°C but discomfort became most pronounced within the population from value above 26.7°C. Nieuwolt (1977) suggested the following THI classification, based on the climate of the United States of America and suggestion of the United States Weather Bureau (1959).

a. 21 - 24 ºC = 100% of the subjects felt comfortable
b. 24 - 26 ºC = 50% of the subjects felt comfortable
c. THI > 26 ºC = 100% of the subjects felt uncomfortably hot

Kyle (1994), on the other hand, using the climate information in Hong Kong, argued that the optimum THI value for defining comfortable conditions occurs between 15 and 20°C. Below the THI of 15°C, evaporation would absorb heat from the body thus requiring defence against cooling. As such series of increasing thermo-genetic mechanisms are required by most bodies to combat increasing cold stress. Perspiration system, however, becomes effective as a cooling mechanism to prevent overheating when THI is about 20°C. The greater the THI, the more ineffective this mechanism becomes, so a series of categories have been introduced above the comfortable zone, where the heat stress is increasing. Table 2.3 describes the series of categories of THI.

Table 2.3: Categories of Temperature-Humidity Index (THI)

THI category	Temperature (ºC)
Extremely cold	-19.9 to -10
Very cold	-9.9 to -1.8
Cold	-1.7 to +12.9
Cool	+13 to +14.9
Comfortable	+15 to +19.9
Hot	+20 to +26.4
Very hot	+26.5 to +29.9
Torrid	Greater than +30

Source: Kyle (1994)

2.3.3.4. Predicted Mean Vote (PMV) and Physiologic Equivalent Temperature (PET) index

The Predicted Mean Vote (PMV) is an index that predicts the mean value of the votes of a large group of people on a 7-point thermal sensation scale. This index (PMV) quantifies discomfort based on human-assessed response and is considered to be one of the most widely used comfort indices today (McGregor et al., 2002). In its simplest form, PMV represents the 'predicted mean vote' (on the thermal sensation scale) of a large population of people exposed to a certain environment. It is derived from the physics of heat transfer combined with an empirical fit to sensation, and establishes a thermal strain based on steady-state heat transfer between the body and the environment. It subsequently assigns a comfort vote to that amount of strain. The PMV ranks from 1 to 7, requesting respondents to 'vote' their feelings at a particular time as either 'cold', 'cool', slightly cool', 'neutral', 'slightly warm', 'warm' or 'hot'. This is obviously subjective and has been used as a supportive or complementing index, rather than a sole test index. Factors causing uncertainties in the votes include the differences in weather experience, body structure, clothing insulation, and level of activities (Johansson and Emmanuel, 2006). The PMV assumes that individuals that are exposed to a consistent metabolic activity for a relatively long period would be understood by the equation below:

$$H - H_{vd} - H_{sw} - H_{res} - L = R + C \qquad 2.5$$

where

H = internal heat production

H_{vd} = heat loss due to water vapour diffusion through the skin

H_{sw} = heat loss due to sweating

H_{res} = latent heat loss due to respiration

L = dry respiration heat loss

R = heat loss by radiation from the surface of the clothed body

C = heat loss by convection from the surface of the clothed body.

Höppe (1999) defined the physiologic equivalent temperature (PET) as the air temperature at which in a typical indoor setting (without wind or solar radiation), the heat budget of human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed. It is based on the Munich Energy-balance Model (MEMI), which models the thermal conditions of the human body in a physiologically relevant way. This way, PET enables a layman to compare the integral effects of complex thermal conditions outside his own experience indoors. PET has been used in several recent studies (Matzarakis et al., 1999; Spagnolo and De Dear, 2003). It is a thermal index derived from the human energy balance. Its threshold level is shown in Table 2.4 as related to the PMV scale. It requires input of air temperature, mean radiant temperature which is often calculated as the weighted average temperature of surrounding surfaces (Emmanuel 2005), humidity, and wind speed. PET results have been presented graphically or as bioclimatic maps. Graphs mostly display the temporal behaviour of PET, whereas spatial distribution is specified in bioclimatic maps. Using this index, Ahmed (2003) on a field study in Dhaka during the hot, humid, summer months derived a set of comfort zone that corresponds roughly between 27°C and 33°C. However, these estimated PET values are uncertain, and the comfort zone found by Ahmed (2003) in Dhaka might not necessarily be transferable to other regions (Johansson and Emmanuel, 2006). The required data for the thermal bioclimate analysis are air temperature, relative humidity, sunshine and wind speed.

Table 2.4: Threshold Values of the Physiologic Equivalent Temperature (PET) and Predicted Mean Vote (PMV)

PMV (votes)	**PET (ºC)**	**Thermal sensivity**	**Level of physiologic stress**
-3.5 – (-0.5)	4-18	Very cold to slightly cool	Cold stress
-0.5- 0.5	18-23	Comfortable	No thermal stress
0.5-3.5	>23	Slightly warm to very hot	Heat stress

Source: Matzarakis et al. (1999), *modified*

2.3.3.5. Spatial Synoptic Classification (SSC)

Spatial Synoptic Classification (SSC) is one other measure, not designed specifically for the purposes of examining human biometeorology but has been widely applied in human comfort studies (Sheridan, 2002). It is an air-mass-like categorical classification that serves as the basis of heat and human health watch and warning systems in implementation world-wide (Kalkstein et al., 1997). It is a hybrid categorization system, employing both manual and automated segments. The initial stage requires manual identification of air masses; once this is completed, an automated classification of days then occurs. The system was originally developed by discriminant analysis (Kalkstein et al., 1996) but very few of its details were found with 'Google scholar' searches in the course of this review.

2.3.3.6. Predicted four-hour sweat rate index (P4SR)

The predicted 4-hour sweat rate index (P4SR) devised by McArdle and others in 1947 (Hicks, 1971; Moran et al., 1998) is based on the assumption that the rate at which man sweats is a good index of heat stress. Perspiration by a person in four hours can be predicted with an empirically devised nomogram. The P4SR nomogram is a graph with three lines graduated so that a straight line intersecting any two of the lines at their known values intersects the third at the value of the related variable. The interpretation is that the greater the quantity of sweat perspired, the more the heat stress. The limiting value of the index is about 4.5 litres. However, it is not certain that anyone could be exposed to a situation where more than 2.5 litres of sweat will be produced in 4 hours. The P4SR combines the effect of air temperature, radiant temperature, humidity, air movement, metabolic heat production and two levels of clothing. The calculation required is complicated, but investigations have confirmed that predictions are quite accurate (Vogt et al., 1981). The single number (index value) that summarizes the effects of the six basic variables is an amount of sweat from the specific population, but it should be used as an index value and not as an indication of an amount of sweat in an individual group of interest. This index, however, requires testing the sensation of individual subjects, such as sweating. It is an empirical study that will be successful at the micro-scale such as a group of subjects and laboratory rather than a city state or national level. It is thus difficult to apply in areas where available climate variables are based on stations within a town or state, rather it requires more meteorological stations than we have in Nigeria. In addition, the index requires quantification of the subjects' clothing materials, one of the variables required for its computation posed a difficulty, and hence the index was not considered for study in this research.

2.3.3.7. Relative Strain Index (RSI)

The relative strain index (RSI), defined by air temperature and vapour pressure is the ratio of the rate at which heat accumulates in the body of one organism to the maximum possible rate at which it can be removed. It is also defined as the ratio of the evaporative cooling required to the maximum evaporative cooling possible. In order to take account of the effects of clothing and net radiation, the relative strain index (RSI) was developed for a sedentary standard man dressed in a business suit (healthy, 25 years old and not acclimatized to heat) (Giles et al., 1990; Lee, 1953). For the conditions specified (internal heat production 100Wper sq. meter, air movement 1m per second, and zero solar radiation income). RSI therefore combines air temperature and vapour pressure per unit time.

The RSI is expressed in the equations below:

$$T_{rsi} = \frac{(t-21)}{(58-e)} \qquad 2.6a$$

$$e = \frac{(H_{rh} \times H_{vp})}{100} \qquad 2.6b$$

$$H_{vp} = 6.11 \times 10^{7.5 \times \frac{t}{237.7} + t} \qquad 2.6c$$

Where
T_{rsi} = Relative Strain Index
H_{vp}=Vapour pressure (hPa).
H_{rh} = Relative humidity (%)
t = air temperature (°C), and
e = Dew point temperature

The RSI threshold for physiological failure is 0.5 for young people and 0.3 for people older than 65 years (Giles et al., 1990). However, the RSI threshold for physiological failure must also depend on the physical fitness of the individual. Under the RSI scale, a quarter of the people would be uncomfortable at an RSI of 0.2 and no one is comfortable at an RSI of 0.3 (Table 2.5). For elderly and ill people, 0.2 is the threshold above which they are subject to heat stress. Given the number of climate variables combined in the index, i.e. relative humidity, temperature and vapour pressure, the RSI has been recommended for application in the tropics (Matzarakis, 2001; Alessandro and de Garín, 2003). Its selection for consideration in this study is based on its applicability in tropical environment and the fact that the variables for its determination are all available for the study period.

2.3.3.8. Still-Air Temperature Index (SAT)

The Still-Air Temperature Index, SAT, is derived from the thermal wind decrement index which expresses the cooling effect of wind in terms of the temperature of the still air with the same cooling effect. First, the value of the thermal wind decrement index is determined using a ‘nomogram’. The result is then subtracted from the dry-bulb temperature to give the still-air temperature. Still-air temperature has the same cooling effect on exposed skin as a given combination of temperature and wind speed. As the wind speed increases, the wind chill equivalent temperature decreases; e.g., an air temperature of -1.1°C with a wind speed of 32.2 km $hour^{-1}$ produces a wind chill of -8°C. As noted by Ayoade (1980) data on wind speed are not consistently available for a reasonably long period in Nigeria, available data on wind were limited to only few of the stations in Nigeria. Hence, the SAT index was not selected for study in this research. Based on the relevance of the comfort indices to the tropics and availability of data on variables required for computation of the indices, the ETI, THI and the RSI are indices selected for the study.

Table 2.5: The Relative Strain Index Classification

RSI	Proportion of persons unstressed /distressed (%)
0.1	100 unstressed
0.2	75 unstressed
0.3	0 unstressed
0.4	75 distressed
0.5	100 distressed

Sources: Kyle (1994), Yan (1997)

2.3.4. Awareness of the Impact of Climate on Physiologic Comfort

Increasing awareness of continued accumulation of greenhouse gases in the atmosphere that is expected to cause an increase in global temperature (Houghton and Callander 1992; Folland et al. 2001) has increased the amount of discussions in the field. Much discussed include the impact of climate on the followings:

a. heat-related mortality and morbidity (Kalkstein et al., 1996; Ferreira et al., 2001; Hajat et al., 2005);
b. infectious diseases, particularly those that are arthropod-borne (Shope, 1991; Hay et al., 2006);
c. malnutrition and dehydration from threatened food and water supply (Bunyavanich et al., 2003; Ebi, 2008);
d. general public health infrastructural damage from weather disasters and sea-level rise, aggravated by climate-related forced human migration (Haines et al., 2000; Tong, 2000; Tong and Soskolne, 2007); and
e. tourism and thermal comfort (Mieczkowski, 1985; De Freitas, 2001; De Freitas, 2003; Lin and Matzarakis, 2008)

Most of these researches appear to have been motivated by the potential usefulness of climate information within planning processes for comfort, tourism and recreation. They mostly address bioclimatology as being adjunct to a variety of decision making processes ranging from those related to such things as study of human health, diseases prevalence, development and location of appropriate recreational facilities, or determining the length of the recreation season during which a facility will operate, to those as specific as planning future activities involving personal decisions of when and where to go for a holiday. There has also been interest in the indirect effects of climate.

Thus, depending on the weather sensitivity of the human livelihood activity, information gathered through the study of bioclimatology can help in the planning, scheduling and promoting of alternative indoor entertainment facilities. It can also be used to condition tourists' expectations of climate at certain locations (Hobbs et al., 1997; Zeng, 2009)

2.3.5. Variable Quantification in Bioclimatology Researches

Considerable efforts have gone into devising numerical indices of climate that summarise the significance of climate on human health (Becker, 1998). This is probably because of the multivariable nature of climate and the complex way they come together to give meaning to a particular weather or climate condition in terms of human health and comfort. These indices facilitate interpretation of the integrated effects of various atmospheric elements and permit places to be compared. The problem is perhaps that most of these are arbitrary (i.e. most were not empirically tested).

Comfort in humans has been described as a response to the integrated effects of the atmospheric environment rather than to climatic averages (De Freitas, 2001; Lin and Matzarakis, 2008). It has also been argued that standard weather data may not be reliable indicators of the significance of atmospheric conditions. At any given air temperature, for example, the thermal conditions experienced will vary depending on the relative influence and, often, offsetting effects of wind, humidity, solar radiation and level of a person's activity. Moreover, the design of a particular thermal assessment scheme will depend on the intended use as well as on the nature of the thermal climatic conditions to which the scheme is to be applied. For example, schemes have been devised for groups of survival in climates of extreme cold (De Freitas and Symon, 1987) and for general purposes of human climate classification (Auliciems and de Freitas, 1976; Freitas, 1985). The importance of this has been recognised in human climate researches (Terjung, 1967; Reifsnyder, 1989), but so far there have been few studies aimed at identifying optimal or preferred comfort conditions. There have been even fewer that examine the human sensitivity to atmospheric conditions generally.

Several authors have described comfort climate in terms of human response in preference to traditional taxonomic methods of portraying regional climates (Giorgi and Mearns, 1991; Patz et al., 2005). In some cases, simple climatic indices such as the Thom Discomfort Index and the Wind Chill Index have been computed from climate data (Davis et al., 2004) while generalised quantitative summations of weather variables arbitrarily weighted have been employed in others (Green, 1967). Other researchers such asTerjung (1967), Danilova (1974),Jackson et al. (2010) have used more sophisticated measures of bioclimate based on the body's thermal exchanges with the environment. Mieczkowski (1985) has devised a broadly based climatic index for evaluating world climates for comfort. However, meaning attached to these measures in most studies has been secondarily derived and interpreted without field investigation.

2.3.6. Methodological approaches in Bioclimatology

Several approaches have been identified as suitable for study in bioclimatology. Some of these have been used in some existing studies, and some are still being proposed because of the hope that they provide adequate framework for the study of climate variability or change on man. These approaches are discussed in the following sub-sections.

2.3.6.1. Meteorological approach

A variety of meteorological approaches can be used in the historical analysis of the impact of climate on health: human comfort indices, water budget analyses and energy budget analyses (Bardossy et al., 1995; Yarnal et al., 2001). The method utilized depends on the health outcome of interest. For example, the synoptic classification scheme, which characterizes distinct air masses, affords greater predictive value than the use of single climate variables such as temperature and relative humidity in modelling heat mortality (Kalkstein, 1991; Sheridan and Kalkstein, 2004; Tan et al., 2004). On the other hand, a water budget approach, which compares supply, or precipitation, with climatic demands for water, such as through evapo-transpiration, has been found to be more useful for other diseases (Martens et al., 1997; Brewer et al., 2003; Rodgers et al., 2005). Insect vectors which include an aquatic stage in their life cycle will lend themselves to a water budget model to study climate vector- borne disease dynamics. For example, in Burkina Faso, where onchocerciasis is endemic, a water budget model was implemented to accurately predict black fly populations which depend on adequate stream flow rates for their development (Mills, 1995). Evaluating gradual changes in climate and disease variables will necessitate the use of time series analysis, which involves the examination of multiple comparisons over a sequence of time (Warrick et al., 1999). Data gathered over a long continuous period and at short time intervals provide the best data for time series analysis, but are often difficult to obtain. Change analysis, which involves pair-wise analysis between two dates or, in the case of remotely sensed satellite data, multi-date images, may be useful in the assessment of climate related ecological change.

2.3.6.2. Sensitivity assessment approach

The term sensitivity as used here refers to the amount a given assessment endpoint is affected by a given amount of change in a climate variable. In an ecological risk assessment, the ultimate sensitivity of a human disease to climate change will often depend on the existence of an organism in the disease system which displays marked alterations in reproductive or other types of behaviour in response to changes in climate variables. For example, infectious agents which cycle through cold-blooded insect vectors to complete their development are quite susceptible to subtle climate variations (Kalkstein and Smoyer, 1993; Altizer et al., 2006). Vector-borne microbes, because of their short life span and temperature dependency, can exhibit marked amplification of transmission capacity with increases in temperature. This has been demonstrated for dengue fever, for instance, in Mexico, where investigators found that median temperature during the rainy season was the strongest predictor of dengue infection in the population (Koopman et al.. 1991; Ferguson et al., 1999). Thus, the sensitivity of dengue fever as a human disease system to climate change is suggested by this potential tripling in viral transmission rate in response to temperature increases within the range predicted by the IPCC assessment.

2.3.6.3. Modelling approach

A specific disease model could be embedded within a more integrated systems approach to better reflect the complexity of the broader relationships between climate, intermediate ecosystem changes, human health, and human adaptive capacity. Such analysis can account for interactions or feedback processes and can simulate dynamic changes over time. Most human diseases have more determinants than just vector populations or climate variables. Many of the primary determinants of human health (adequate food, clean water and secure shelter) are related to the outcomes of sectors such as agriculture, water resources and fisheries. In populations suffering from malnutrition problems, the effect of climate change on agricultural production may have a greater adverse effect on human health than any given disease. Therefore, it is important to integrate these relevant systems into the human health assessment. Mathematical models are also necessary because predicted climate changes could lie outside the range of past observations. A number of integrated models are currently under development for such diseases as dengue and malaria (Matsuoka et al., 2001).

Understanding of human disease and the ability to model disease rates in the absence of climate change is still relatively undeveloped. While many scientists agree that socioeconomic factors play a significant role in health and susceptibility to disease, how to quantify socioeconomic factors for use in disease prediction has not yet been determined. Moreover, even when there were adequate ways to express socioeconomic factors quantitatively, there is a general paucity of data, both for socioeconomic and disease variables. Without geographically organized data to input, even the best models will have difficulty making accurate prediction

2.3.6.4. Descriptive mapping and Geographic information systems (GIS)

Many studies have attempted to describe the comfort in a particular place or region by mapping using appropriate bioclimate indices. Examples of these studies include Ayoade (1978) and Olaniran (1982) on Nigerian climate. These studies have provided descriptive information about the studied region. Kalkstein and Greene (1997) and Kalkstein and Sheridan (2007), for example, have also adopted this method to reveal the comfort zones in the United States of America at different seasons. Recently, however, advances in computer technology have increased its use, and in many applications, including the study on bioclimatology. Because much of the analysis of human health vulnerability will require the superimposition of data on disease incidence, vector populations, demographics, and climate with linkage to specific geographic locations, a geographic method of organizing and storing this data will be very useful. GIS technology provides the capacity to integrate multivariate data to produce meaningful information. The use of GIS systems in human climatological studies is rather new. It should be stressed that GIS systems will not provide better outputs than the quality of the data that are entered into them; therefore attention needs to be paid to the proper collection and organization.

In this study, the time-series analysis of the temperature, relative humidity and indices of physiologic stress were considered the meteorological approach, and the mapping of the indices was considered to be the descriptive mapping and GIS approach. The sensitivity assessment approach was considered with the assessment of the perceptions of selected individuals in selected areas in Nigeria, and the modelling approach as considered in this study involves the projection or trend analysis used to derive future trend of physiologic stress.

The review showed that the field of bioclimatology is yet to be fully understood, and much study is required to raise its understanding in Africa, and Nigeria in particular. For example;

(1) The latest published study (as far as Google searches could find as at the time of this study) on Nigeria as a country was for 1951-1965 (Ayoade, 1978). This study extends such knowledge with an examination of about 30 more years data from this (Ayoade, 1978) study. In all, this study examines 59 years (1951-2009) data.
(2) Most of the existing studies have examined the effective temperature index or other indices and described them. There has been little or no information on the effect of adopting any of the indices on the interpretation of the results. This study has compared three popular indices (ETI, THI and RSI) in the tropics, with the intention of gaining insights into their applications and interpretations of the country's comfort climate
(3) Except the studies by Peel (1958, 1961), none of the existing studies on the Nigerian comfort climate considered the perspective of the people, especially their capacity for adaptation in any case of discomfort climate.
(4) The need to advance the methodological approach for investigations on climatological studies was also shown in Section 2.3.6. This study has considered this with a balanced application of meteorological, social and geographical information systems to present the results for adequate understanding.

Subsequently, the hypotheses below have been adopted for investigation:

2.4. Hypotheses

Hypotheses (H_1) for this study include the following:

i. Physiologic climate (in terms of thermal discomfort) in Nigeria exhibits significantly increasing (worsening) trend from 1951 to 2009;
ii. Indices for evaluation of physiologic climate examined in this study (temperature, relative humidity, effective temperature index, temperature-humidity index and relative strain index) are significantly correlated;
iii. Physiologic climate exhibits direct relationship with increasing distances away

from the Atlantic Ocean.

iv. Physiologic climate exhibits direct relationship with increasing altitude;

v. Adaptive approaches to physiologic stress are adequate for protection against prevailing physiologic climate in most regions in Nigeria.

CHAPTER THREE

METHODOLOGY

3.1. Database for the study

Synopsis of the literature review on physiologic climate has established that data on air temperature, solar radiation, relative humidity and wind speed were considered to be most suitable for researches on physiologic comfort until late 1960s, when the integrative indices were hypothesised. Integrative indices are a combination of two or more of the heat indices (Terjung, 1967). Recently, hospital records, measured human feelings and responses of people, have been used in many studies, to validate or complement the heat elements and integrative indices (e.g. Smoyer et al., 2000).

The Nigeria Meteorological Agency (NIMET) is the agency that is responsible for the monitoring of the meteorological stations and subsequent collection of meteorological data from these stations in Nigeria (Aderinto, 2006). According to Aderinto (2006), meteorological data were observed with standard meteorological equipment (including air thermometers and hygrometers for temperature and relative humidity, respectively) and manually recorded in weather notes. From 2005, Aderinto (2006) noted that the recording is automated, suggesting a shift from the manual data recording approach to auto-recording or data auto-logging approach. Each of these approaches has its strengths and weaknesses. For example, while the auto-recording approach could be argued to be faster, more prompt and less vulnerable to human error, it should be cautiously watched for machine malfunction and calibration errors. The auto-recording (digital) stations are equipped to measure air temperature, relative humidity, rainfall, wind speed and direction, solar radiation and soil moisture (Aderinto, 2006; Efe, 2006). Although the digital equipment are expected to provide more accurate data than the manual method of data collection, there has been no study in this perspective to arrive at a conclusion. Out of the 55 stations placed on record by NIMET, only about 44 have their data directly held at the time of study. Others, including the stations at the International Institute for Tropical Agriculture, Ibadan, Sokoto Rima Basin, Benin-Owena River basin, Obafemi Awolowo University, Ile-Ife, Jibia River Basin, Umuahia station, Ismol Island, Bebi airstrip and Obudu ranch

(Aderinto, 2006), were either considered very recent or their data were not available for use at the commencement of this study, and were therefore not included among the probable stations selected.

The study period selected for this study is 1951-2009 (59 years). The beginning data of 1951 was chosen in consideration that higher records of relative humidity data are available for most stations around the year. Relative humidity became the ‘ruling factor’ because temperature data was available at many stations for many years, even before 1951 but relative humidity data were not. Both temperature and relative humidity are however important inputs into all the equations used to calculate the effective temperature, temperature-relative humidity and relative strain indices used for the study. Although, a climate period has been considered in most studies as a minimum of 30 years, available data sets were only comparable for 59 years (i.e. 30 (1951-1980) and 29 (1981-2009) slices). There was also a significant data loss between 1967 and 1970; a scenario that was noted in some previous studies on Nigerian climate (e.g. Adebayo, 1999) to be attributed to the civil war in Nigeria. As a consequence, there was change from analogue data collection approach to digital by NIMET in 2005. More so, relatively insignificant number of affected years (i.e. 4 (2006-2009)) is concerned in this study, attempt was therefore not made to identify possible impact of this change in procedure of data recording at the NIMET, because such effect, if any, is assumed to be negligible.

Air temperature records are usually obtained from spot measurements with mercury-in-glass minimum and maximum thermometer and relative humidity by hygrometer from about 55 stations over Nigeria. These weather instruments were constructed in accordance to the standards of the World Meteorological Organisations, which Nigeria is a member. The primary concern for the data from these locations is their spatial representativeness. Airports in which most of the stations are located are often in the outskirts, and may therefore be inadequate to represent the city centres in many urban areas. Furthermore, the manual nature of data compilation discourages (perhaps until 2005) easy retrieval of daily data, many records of which have been lost in the process of digitisation of the Agency.

3.2. Data Collection Procedure

Two sets of data were collected for this study. These are the monthly temperature and relative humidity data for 1951-2009, collected from NIMET, and responses to a structured, mostly close-ended, set of questionnaire (Appendix 1), which was used with a view of collecting responses on the human perception of physiologic comfort, and the adaptation strategies across Nigeria.

3.2.1 Air temperature and relative humidity data

As earlier noted (Section 3.1), only 18 stations were considered for this study. This consideration was based on the conditions that (a) the data were available, and (b) the need to use stations that will represent a vast area and climate condition across the country. Based on these considerations, potential stations were examined as representative samples using the following steps:

Condition 1: 2^o x 2^o line grids were 'overlay' on a map of Nigeria, which shows the distribution of the stations. Every station within a particular grid is considered a representative of that grid. Based on the latitude and longitude dimensions of Nigeria, a total of 28 (2^o x 2^o) grids were obtained, but 20 grids could be presented, because some grids have no stations in them (Figure 3.1).

Condition 2: All potential stations for each grid were considered against the date for which data was available (i.e. the date the station began operation). Stations that were established before 1951 were specifically considered useful for this study. The list of all the synoptic stations and the finally selected stations for the study are shown in Table 3.1.

Condition 3: Grid representative stations whose data were missing for more than five years in a row (other than 1967-1970) were removed. Turkes et al (1995) in a study on Turkey argued that monthly data loss for more than five years at a station may negatively affect the quality of the results. In this study, Kaduna and Kano were disqualified because the relative humidity data were not available for approximately 30% of the total datasets for each of these stations, but were however used for diurnal consideration.

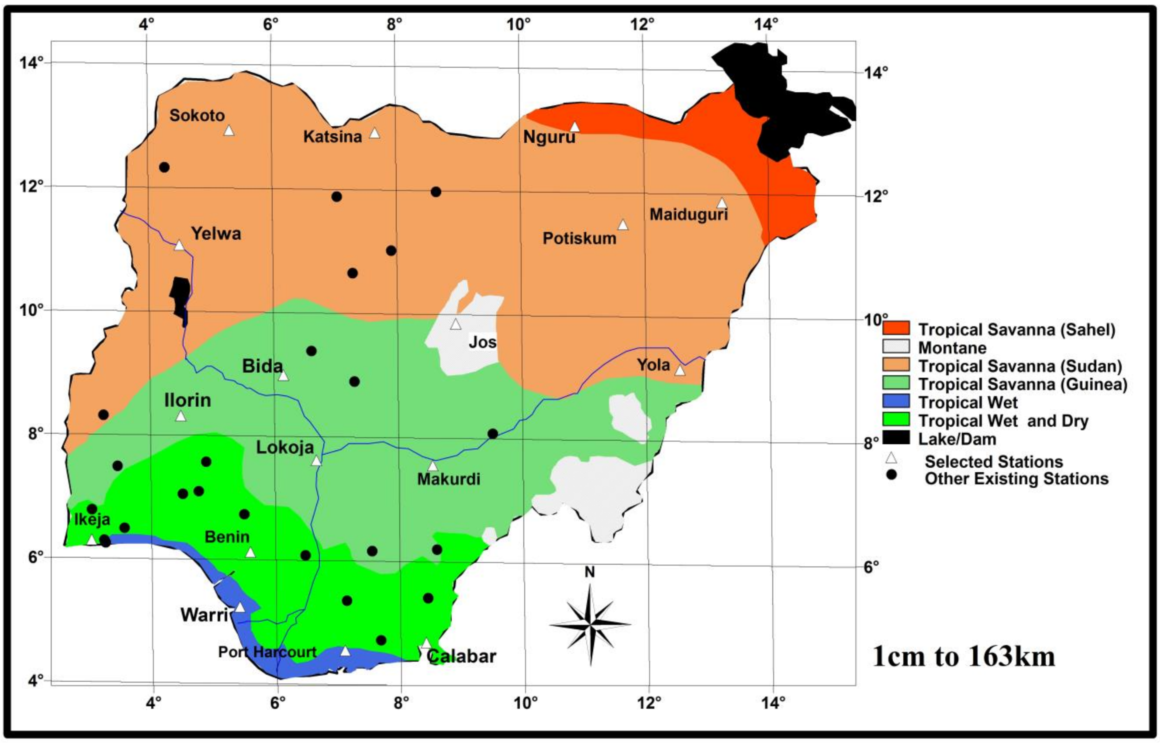


Figure 3.1: Distribution of Existing Meteorological Stations across different Eco-Climatic Regions of Nigeria (excluding the new Stations established since 2005).

Table 3.1: List of Meteorological Stations in Nigeria, and those Selected for Study

S/N	Station Name	Latitude (ºN)	Longitude (ºE)	Elevation (m)	Year of Establishment	Remark
1	Abeokuta	07.1	03.2	104.0	1905	Not selected
2	Abuja	09.2	07.0	343.0	1981	Not selected
3	Akure	07.2	05.2	375.0	1979	Not selected
4	Bauchi*	10.2	09.5	609.0	1906	Selected
5	Benin*	06.2	05.4	77.8	1906	Selected
6	Bida*	09.1	05.6	144.0	1928	Selected
7	Birni kebbi	12.3	04.1	220.0	1975	Not selected
8	Calabar*	04.6	08.2	61.9	1901	Selected
9	Enugu*	06.3	07.3	141.8	1916	Not selected
10	Gusau	12.1	06.4	464.0	1962	Not selected
11	Ibadan*	07.3	03.5	227.2	1905	Not selected
12	Ibi*	08.1	09.5	110.7	1909	Not selected
13	Ijebu-ode	06.5	03.6	77.0	1973	Not selected
14	Ikeja*	06.3	03.3	39.4	1944	Selected
15	Ikom	05.6	08.4	119.0	1972	Not selected
16	Ilorin*	08.3	04.3	307.0	1905	Selected
17	Iseyin	07.6	03.4	330.0	1981	Not selected
18	Jos*	09.5	08.5	1285.0	1921	Selected
19	Kaduna*+	10.3	07.3	642.0	1913	Selected for diurnal analysis
20	Kano*+	12.0	08.3	481.0	1905	
21	Katsina*	13.0	07.3	427.0	1922	Selected
22	Lagos (marine)	06.3	03.3	2.0	1901	Not selected
23	Lagos (roof)*	06.3	03.2	14.0	1892	Not selected
24	Lagos(LUTH)	06.3	03.2	14.0	1892	Not selected
25	Lokoja*	07.5	06.4	62.5	1901	Selected
26	Maiduguri*	11.5	13.2	354.0	1909	Selected
27	Makurdi*	07.4	08.4	112.9	1926	Selected
28	Minna*	09.4	06.3	256.0	1914	Not selected
29	Nguru*	12.5	10.3	344.0	1942	Selected
30	Ogoja	06.4	08.5	117.0	1976	Not selected
31	Ondo*	07.1	04.5	287.3	1906	Not selected
32	Onitsha	06.1	06.5	67.0	1973	Not selected

Note:
Asterisked (*) are stations that qualified for selection based on year of establishment (stations established before 1951)
Not selected= Stations not used for this study
Selected = Stations selected as representatives
Selected for diurnal analysis= Stations which were included in the diurnal analysis but could not be used for long term analysis because of insufficient data.

Table 3.1(Continued)**:** Location of Meteorological Stations in Nigeria, and those Selected for Study

S/N	Station Name	Latitude (ºN)	Longitude (ºE)	Elevation (m)	Year of Establishment	Remark
33	Oshodi (Agromet)	06.3	03.2	19.0	1965	Not selected
34	Oshogbo*	07.5	04.3	302.0	1935	Not selected
35	Owerri	05.3	07.0	91.0	1972	Not selected
36	Port-Harcourt*	04.4	07.0	19.5	1916	Selected
37	Potiskum*	11.4	11.0	488.0	1915	Selected
38	Shaki	08.4	03.2	304.0	1981	Not selected
39	Sokoto*	13.1	05.2	302.0	1904	Selected
40	Uyo	05.3	07.6	38.0	1981	Not selected
41	Warri*	05.4	05.5	6.1	1907	Selected
42	Yelwa*	10.5	04.4	244.0	1926	Selected
43	Yola*	09.1	12.3	186.1	1904	Selected
44	Zaria	11.0	07.4	111.0	1968	Not selected

Asterisked (*) are stations that qualified for selection based on year of establishment (stations established before 1951)
Not selected= Stations not used for this study
Selected = Stations selected as representatives

The selected stations are Yelwa, Sokoto, Bauchi, Nguru, Potiskum, Maiduguri, Katsina, Yola, Markurdi, Ilorin, Lokoja, Bida, Jos, Warri, Ikeja, PortHarcourt, Benin and Calabar. Selected stations were regrouped based on the climate regions i.e. the Tropical Rainforest; which consists of the tropical wet (represented by Warri and Port Harcourt) and tropical wet and dry belts (represented by Ikeja, Benin and Calabar), the Tropical Savanna; consisting of guinea (represented by Bida, Ilorin, Lokoja and Makurdi), sudan (represented by Sokoto, Bauchi, Katsina, Yelwa, Potiskum and Yola), and Sahel (represented by Nguru) savanna, and montane region (represented by Jos) (Figure 3.2). The montane eco-climatic region is influenced by altitude; the tropical wet region is influenced by proximity to the land and sea breeze influence of the Atlantic Ocean, and such influence decreases towards the savanna region. Temperature and relative humidity data were grouped into annual, seasonal, monthly, daily and hourly distributions before they were analysed.

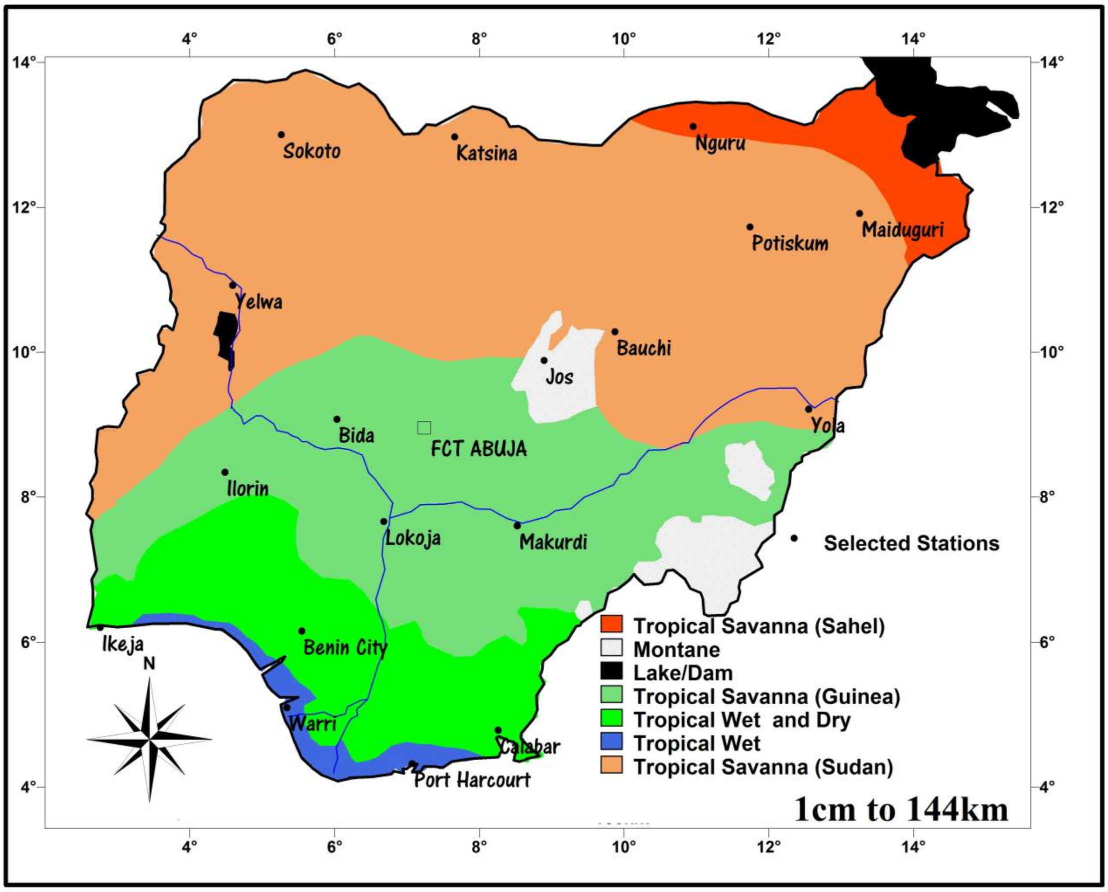


Figure 3.2: Distribution of Meteorological Stations Selected for the Study.

3.2.2. Responses to Questionnaire

The use of questionnaire in this study was guided by some published studies (e.g. Aggelakoudis and Athanasiou, 2005). The use of questionnaire becomes useful as a form of mean vote index, suggested by Fanger (1970) as a complement of the meteorological variables. The only difference in the approach used here is that while Fanger (1970) suggested a 'predicted mean vote index' (Section 2.3.3.4), the use of questionnaire provides a 'representative mean votes'. Studies in developed countries (e.g. Smoyer, 1988; Smoyaer et al., 2000) have suggested that responses from an individual or a group of respondents, within a relatively small area such as an office, college or hospitals could be acceptable as valid representatives of larger populations or may even be used as warning system for a country (e.g. Smoyer et al., 2000). In addition, Crocombe and Malama (1989) argued that the responses from a tertiary institution could sometimes be stronger than that of a community, because those in schools are more likely to be more conscious and inquisitive than others within the entire community.

The purpose of sampling responses was to test the hypothesis on the dynamics of physiologic comfort. Responses were therefore requested for 30 structured, close-ended questions from randomly selected institutions in Nigeria. Studies such as Alessandro and de Garin (2003), and Aggelakoudis and Athanasou (2005) have sampled opinions of selected population based in institutions (colleges and tertiary institutions) and examined their responses, in addition to some physiologic climate indices. Purposive or judgement sample, is one in which the researcher actively selects the most productive sample to answer the research question. Tertiary institutions were considered for selection because respondents can easily be tracked, and this was guided by validated approaches to questionnaire administration by Marginson and Wende (2007). In this study, especially with the problem of security in the northern part of Nigeria, higher institutions were considered as one safe for the study (perhaps until recently). Figure 3.3 shows the distribution of the institutions that were selected for questionnaire administration. In each institution, 242 copies of questionnaire were administered to randomly, but proportionately selected indoor and outdoor workers. For the institutions used, targeted total population consisted of academic and non-academic workers, and those who trade around the campuses, including kiosks operators, restaurant operators and photocopy or computer operators. An average of this targeted population was 400 to 500 in each institution. To determine the sample population the Slovin's formula (equation 3.1) was applied.

$$\text{Sample population} = \frac{N}{1+Ne^2} \qquad 3.1a$$

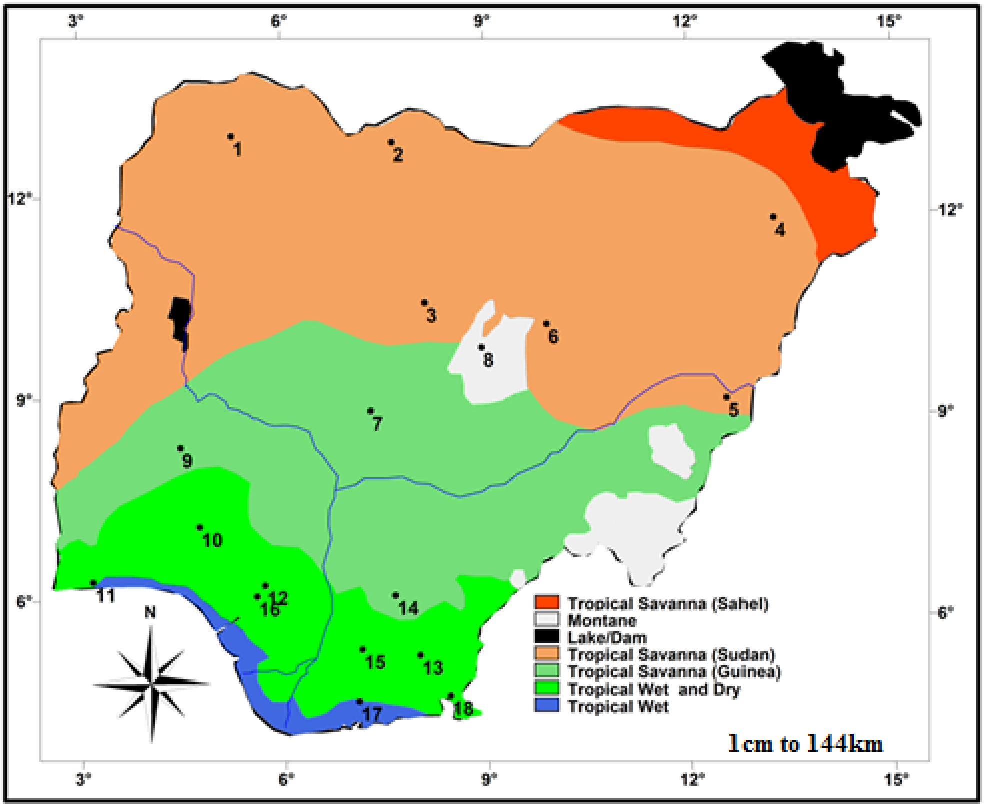
$N = total\ targeted\ population, e = confidence\ level$ (0.05 for 95%).

For example, for a population of 500;

Sample population was estimated as in equation 3.1b:

$$\frac{500}{(1+500\times0.05^2)} = 222 \qquad 3.1b$$

A sample size of 200 was finally accepted because less than the targeted sample sizes for most institutions were returned. To control for refusals or non-returned copies, 20 copies of questionnaire were added to each institution as advised by Boynton (2004) and Boynton and Greenhalgh (2004), making the total administered questionnaire 4056. The return rate for each sampled institution is as shown in Table 3.2. The first well answered and completed 200 copies of questionnaire were subsequently coded for analysis, for each institution. The questionnaire survey was carried out between March and November 2010.



1. Usman Dan Fodio University Sokoto
2. Hassan Usman Katsina Polytechnic
3. Kaduna Polytechnic, Kaduna
4. University of Maiduguri
5. Federal University of Technology, Yola
6. Federal Polytechnic, Bauchi
7. University of Abuja
8. University of Jos
9. University of Ilorin
10. Obafemi Awolowo University, Ile-Ife
11. University of Lagos
12. Adekunle Ajasin University, Akungba-Akoko
13. Abia State University
14. Enugu State University
15. Imo State University
16. University of Benin
17. University of Port Harcourt
18. University of Calabar

Figure 3.3: Locations where Questionnaire were administered for this Study

Table 3.2: Locations where Questionnaire were Distributed and the Number of Questionnaire Distributed, Returned and Analysed for this Research

Sampling location	Eco-Climatic zone	Coordinates	No of Questionnaire distributed	No of Questionnaire returned	No of questionnaire analysed
Usman Dan Fodio University, Sokoto State	Tropical Savanna (Sudan)	12°54'N; 5°18'E	242	202	200
Hassan Usman Katsina Polytechnic, Katsina		12°52'N, 7°39'E	242	206	200
Kaduna Polytechnic, Kaduna State		10°31'N, 8°07'E	242	201	200
University of Maiduguri, Borno State		11°51'N, 13°15'E	242	210	200
Federal University of Technology, Yola, Adamawa State		9°10'N, 12°35'E	242	208	200
Federal Polytechnic, Bauchi State		10°13'N, 9°56'E	242	201	200
University of Abuja, Federal Capital Territory	Tropical Savanna (Guinea)	8°56'N, 7°16'E	242	206	200
University of Ilorin, Kwara State		8°16'N 4°30'E	242	201	200
Enugu State University		6°06'N, 7°37'E	242	203	200

Table 3.2 (continued)**:** Locations where Questionnaire were Distributed and the Number of Questionnaire Distributed, Returned and Analysed for this Research

Sampling location	**Eco-Climatic zone**	**Coordinates**	**No of Questionnaire distributed**	**No of Questionnaire returned**	**No of questionnaire analysed**
University of Jos, Plateau State	Montane	9º50'N, 8º55'N	242	201	200
Obafemi Awolowo University, Ile-Ife, Osun State	Tropical Wet and Dry	7º11'N, 4º48'E	242	218	200
University of Lagos, Lagos State		6º17'N, 3º10'E	242	215	200
Adekunle Ajasin University, Akngba-Akoko, Ondo State		6º20'N, 5º44'E	242	220	200
Abia State University, Uturu, Abia State		5º15'N, 7º58'E	242	201	200
University of Benin, Edo State		6º08'N, 5º35'E	242	211	200
Imo State University		5º19'N, 7º06'E	242	200	200
University of Port Harcourt, Rivers State	Tropical Wet	4º34'N, 7º06'E	242	215	200
University of Calabar, Cross River State		4º42'N, 8º26'N	242	207	200
		Total	4056	3726	3600

3.3. Limitation of Data

Data used for this study are monthly records of air temperature and relative humidity for the selected stations for 59 years. Main limitation includes many missing data at most stations between 1967 and 1970, a situation attributed to the civil war in Nigeria during this period. Another limitation is the relatively poor network of synoptic stations at different regions of Nigeria. About 25.3% of the meteorological stations are located in northern Nigeria (north of Rivers Niger and Benue), 47.3% in the Southwest (west of River Niger) and 12.7% in the east. One systematic approach of sampling selection is the gridding system (Payne, 2009). Gridding offers spatial representation of data, and near equally distributed points (stations) than arbitrary selection or use of sample points that are irregularly located (Wheeler et al, 2010).

The age of the data is equally qualified as important. Given that climate is the average weather condition for at least 30 years, comparing two climate periods means 60 years, and three means 90 years, etc. Considering the problem that the longest series of data available for this study is less than 60 years; only two climate periods (1951-1980 and 1981-2009) could be compared. The latter climate period (1981-2009) does not make 30 years, because the records for 2010 were not available for use as at the time of this study, probably due to the need for data quality control (by NIMET) before the data is made available for use. Temperature and relative humidity records for 1971 and 2001, representing relatively cold and relatively warm years respectively, were used for the hourly considerations due to unavailability of data. The Sahel savanna climate region was not included in the administration of questionnaire for security challenges.

3.4. Data Pre-processing

Monthly and hourly records of air temperature and relative humidity obtained from NIMET, originally in Microsoft Excel files, were fed into the SPSS (Statistical Package for the Social Sciences) (version 16). SPSS, first released in 1968 is regarded to be among the most widely used programs for statistical analysis in social science (Levesque, 2007). In the SPSS software environment, the data were arranged under different columns or fields (i.e. ‘region’, ‘station’, ‘year’, ‘month’, ‘Tmin’ (i.e. minimum temperature), ‘Tmax’ (i.e. maximum temperature), ‘RH’ (i.e. relative humidity), and altitude). Each field was subsequently examined for ‘outrageous’ figures. Outrageous figures in the set of data used was mainly '-99' or '-999', which was confirmed by the contact at NIMET to suggest either missing values or zero (0). They (-99 and -999) were subsequently considered as missing values for this study. These were nonetheless very few, constituting less than 1% of the total number of records. The fields representing temperature, relative humidity and elevation values were represented as ratio *scale*, 'region' and 'station' were represented as *numeric* but *nominal scale*, while 'year' and 'month' were represented as *numeric* and *ordinal* measure. Classifying all the fields as *numeric* was to ensure that can be used for subsequent analysis as necessitated by the SPSS software. Datasets on ratio *scale* can have decimal values, those on *ordinal* scale representation define a value as greater than the one before it, and lower than the one after it (e.g. year 1953 is greater than 1952 but less than 1951). Datasets on *nominal* representation are not greater than the other, and are therefore on same platform for comparison.

All the missing values were thereafter replaced by results of five year (same month) simple linear interpolation. An interpolation is useful to make an approximate estimate of a missing data based on the neighbouring values, and has been found useful in climate studies and health studies (e.g. Hay and Lennon, 1999). Using this approach, the linear interpolation on a set of data points (x_0, y_0), (x_1, y_1)... (x_n, y_n) is defined as the concatenation (a computer operation of joining two values, end to end) of linear interpolants between each pair of data points, which usually results into a continuous curve (i.e. curve with small changes), and large variation is considered to be insignificant. The disadvantage of this approach is that although data are generated to fix the missing gaps, extreme values (very high deviations from means) are assumed to be insignificant during the period considered. To minimise such issues, Turkes et al. (1995) argued for the restriction of filling the missing gap to five years, and this was considered too in this study. Using the SPSS software, simple linear interpolation was achieved by choosing *replacing missing values* from *transform* on the menu of the software. Subsequently, the variable (i.e. each one of 'Tmin', 'Tmax', and 'RH' at separate period for a specified range of records) was selected, and *linear interpolation* was selected as method. The data was subsequently organised into batches for analysis; i.e. 1951-2009 (original dataset), 1951-1980, 1981-2009, and rainy (April-October), dry (November-March) seasons and Harmattan (December-February). Dry season includes the Harmattan, but the decision to identify the Harmattan separately is justified by the importance of this period to human health, outdoor and indoor coping activities identified in some studies (e.g. Miller, 1952; Adefolalu, 1984).

For the questionnaire analysis, responses to each of the questions asked in the questionnaire were coded (e.g. 1=Yes, 2=No) and input in a separate page on SPSS file. The fields were either categorised as *nominal* or *ordinal* scale for representation, and the questions selected for analysis were inserted as *numeric* for compatibility with the software (SPSS) used.

3.4.1 Determination of Selected Integrative Indices

Based on the review of previous studies on Nigeria and elsewhere, Effective Temperature index (ETI), Temperature-Humidity Index (THI) and Relative Strain Index (RSI) were selected for study based on their use in previous studies in the tropics, including Nigeria (e.g. Ayoade, 1978; Aggelakoudis and Athanasiou, 2005). Their monthly values were estimated from the monthly records of temperature and relative humidity that were earlier identified to be available for use (Sections 3.2-3.3). Using the monthly minimum and maximum temperature values for each of the 18 stations, the mean temperature was estimated by adding the minimum and maximum values together, and dividing the result by 2. This was achieved for all the years (1951-2009) and stations (18) in SPSS by choosing the *compute variable* menu from *transform* and *Tmean =MEAN [Tmin, Tmax]* was written in the column provided. *MEAN* is an inbuilt function of SPSS to determine the average of selected (minimum of two) fields, and in this case, the fields or columns containing the minimum and maximum temperature values (*Tmin, Tmax*) for each month and station were selected.

The formulae used for computation of ETI, THI, and RSI in this study have been found to be valid and generally accepted for use on Nigeria and the tropics by scholars, including Ayoade (1978), Olaniran (1982) and Ogbonna and Harris (2008) on ETI; Olaniran (1982), Unger (1999) and Kiang et al. (2006) on THI; and Unger (1999) and Alenssandro and de Garin (2003) on RSI. These accepted formulae were used in this study, and were only interpreted into simpler form for the understanding of the programming languages used in the study. The ETI was computed using the equation

$$T_{eti} = Tmean - 0.4(Tmean - 10)(1 - H_{rh} / 100) \qquad 3.2a$$

Where

T_{eti} = effective temperature index, *Tmean* = mean air temperature, H_{rh} = relative humidity

From the data page of the SPSS software, the value for ETI (T_{eti} in equation 3.2a) was determined using similar approach with which the mean temperature was created from the average of the minimum and maximum temperature values. Using this, the equation written in the *compute variable* frame is shown in equation 3.2b

$$ETI = Tmean - 0.4 * (Tmean - 10) * (1 - \frac{RH}{100}) \qquad 3.2b$$

where: *ETI* =effective temperature index, *Tmean*=mean air temperature, *RH*= relative humidity

To determine ETI, the columns for *Tmean* and *RH* have been identified as name of fields in the data page. The values for THI was also determined using the same procedure but with different program. For THI, equation 3.3a was re-written as 3.3b in the *compute variable* frame of the SPSS software, i.e.

$$T_{thi} = 0.8 * Tmean + \frac{H_{rh} * Tmean}{500} \qquad 3.3a$$

T_{thi} = Temperature-humidity index, *T*= air temperature, H_{rh}= relative humidity

$$THI = Tmean * 0.8 + (\frac{RH * Tmean}{500}) \qquad 3.3b$$

Where: *THI* =temperature-humidity index, *Tmean* = mean air temperature, *RH*= relative humidity

Determining RSI was complicated because of the number of the *unknowns* involved. The formula given in literature are given as equations 3.4a-c

$$T_{rsi} = \frac{Tmean - 21}{58 - e} \qquad 3.4a$$

$$e = \frac{H_{rh} * H_{vp}}{100} \qquad 3.4b$$

$$H_{vp} = 6.11 * 10^{\frac{7.5 * Tmean}{237.7 + Tmean}} \qquad 3.4c$$

Where

T_{rsi} = Relative Strain Index, H_{vp}=Vapour pressure (hPa), H_{rh} = Relative humidity (%), *Tmean* = mean air temperature (^{o}C), *e* = Dew point temperature

To compute RSI, the equations were solved in ascending order, i.e. eq. 3.4a, 3.4b and 3.4c. Equation 3.3ai was solved for RSI values in SPSS in following order (equations 3.4a-d):

$$Let\ X = \frac{7.5 * Tmean}{237.7 + Tmean} \quad 3.4a$$

$$\therefore\ H_{vp} = 6.11 * 10^{X} \quad 3.4b$$

$$e = \frac{RH * H_{vp}}{100} \quad 3.4c$$

$$T_{rsi} = \frac{Tmean - 21}{58 - e} \quad 3.4d$$

Where:

T_{rsi} = Relative Strain Index, H_{vp}=Vapour pressure (hPa), H_{rh} = Relative humidity (%), *Tmean* = mean air temperature (°C), *e* = Dew point temperature

The final results (values) of ETI, THI and RSI were also validated by sets of 'GenStat' programs (Webster, 2011). GenStat is a general statistical package, programmed in FORTRAN language (Payne, 2009) which was developed at the Rothamsted Research (formerly Rothamsted Experimental Station), Harpenden, United Kingdom, where the final analysis were achieved between March and August 2011.

3.4.2. Data selection for hourly variations in physiologic climates

Hourly (0600, 0900, 1200, 1500 and 2100 Local Standard Time) ETI, THI and RSI were obtained for March 1, July 25 and December 24 (representing the dry season, wet season and Harmattan) in 1971 and 2001 at 20 stations (all the previously selected 18 stations and two more - Kano and Kaduna). The choice of these dates were informed by previous studies which showed that most days in 2001 were warmer than those in 1971 as a result of increased urbanization and general global temperature increase (Romero et al, 1998; Tank et al, 2002; Le Treut et al, 2007). The global temperature model scenario created at the University of East Anglia (Le Treut et al, 2007) also showed that 1971 exhibited the lowest mean deviation from the mean global annual temperature (-2°C) while the highest temperature increase (+4°C) between 1900 and 2005 deviation occurred in 2001 (refer to Figure 1.3 for the trend values). Justifications for temperature increase in 2001 than 1971 has also been attributed to globally increased urbanisation, population (Chung et al, 2004; Le Treut et al, 2007), emission of greenhouse gases and increased sea surface temperature (Travis et al, 2002). Selected days (March 1, July 25 and December 24) were the mid-periods of the different seasons in the year, and are considered to be representatives of the seasons.

3.5. Data Analysis

3.5.1. Identification of statistical methods: Test of homogeneity and reliability analysis

Monthly records of temperature, relative humidity, ETI, THI and RSI data were subjected to statistical tests of homogeneity of variance and residual analysis to identify the relevant statistical approaches to be used. The results show that the data exhibit significant level of variance ($p \leq 0.01$) (Table 3.3a). Homogeneity of variance occurs where variance across multiple samples, possibly in different conditions is similar, and Levene's test (Levene 1960) is widely considered to be the standard homogeneity of variance test (Institute, 1999). This has become necessary because of the need to avoid the error of rejecting the right hypothesis or accepting the wrong one (Type 1 or Type II errors, Buhl-Mortensen, 1996; Jones et al. 2003). Buhl-Mortensen (1996) noted that these errors must be avoided to obtain objective conclusions.

In addition, the coded responses to the questionnaire were subjected to reliability test to measure their internal consistency or repeatability. This was achieved using Reliability analysis. Reliability analysis allows properties of the coded responses to be studied, and can be useful for the determination of relationships between individual items and inter-rater reliability estimates (Meeker and Escober, 1998). Using this method, one of five models ('split-half', 'Guttman' 'parallel', 'strict parallel' and 'Cronbach's alpha') are available in SPSS, but the most widely used (because of its direct interpretation) is the Cronbach's alpha (Bland and Altman, 1997). In SPSS, *Cronbach's alpha was* selected under *Reliability Analysis* which was selected from *Scale* and *Analyze* menu. The derived Cronbach's alpha averaged 0.343 (0.1442-0.4708), suggesting 'low' repeatability among the responses. This is acceptable since responses are expected to vary with respondents' socio-economic status, condition of work (outdoor or indoor), region of residence (north, south, etc.), age, etc. Given the significant variance in the temperature, relative humidity, ETI, THI and RSI, as well as a general low predictability in the questionnaire based on the results of Cronbach's alpha, analysis of variance (ANOVA) and regression analyses were found relevant to the study.

3.5.2. Descriptive statistics

All the variables and questionnaire used for this study were described (in terms of their mean, median, standard deviation and coefficient of variation) as advised by Carver and Nash (2005) for every data. Using SPSS, this was achieved by choosing *statistics* from the software menu, then *report*, and *summarise cases*. All preferred fields (columns) were selected and summarised to the required statistics. Some of the values (e.g. mean monthly and mean annual data) were subsequently presented in graphs. Some of the results were also used in the generation of descriptive maps explained in Section 3.7.2.

3.5.3. Analysis of Variance (ANOVA)

ANOVA is a statistical procedure for summarizing a classical linear model, a decomposition of sum of squares into a component for each source of variation in the model, along with an associated test (the F-test) (Bechhofer, 1960; Martin and Games, 1977; Gelman, 2005). When applied to generalized linear models, multilevel models, and other extensions of classical regression, ANOVA can be extended in two different directions. First, the F-test can be used to compare nested models, to test the hypothesis that the simpler of the models is sufficient to explain the data. Second, the idea of variance decomposition can be interpreted as inference for the variances of batches of parameters (sources of variation) in multilevel regressions. The ANOVA operations usually produce a table containing the between-group and within-group's sum of squares, degree of freedom and mean square (the variance). F-statistic is subsequently derived from the latter two (degree of freedom and mean square) and its random probability (P-value or significant value) is given, avoiding the need to consult the tables of critical values (Wheeler et al., 2010).

In this study, ANOVA was used to examine the variation in 1951-1980 and 1981-2009's temperature, relative humidity, ETI, THI and RSI values. Using SPSS, *One-way ANOVA* was selected from the *Analyze* menu. Temperature, relative humidity, ETI, THI and RSI were separately selected as dependent variable, while a field (column of data) termed 'period' (i.e. 1951-1980 and 1981-2009, coded as '1' and '2', respectively in an *ordinal* scale format) were selected as a factor. The mean (monthly, annual and period; 1951-1980 and 1981-2009) differences for temperature, relative humidity, ETI, THI and RSI, F-statistic and F-probability were produced. Statistically, ANOVA is derived using equation 3.5a-c. In equation 3.5a, the F-statistic compares the variability between the groups to the variability within the groups.

$$F = MST/MSE \qquad 3.5a$$

$$MST = \frac{\sum_{i=1}^{k} [(t_i{}^2/n_i)-(g^2/n)]}{k-1} \qquad 3.5b$$

$$MSE = \frac{\sum_{i=1}^{k}\sum_{j=1}^{n_i} y_{ij}{}^2 - \sum_{i=j}^{k}(t_i{}^2/n_i)}{n-k} \qquad 3.5c$$

where

F = variance ratio,

MST = mean square due to treatments/groups (between groups),

MSE = mean square due to error (within groups, residual mean square),

y_{ij} = an observation, *k* = total group of observations, t_i = a group total, g = grand total of all observations, n_i = the number in group, *i* and *n* = total number of observations.

Table 3.3a: Data Characteristics: Results of Levene's Test of Variance

Variables	**Coefficient values**			
	F-value	df1	df2	P-value
Max Temperature	67.75	17	10180	0.01
Min Temperature	299.07	17	10180	0.01
Relative Humidity	562.34	17	10180	0.01
Mean Temperature	145.48	17	10180	0.01
Effective Temperature Index	176.02	17	10180	0.01
Temperature-Humidity Index	99.34	17	10180	0.01
Relative Strain Index	45.96	17	10180	0.01

Table 3.3b: Data Characteristics: Results of Cronbach's Alpha

Number of Test	**Region**	**Cronbach's alpha**
1	South-south	0.37
2	North-East	0.47
3	North West	0.14
4	North Central	0.41
5	Southwest	0.46
6	South East	0.20
	Overall	0.34

3.5.4. Analysis of trend and rate of change (Regression Analysis)

Trend (1951-2009) in each of temperature, relative humidity, ETI, THI and RSI was determined using the linear regression analysis. Regression analysis resulted into parameters of estimates ($x_1 \ldots x_n$), which indicate how a change in one of the independent variables (year, decade or 'period', as used in this study) affects the values taken by the dependent variable (temperature, relative humidity, ETI, THI or RSI) and offer possibility for future predictions. Regression parameters for a straight line model were calculated by the least squares method (minimisation of the sum of squares of deviations from a straight line) (equations 3.6a and b), as the slope (*b*) and *y* intercept (*a*) of the line model

$$y = a + bx \quad 3.6a$$

where

$$a = \overline{y} - b\overline{x} \quad 3.6b$$

$$b = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \quad 3.6c$$

This was performed separately for each of the 18 stations. Using the linear regression equation, the F-value (also known as F-statistics or variance ratio) is used to determine the level of significance of the regression coefficients (i.e. *a* and *b*). F-value is defined as the ratio of the explained variance to the unexplained variance (equation 3.7a-c)

$$F = Sy^2/Se^2 \quad 3.7a$$

$$Sy^2 = \frac{\Sigma(\hat{y} - \overline{y})^2}{k} \quad 3.7b$$

$$Se^2 = \frac{\Sigma(y - \hat{y})^2}{n - k - 1}$$

3.7c

where

Sy^2 = explained variance, Se^2= unexplained or residual variance, $\hat{y}$ = best estimate of y, $\overline{y}$ = mean of y, y= individual observations of y, n= number of pairs of observations, and *k* = number of predictors

3.5.5. Correlation analyses to determine seasonal similarities

Similarities in the seasonal values of the variables were determined using the Pearson's product moment correlation coefficient (r), which is defined as a measure of linear association between two seasons. It is statistically defined as

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}} \qquad 3.8$$

where

$x, \bar{x}$= sample (season A) mean and standard deviation
$y, \bar{y}$ = sample (season B) mean, and standard deviation

The Spearman correlation coefficient is defined as the correlation coefficient between the ranked variables (Myers and Well, 2003). While Pearson's correlation coefficient requires both variables to be measured on an interval or ratio scale, using the actual values, Spearman rank correlation coefficient requires data that are at least ordinal, and the calculation requires that each variable is ranked separately by putting the values of the variable in order and numbering them: the lowest value is given rank 1, the next lowest is given rank 2 and so on. If two data values for the variable are the same they are given averaged ranks, so if they would have been ranked 14 and 15 then they both receive rank 14.5. Using SPSS, Spearman's correlation was selected in place of Pearson's to determine this on the questionnaire responses.

3.6. Descriptive mapping

Descriptive mapping using the geographic information systems (GIS) was used to show the spatial and temporal variations of the variables (temperature, relative humidity, ETI, THI and RSI) investigated in this study. Using the GIS procedure, the maps were drawn in the Integrated Land and Water Information System (ILWIS version 3.3). The ILWIS software is a software product of the ITC Enschede, Netherlands, and it is capable of handling both raster and vector data format. A raster format data include images while vector data include those obtained with surveying equipment. A map of Nigeria, showing the ecological regions was converted to digital format when it was scanned (in *.jpeg* format), and subsequently imported to ILWIS environment for use. The image was georeferenced using known locations whose coordinates (x, y) are already known. A georeference defines the relation between rows and columns in a raster map and XY-coordinates, in a coordinate system which may contain projection information (ILWIS Help). Each map theme was subsequently created from the georeferenced map by on-screen digitising (for segment and polygon or area objects) and *add point* menu (for stations whose coordinates are known, and values).

The value maps were interpolated or gridded to produce a raster map, whose value (for each pixel) are calculated (by the software) for each by the weighted average of the input values of the surrounding pixel. This was achieved for different themes of scenarios for the variables, in terms of their means and variability (coefficient of variation). Coefficient of variation (CV) was determined by

$$CV = \frac{SD}{\bar{y}} * (100) \qquad 3.9$$

Where: SD= Standard deviation, $\bar{y}$ = mean of y

Each map was thereafter added ('overlay') by digitised shape of the national boundary, climatic regions, main rivers and location of some settlements.

Hourly variations of ETI, THI and RSI for selected stations in each of the climate regions in 1971 and 2001 were mapped using Surfer (8) for Windows software. The choice of years and stations were based on data availability. The selected stations include Calabar (tropical wet), Benin (tropical wet and dry), Jos (montane), Kano (tropical sudan savanna), Lokoja (tropical guinea savanna) and Nguru (tropical sahel savanna). Both missing and unknown values were obtained by weighted average (kriging) interpolation method. Kriging, in general, assumes spatial correlation between the input point values, and the existing methods include 'Simple', 'Ordinary', 'Anisotropic', 'Universal' and 'Co-kriging' (ILWIS Help, 1999). The Ordinary Kriging, which is often used in environmental researches (Hendrikse, 2000), and the method estimates the mean at each new location within a limiting distance and a minimum and maximum number of points such that only the points that fall within the limiting distance to an output pixel is used in the estimation of new location (ILWIS Help, 1999).

All the daily maps are plotted using the moving average statistics in Surfer (for Windows, 8 version) software. In statistics, a moving average is a calculation to analyze data points by creating a series of averages of different subsets of the full data set (Carver and Nash, 2005).

3.7. Delineation of Physiologic Climates in Nigeria

Physiologic climates in Nigeria from this study were delineated using different scenarios:

(1) Inventorying the year (1951-2009) with values of index of physiologic climates (ETI, THI and RSI) above or below thresholds for comfortable climate (18.9^{o}-25.6^{o}ETI, 15^{o}-24^{o}THI or 0.1-0.2 RSI), and subsequently converting the frequencies to their percentages, before classifying Nigeria, based on the results obtained. The threshold values have been widely accepted as comfort thresholds for Tropical countries, e.g. Nieuwolt, 1977; Kyle, 1994; Gulyas and Matzarakis, 2007; Ogbona and Harris, 2008). The frequencies were converted to percentages because some of the stations do not have same number of data period. Nigeria was subsequently classified into different 'regions' using K-mean cluster analysis. K-means cluster analysis is a tool designed to assign cases to a fixed number of groups (clusters) whose characteristics are not yet known but are based on a set of specified variables (SPSS Helpfile, 2012);

(2) Inventorying the means below or above the threshold values for (i) 1951-2009, 1951-1980 and 1981-2009 overall means for ETI, THI and RSI, and (ii) seasonal (Harmattan, rainy and dry) means for 1951-2009. Mean values within the thresholds were used as comfortable limits.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter describes and discusses the results of the analyses conducted in the study. The results are discussed in terms of their annual (1951-2009), periodic (1951-1980 and 1981-2009), seasonal (rainy, dry seasons and Harmattan period), monthly and diurnal patterns, respectively. Also discussed is the relationship among temperature, relative humidity and selected physiologic indices (effective temperature index, temperature-humidity index and relative strain index) with latitude, longitude and altitude of the locations of synoptic stations. Attempt is also made to classify Nigeria into different physiologic climate regions using the K-mean cluster statistics. In this study, classification is therefore reported in annual means of 59 (1951-2009) years, seasonal (rainy and dry seasons, and Harmattan) means, periodic (1951-1980 and 1981-2009) and daily means (means of selected years; 1971 and 2001). The monthly means are described in line graphs. Responses from about 3600 sampled Nigerian population on perception on physiologic climate and coping strategies for stressful periods are also reported.

4.1. Annual Patterns of Temperature and Relative Humidity

Annual patterns of minimum, maximum and mean temperatures as well as the relative humidity are described in this section. Their summaries are provided as Appendices 4.1 – 4.7.

4.1.1. Minimum temperature

The overall average minimum temperature for all the 18 synoptic stations is 21.4±3.43^{o}C (Appendix 4.1). Stations whose average annual minimum temperatures were below the overall average are Katsina, Yelwa, Potiskum, Bauchi, Jos, Ilorin, Nguru and Maiduguri; which are all in the tropical savanna and montane climate regions. The range of mean minimum temperature is between 16.0±2.28^{o}C and 23.1±0.93^{o}C. Minimum temperature has significantly increased ($b \leq 0.05$; $p<0.05$) in all the climate regions ($b=-0.03$; $p<0.05$).

This increasing trend in the minimum temperature has also been reported by Adebayo (1999). Adebayo (1999) suggested that the increasing trend in minimum temperature indicates increased night-time temperatures, and a situation that is linked to global warming effect. Global warming is a condition of temperature rise caused by natural and anthropogenic causes (Ayoade, 2003). Global warming effect has been argued to account for about 0.3-1.1^{o}C temperature rise.

Annual variations in mean minimum temperature at different eco-climatic regions are shown in Figure 4.1. Similar to the results of the regression analysis, the temporal trends of the annual means show that there was a generally increasing pattern in most regions, except montane where minimum temperature has decreased from an apparently fair stability in the first 28 (1951-1978) years. This decline in the minimum temperature which occurred between 1978 and 2004 precedes a sharp rise in 2005. The onset of the rise in minimum temperature at the Sahelian station (Nguru) was however earlier (1984). Except for some degree of fluctuations (insignificant in most cases) at some stations, all the stations in the remaining regions exhibited steady increasing trend from 1951-2009.

The mean annual minimum temperature and its variability for 1951-2009 as obtained from the geoinformation-based kriging interpolation techniques used for this study are presented as Figures 4.2a and 4.2b, respectively. The variability (i.e. coefficient of variation) map was derived by same method. Figure 4.2a shows that the southern region, including the tropical wet, tropical wet and dry climate regions, and some parts of tropical savanna (guinea and sudan) are characterised by relatively higher mean minimum temperature than the montane and the north-central part of the sudan savanna regions. The lowest (16-18^{o}C) mean annual minimum temperature occurred in the montane region. The low minimum temperature and the fairly late onset of temperature rise as well as relatively steady temperature at the montane region could be explained by the known principle of Environmental Lapse Rate (ELR), which suggests that temperature at high altitude drops by 0.6^{o}C at every 100 m or 1^{o}C at 164 m ascent (Strahler and Strahler, 1994).

The map showing the variability in the mean annual minimum temperature shows 20-25% coefficient of variation in the north-eastern Nigeria and Katsina region (Figure 4.2b). Calabar and Warri in the extreme southern region of tropical wet climate recorded only 0-5%. Variability also appears to increase from the southern region to the north-eastern part, suggesting a direct relationship of variation in minimum temperature with latitude. The observed relationships between latitude, altitude, longitude and all the investigated indices are reported later in this Chapter. Nonetheless, it could be argued at this stage that proximity or distance from the Atlantic Ocean is a possible explanation for the occurrence of the pattern of the relationship that is observed between the minimum temperature and latitude in this case. Agboola and Hodder (1979) argued that the moisture-carrying Tropical Maritime airmass from the Atlantic Ocean could push through the south-western coastal region, causing the temperature to reduce considerably in the southern region, especially in the rainy season. The influence of the Tropical Maritime airmass however reduces with distance away from the Atlantic Ocean. The contrasting thermal properties of land and water as regards absorption and reflection of heat could account for higher minimum temperature variability in the north than the south, as minimum temperature drops faster on continental surfaces than areas close to the Ocean. In addition, Oguntoyinbo (1986) and Adebayo (1999) reported that drought condition occurred in the north-eastern Nigeria between 1951 and 1973; a situation that could also account for high temperature variability in the region.

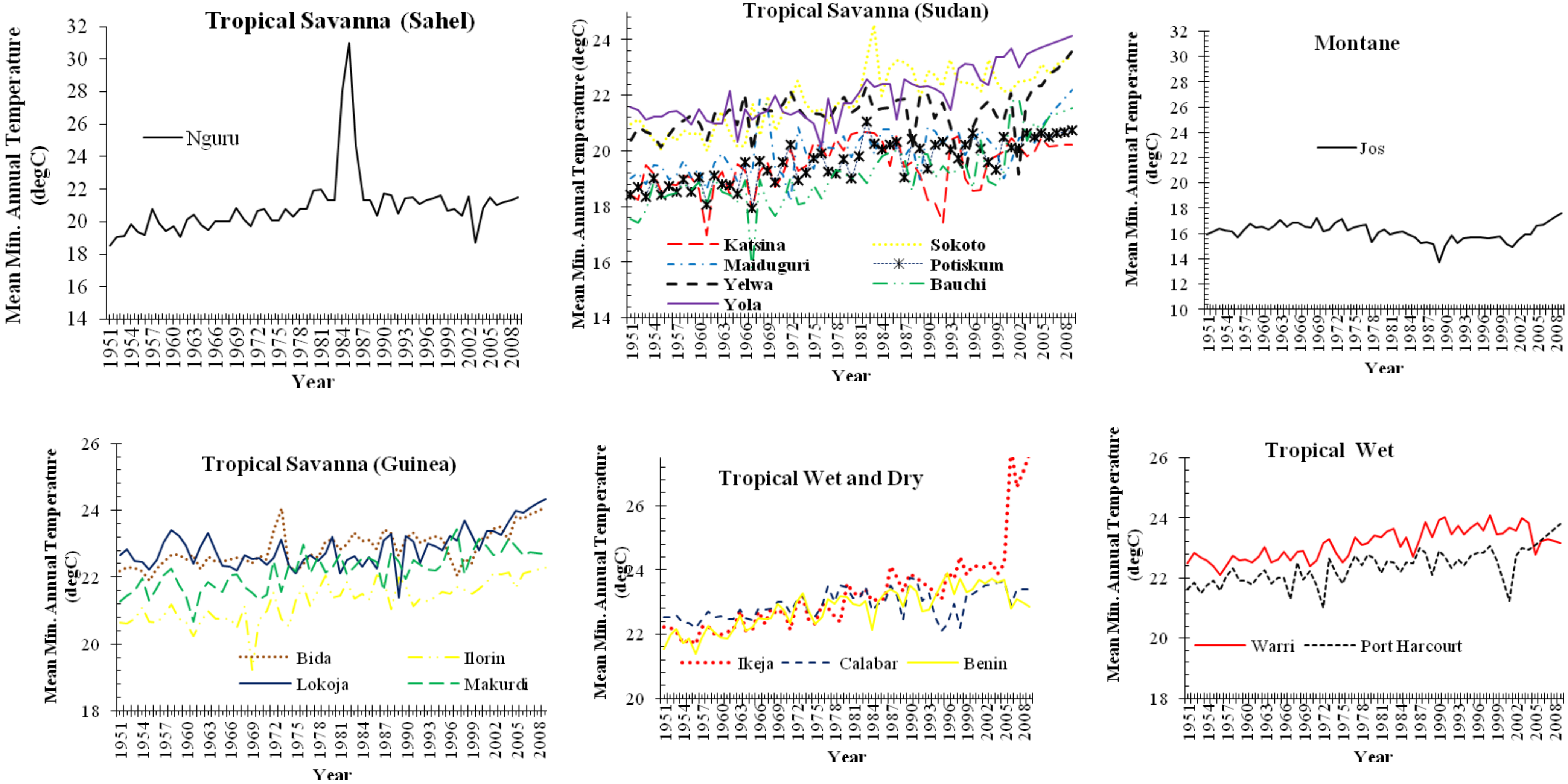


Figure 4.1: Annual Variations in Minimum Temperature at Different Eco-Climatic Regions (1951-2009)

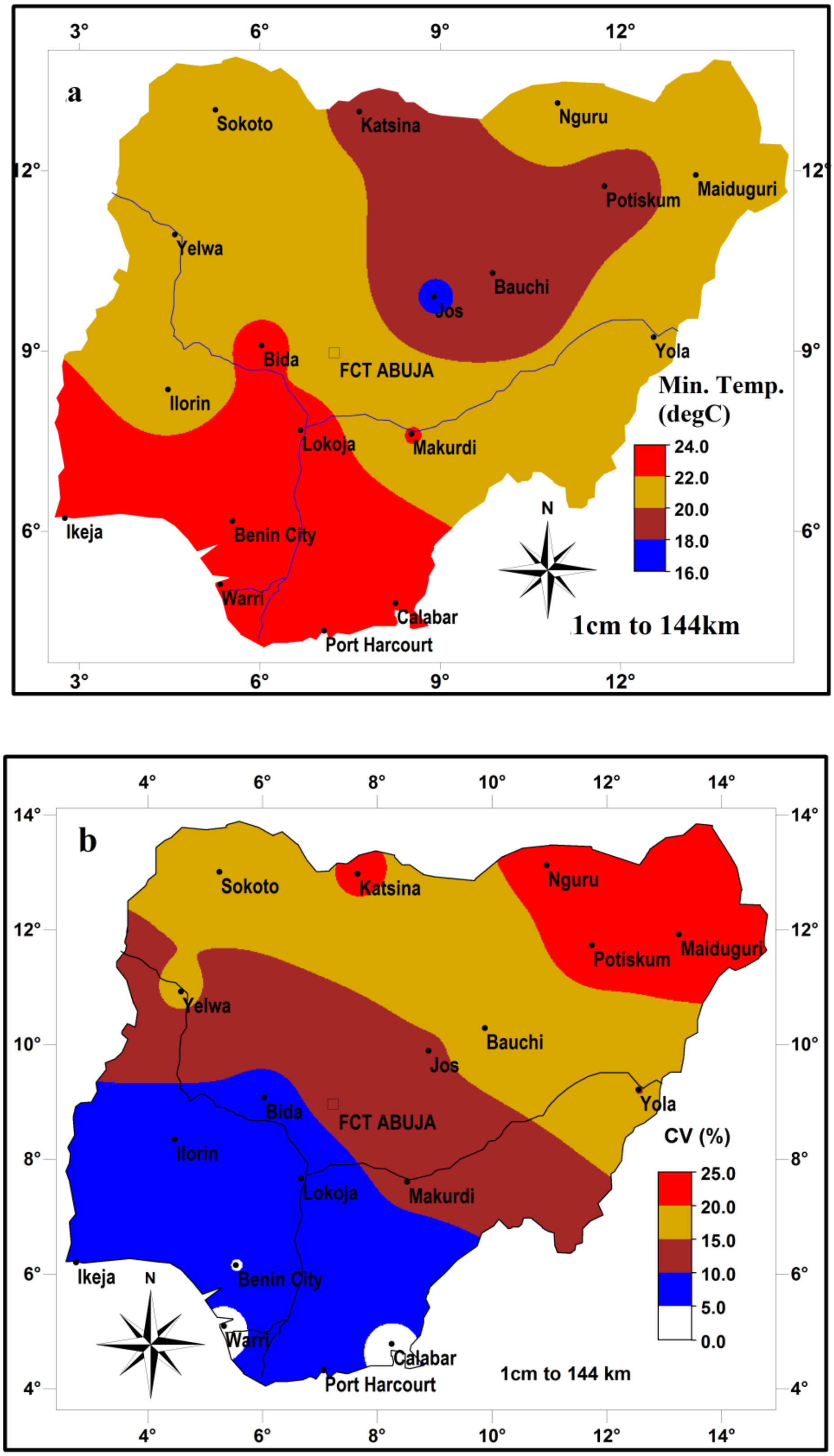


Figure 4.2a-b: (a) Mean Minimum Temperature (°C) and (b) Coefficient of Variation (%) for the Period of 1951- 2009 over Nigeria

Investigation of the 1951-1980 and 1981-2009 mean annual minimum temperature as shown in the results of the geoinformation-based kriging maps (Figures 4.3a and 4.3b) suggest that the minimum temperature has increased at most part of Nigeria in the 1981-2009 period. Visual comparison of the maps (Figure 4.3a and 4.3b) suggest that except for the montane region and the neighbouring station of Bauchi, minimum temperature has increased in Nigeria. Reduced vegetation due to urbanisation and industrialization, decrease in surface water bodies by sand filling, construction and related activities, and global warming phenomenon (Adebayo, 1991; Barradas, 1991; Piguet, 2010) are causes of increase in minimum temperature.

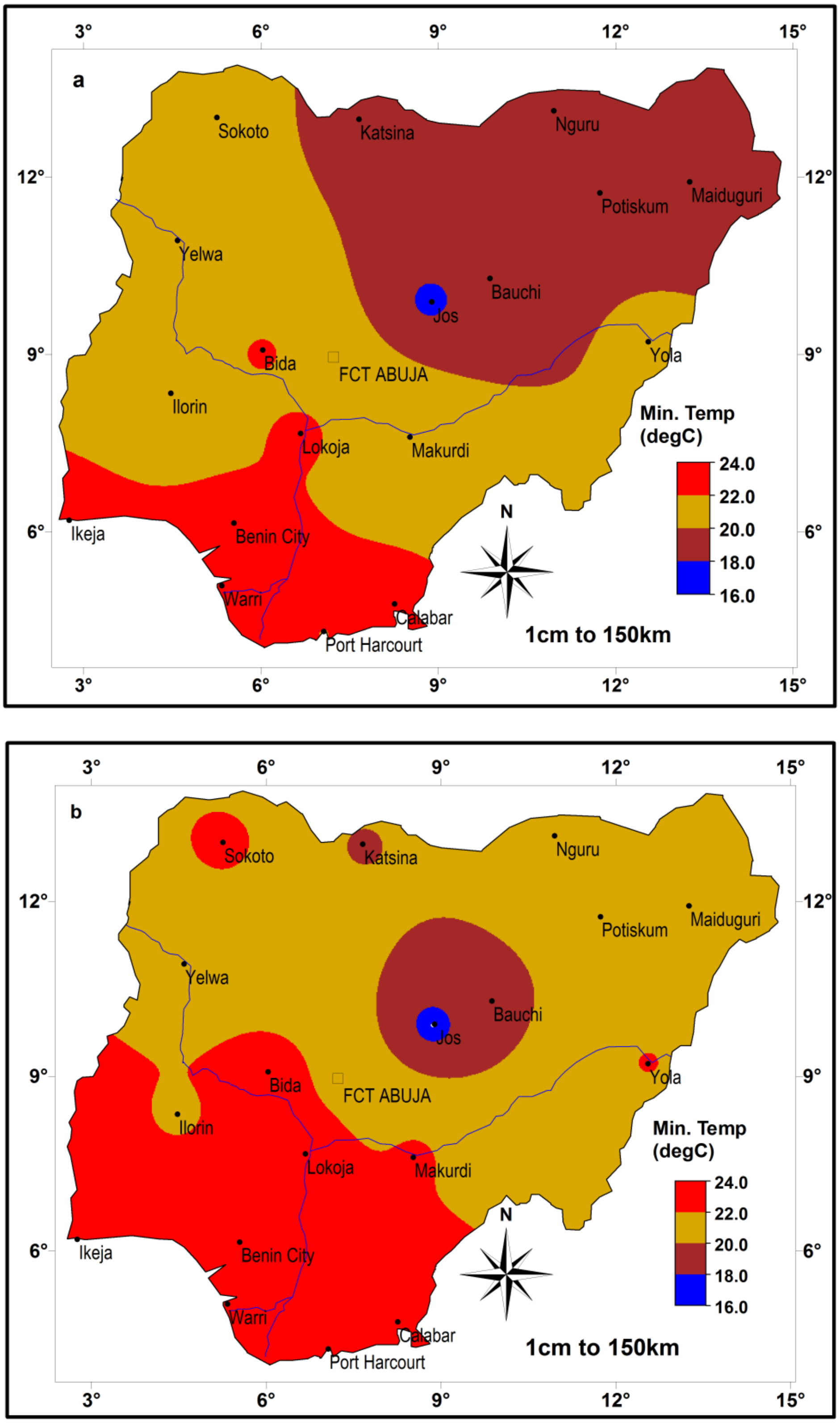


Figure 4.3a-b: Mean Minimum Temperature (a) 1951-1980 and (b) 1981-2009 over Nigeria

4.1.2. Maximum temperature

Mean annual maximum temperature ranged between 27.6±2.27 and 35.3±3.58^{o}C while the overall average for the selected 18 meteorological stations is 32.8±3.37^{o}C (see Appendix 4.2). Most stations in the savanna region (except Bauchi and Ilorin) exhibited higher maximum temperature than the overall average, while stations in the rainforest (tropical wet and dry and tropical wet climates) and montane regions exhibited relatively lower maximum temperature than the overall average. The result of linear trend analysis shows that maximum temperature increased significantly at most meteorological stations ($b \geq 0.01$; $p<0.05$), except at Yelwa, Maiduguri, Yola and Ilorin in the savanna region. The only station that recorded significant decreasing trend is Yelwa, in sudan savanna ($b=-0.03$; $p<0.05$). In the study by Adebayo (1999), about 81% of the investigated stations in Nigeria exhibited decreasing trends in maximum temperature between 1900 and 1990, while about 19% exhibited significant rise. Adebayo (1999) attributed the increasing trend in the few 19% of the (27) meteorological stations to the influence of dust haze, identified in earlier study on Nigerian climate (Adedokun and Adeyefa, 1991) to be capable of increasing maximum temperature. Nevertheless, recent studies (e.g. Barradas, 1991; Le Treut et al., 2001; Svensson and Tarvainen, 2004) have shown that maximum temperature have increased in many parts of the world as urban activities, including traffic and vehicular activities, building density, construction, population and industrialisation increase.

Figure 4.4 shows that the observed increase is less than 2^{o}C interval, suggesting a slight increase at most stations. Nevertheless, studies (e.g. Mohammed et al, 2000; Matzarakis, 2001) have suggested that temperature increase as small as 1^{o}C, given inadequate coping strategy could endanger people's lives, especially if it continues for a relatively long period of days. In addition, rapid change in maximum temperature or extreme weather events have been linked with increased mortality in some cities in southern Ontario, Canada, between 1980 and 1996 (Smoyer et al, 2000).

The geoinformation based kriging maps of the annual maximum temperature and the coefficient of variation for 1951-2009 period, is presented in Figures 4.5a-b, respectively. Figure 4.5a shows that the montane region exhibited the lowest maximum temperature (27-29^{o}C) while higher temperature occurred in the north (>33^{o}C). Peaks of maximum temperature (35-37^{o}C) for the period occurred at Sokoto, Nguru and

Maiduguri, in the sudano-sahelian region. Temperature extremes experienced in this region could be explained by the intense insolation received at the region for most part

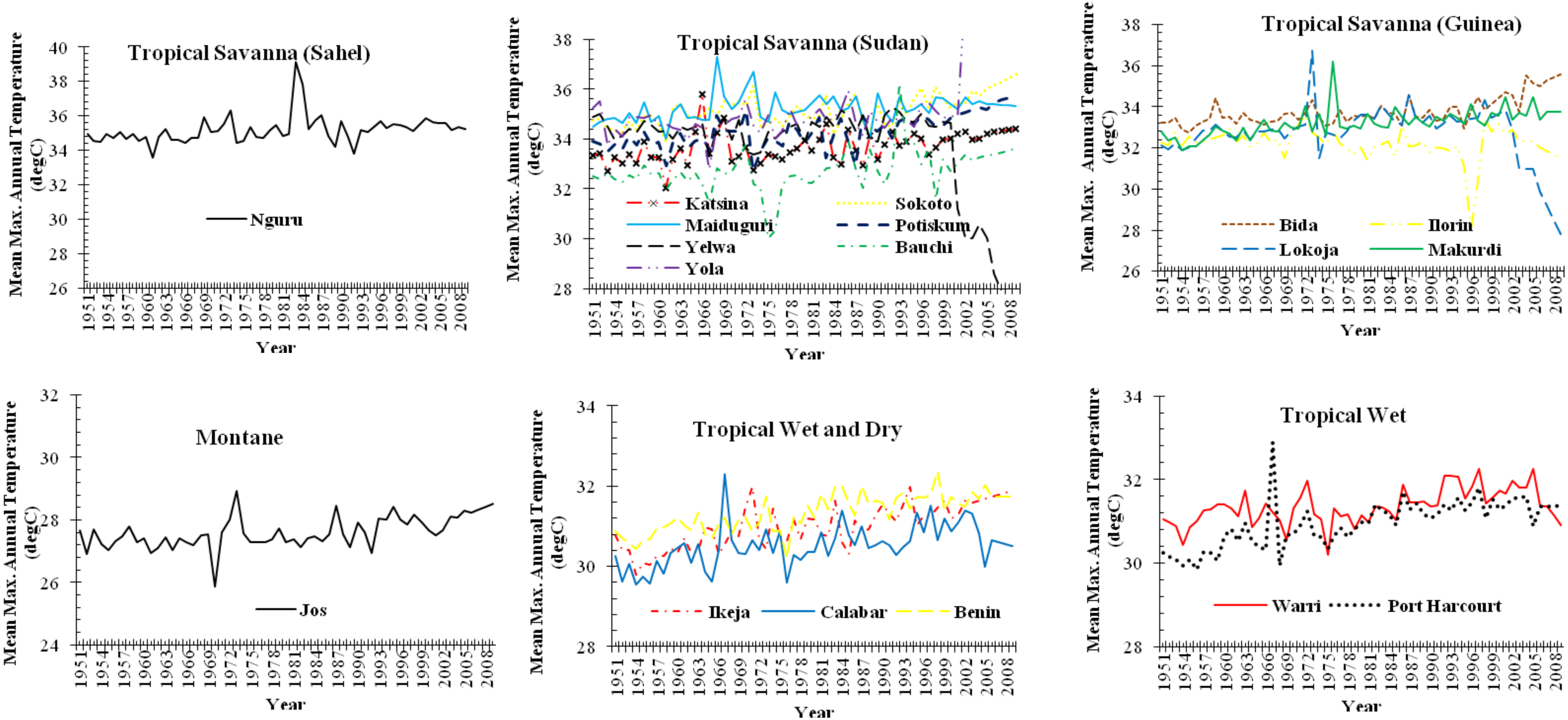


Figure 4.4: Annual Variations in Maximum Temperature at Different Eco-Climatic Regions (1951-2009)

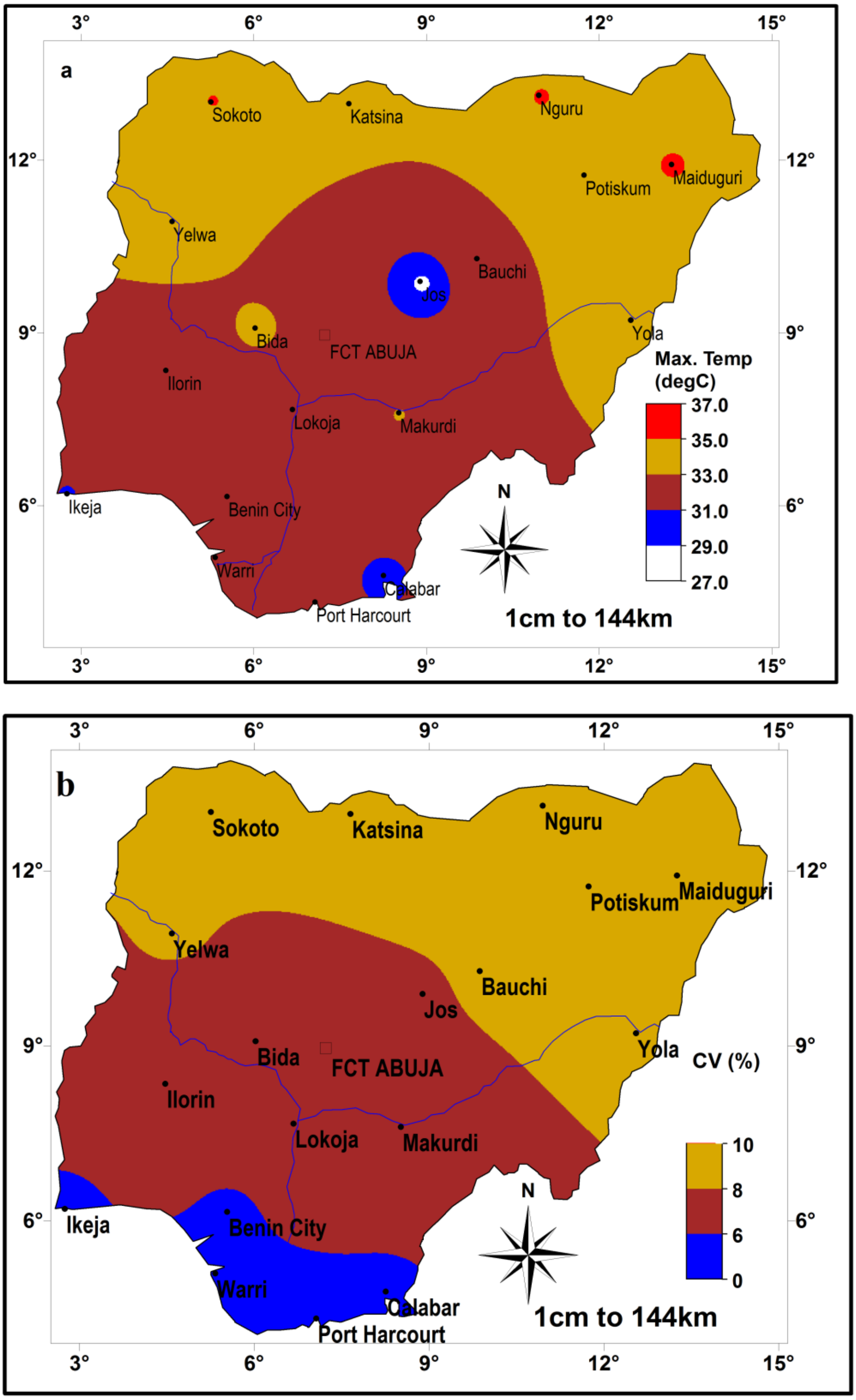


Figure 4.5a-b: (a) Mean Maximum Temperature (ºC) and (b) Coefficient of Variation (%) for the period of 1951-2009 over Nigeria

of the year, especially in the dry season. Variability as measured by coefficient of variation was lower than what obtained in the minimum temperature (discussed earlier in section 4.1.1) but both follow similar pattern of south to north increase. Moreover, when compared, maximum temperature has significantly increased in the 1981-2009 period (Figure 4.6b) than the earlier 30-year (1951-1980) (Figure 4.6a) period, by about 2^{o}C. Cases of extreme heat are shown to occur at some stations, including Maiduguri, Nguru, Yola and Sokoto in the sudano-sahelian region, while the montane region and Calabar in the tropical wet climate has remained relatively stable between 1951-1980 and 1981-2009 periods (Figures 4.6a and 4.6b). Extreme heat events in northern Nigeria, especially Zaria have been linked with 6 -19 per thousand increases in cases of measles and meningitis in the area (Sawa and Buhari, 2011). Boko et al (2007) also showed that temperature increase in Africa could cause severe heat stress, especially where infrastructure are inadequate for the increasing urban population.

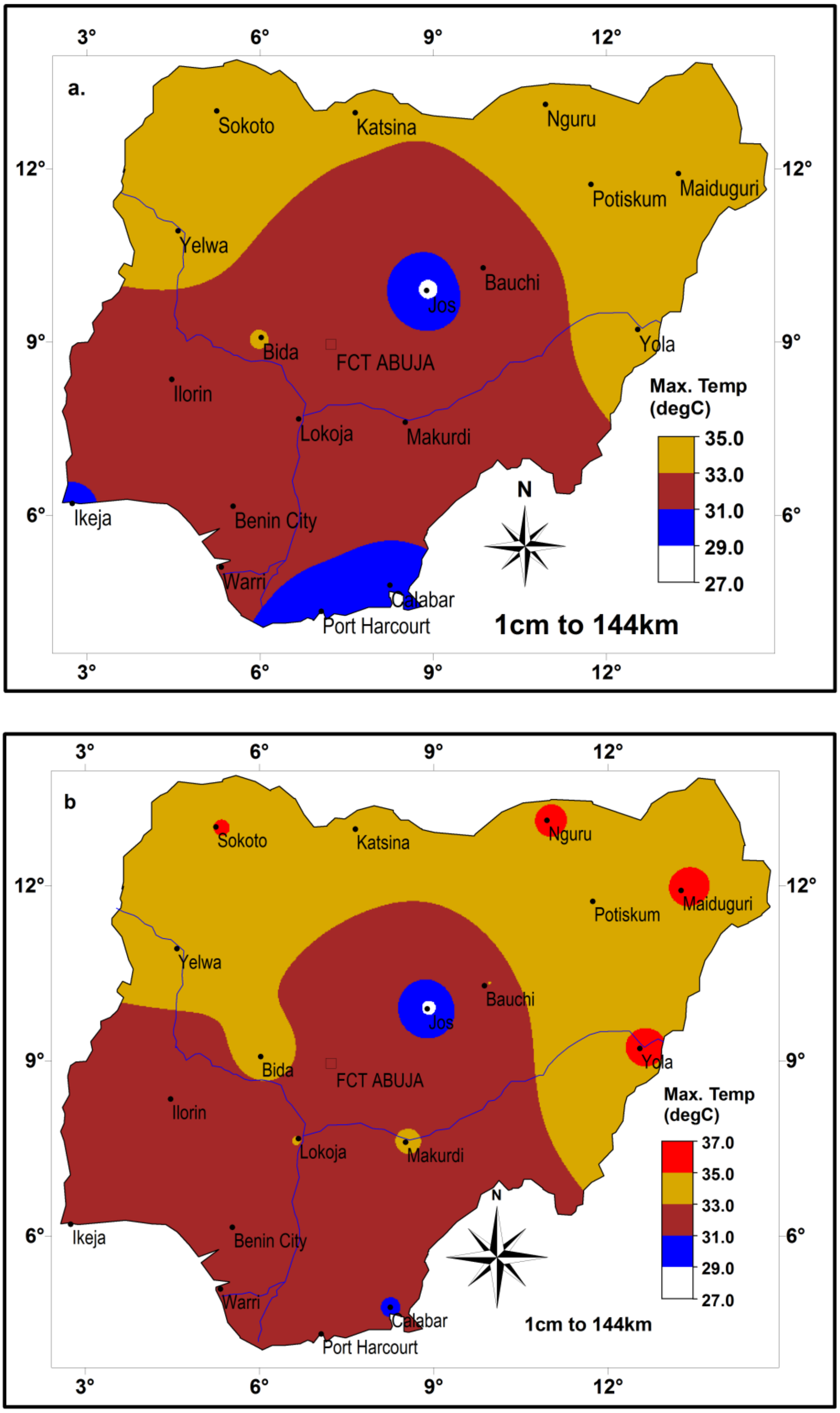


Figure 4.6a-b: Mean Maximum Temperature (°C) over Nigeria in (a) 1951-1980 and (b) 1981-2009

4.1.3. Mean Temperature

The annual mean temperature at the investigated meteorological stations ranged between 21.8±1.68 and 28.6±2.98°C while the overall average is 27.0±2.79 °C (see Appendix 4.3). Mean temperature at most stations exhibited higher mean temperature than the overall average while Katsina, Bauchi, Jos, Ilorin, Calabar and Port Harcourt, representing almost all the eco-climatic regions exhibited lower mean temperature than overall average. This suggests that the mean temperature-latitude relationship may be weak. The actual relationship is described in Section 4.9.

The results of the trend analysis shows that mean temperature increased at all regions ($b \leq 0.03$; $p \leq 0.05$), except at the montane region ($b \leq -0.01$; $p \leq 0.05$), and Yelwa, in the sudan savanna ($b = -0.01$; $p \geq 0.05$). In addition, as obtained for the minimum and maximum temperatures, the mean annual temperature at the montane region appear to have uniformly fluctuated from 1951 to 2009 but stations in other climate regions exhibited steadily increasing patterns (Figure 4.7). The apparently lower temperature in the montane region has been earlier explained within the principle of environmental lapse rate; a principle that suggests that temperature tends to decrease by 1^0C at 164 m ascent (Strahler and Strahler, 1994) while the higher temperature observed at many stations in the savanna could be explained by their location in the north- a situation that has made them vulnerable to the prevailing dry tropical continental airmass from the Sahara desert (Iloeje, 2001). The sharp rise in mean temperature observed towards the tail end of the study period could be explained as part of the temperature increase that have been associated with global warming phenomenon (Oguntoyinbo, 1986; Adebayo, 1999).

The geoinformation based kriging maps which show the delineation of Nigeria into mean temperature averages and their coefficient of variation are presented as Figures 4.8a and 4.8b, respectively. Figure 4.8a shows that mean temperature was lower in the montane region and neighbouring Bauchi (20-24°C) than the other parts of Nigeria. Sokoto, Nguru, Yola and Bida stations in the north exhibited the peak of mean temperature. Figure 4.8b shows that variability increased from southern Nigeria towards the north, reaching the peak (14%) in the north-east and Katsina. Variability is apparently lower in the southern Nigeria than the north. When aggregated into 1951-1980 and 1981-2009 means, the produced maps suggested that significant increase in mean temperature occurred from 28 to 30^oC in the 1981-2009 period at locations in the sudano-sahelian region (Yola, Sokoto, Bida and Nguru) (Figure 4.9a and 4.9b).

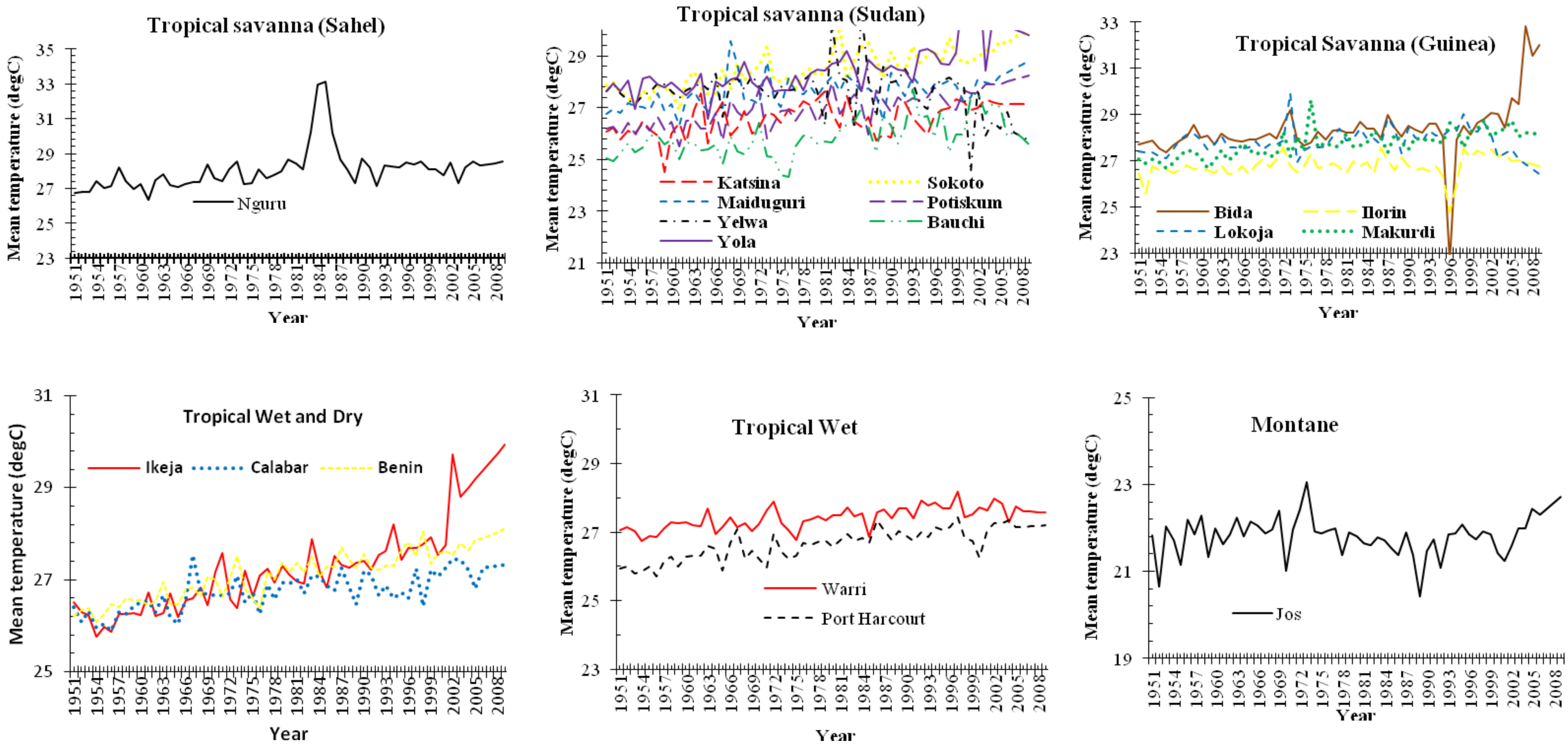
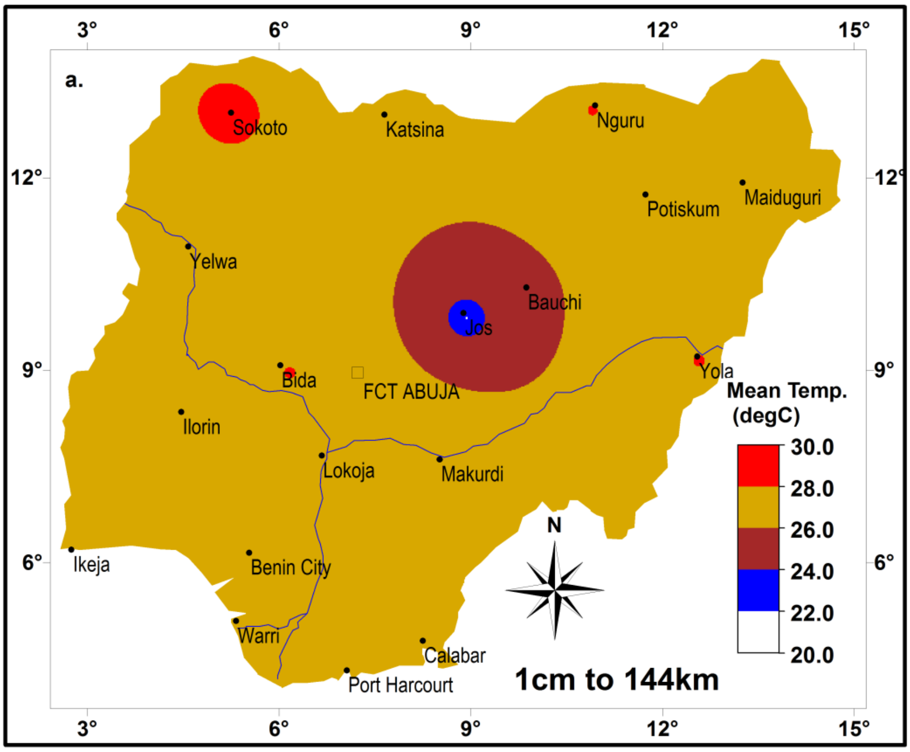


Figure 4.7: Annual Variations in Annual Mean Temperature at different Eco-Climatic Regions (1951-2009)



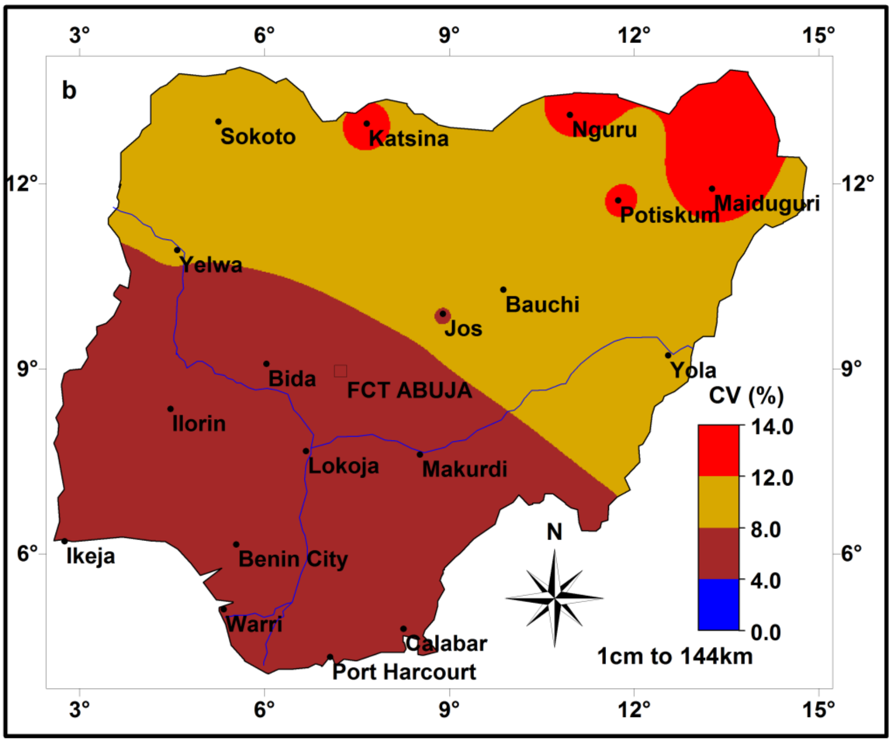
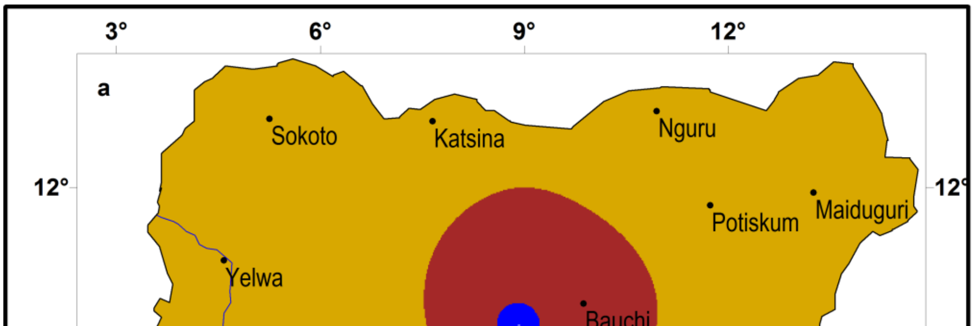


Figure 4.8a-b: (a) Mean Temperature (°C) and (b) Coefficient of Variation (%) for the period of 1951 – 2009 over Nigeria



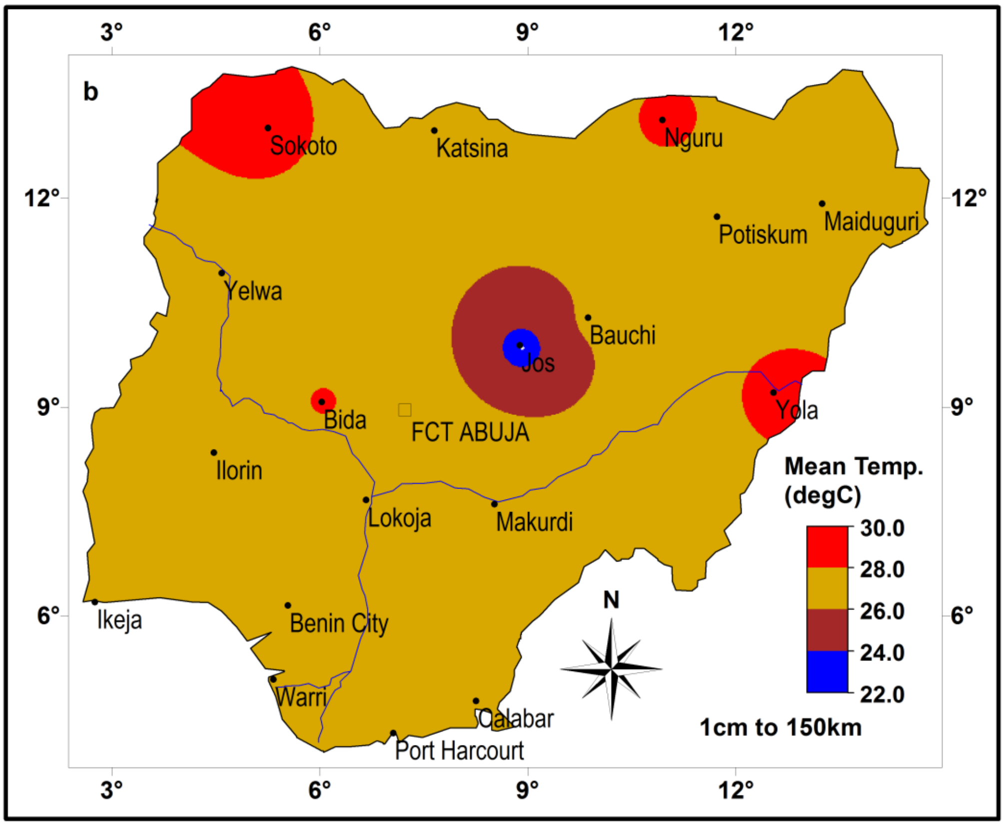


Figure 4.9a-b: Mean Temperature (^{o}C) over Nigeria in (a) 1951-1980 and (b) 1981-2009.

In simple terms, the results have shown that many stations in the savanna region experienced higher maximum temperature but lower minimum temperature than the rainforest region. Mean temperature was however almost evenly distributed, except for instances of higher means at Sokoto and Yola. The montane climate was characterised with the lowest annual minimum, maximum and mean temperature.

4.1.4. Relative Humidity

Relative humidity, an important form of humidity and a relative index for measuring thermal comfort in bioclimatology (Voogt, 2002; Wolkoff and Kjaergaard, 2007), is described in this study in terms of its annual average, range, coefficient of variation and linear trends in Appendix 4.4. The overall average relative humidity for the period of study is 61.98±24.8%. Stations in the sahel and sudan savanna and montane regions (Sokoto, Katsina, Nguru, Yola, Yelwa, Potiskum, Bauchi, Maiduguri and Jos) exhibited lower means than the overall mean relative humidity while the tropical guinea and the rainforest exhibited higher than the overall mean.

The range of the mean relative humidity varies between 36.5±21.1% and 85.11±4.96%. Coefficient of variation was also significantly lower in the guinea savanna and rainforest region than in the sudano-sahelian region. Converse to the trends of temperatures, where positive and increasing trends were observed, relative humidity has decreased in most regions, especially in the tropical rainforest region ($b \geq -0.07$; $p < 0.05$). Bauchi, a station in the sudan savanna and neighbouring station to the montane region however exhibited significant increase ($b = 0.17$; $p < 0.05$), and the decreasing trend at most stations in the savanna region was insignificant. Figure 4.10 shows that mean annual relative humidity has significantly reduced in the rainforest region while it appears more complex in the savanna region. As observed for the temperature, the montane region exhibited a steady rise in relative humidity from 1981 while the pattern at the other regions exhibited insignificant fluctuations.

The geoinformation-based maps generated for the 1951-2009 mean relative humidity (Figures 4.11a) show that relative humidity decreases from south to northern Nigeria, converse to its variability, which increases south-northwards (Figure 4.11b). Hulme et al (1992) suggested that areas with low (<30%) humidity are classified by the global moisture index as ‘drylands’, and those with high (>70%) humidity as ‘wetlands’. Following this suggestion (Hulme et al., 1992), no station in Nigeria could be described as a ‘dryland’ based on the annual average of the relative humidity but the

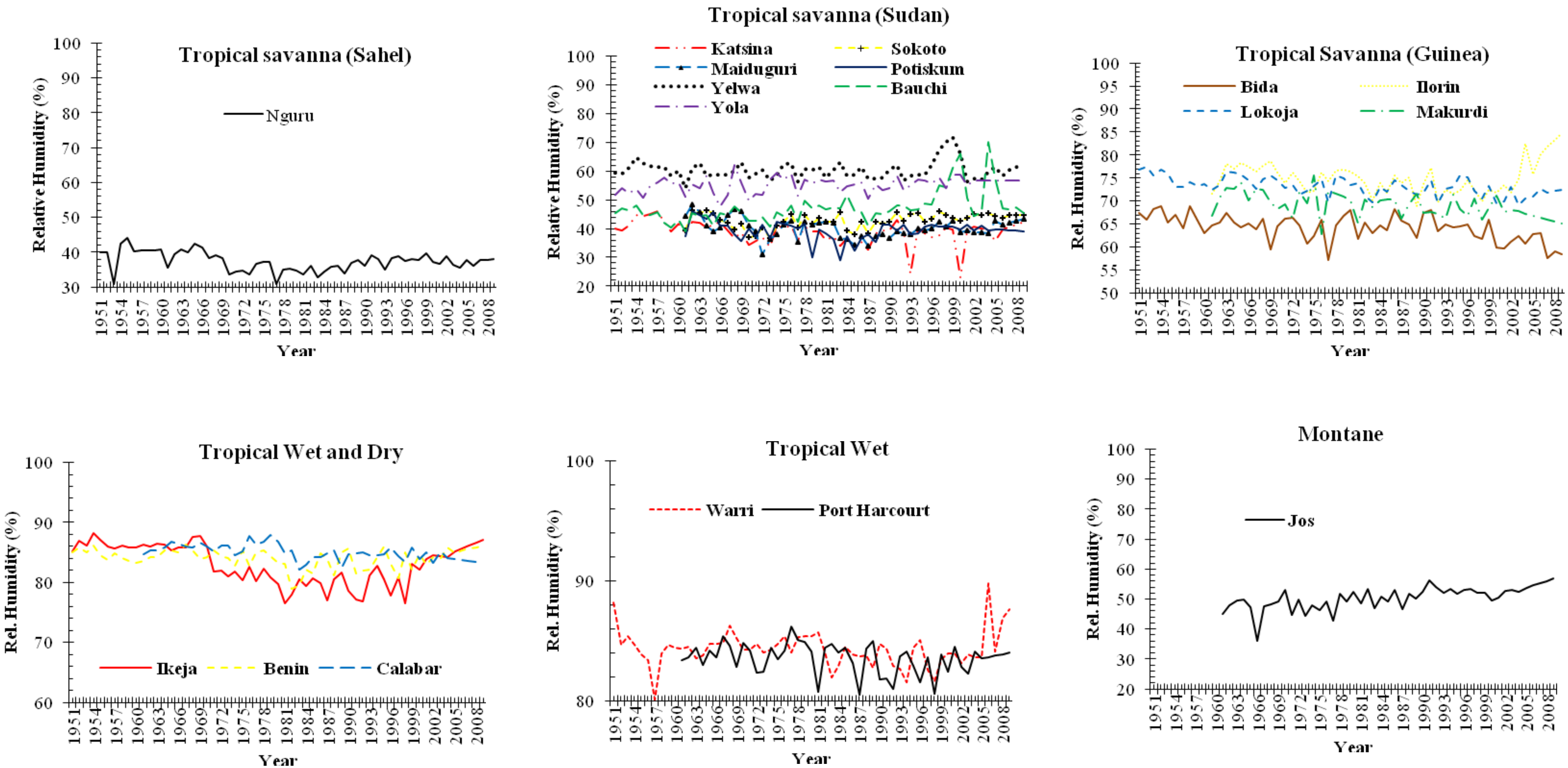


Figure 4.10: Annual Variations in Relative Humidity at different Climatic Regions (1951-2009)

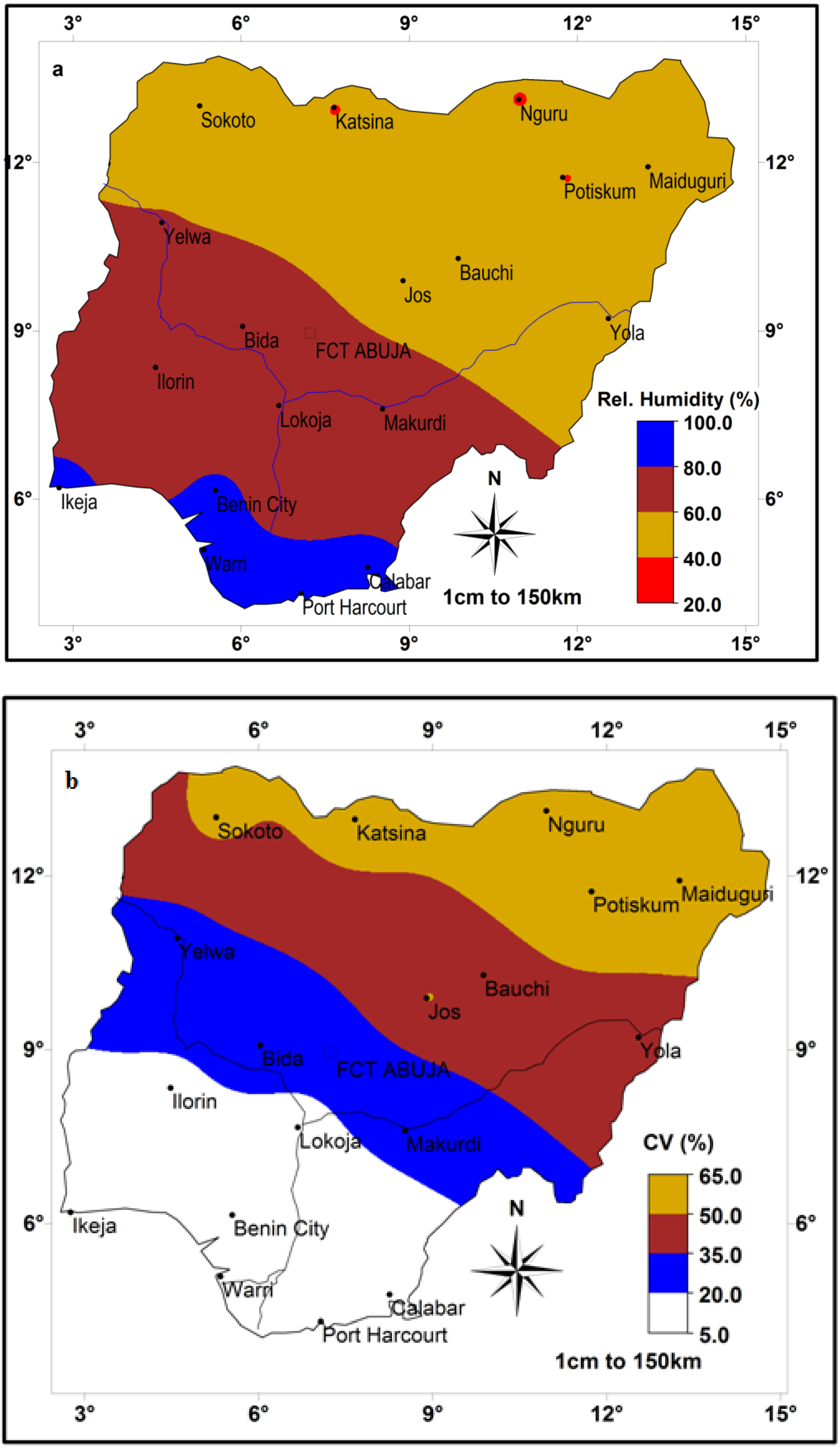
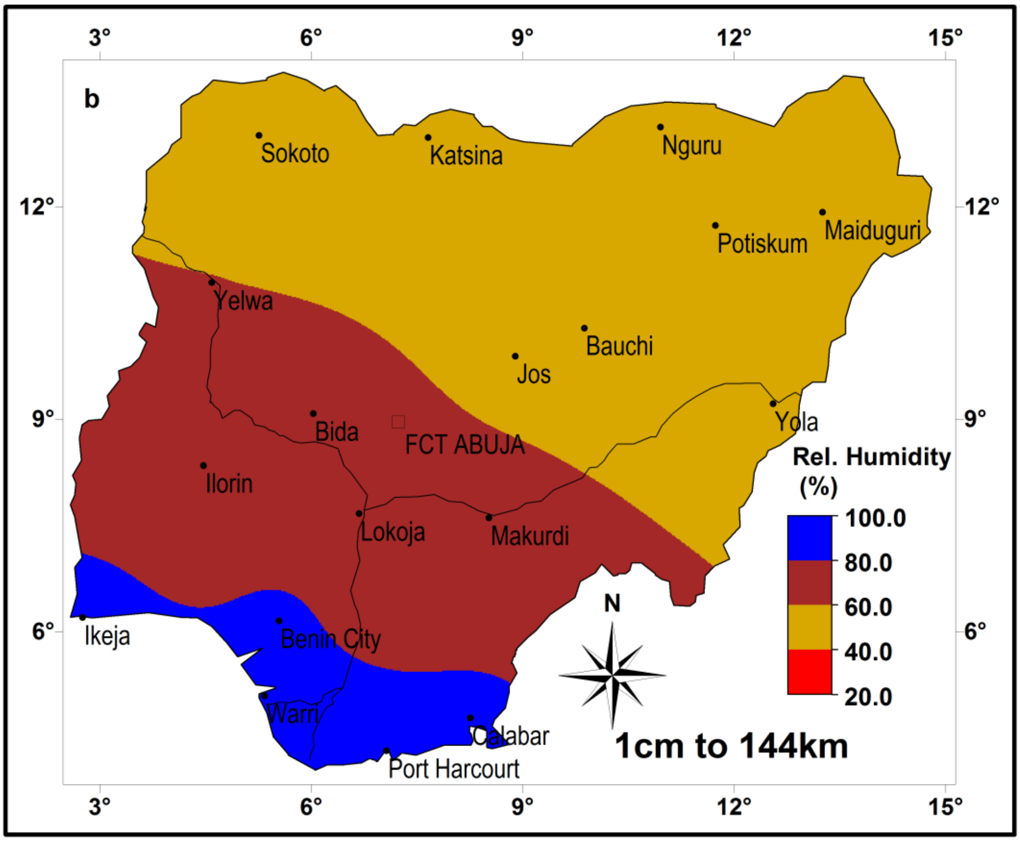


Figure 4.11a-b: (a) Mean Relative Humidity (%) and (b) Coefficient of Variation (%) for the Period of 1951 - 2009 over Nigeria

rainforest region could be described as ‘wetland’. The tropical wet region was the most humid (80-100%) part of Nigeria while the least humid were some areas in sahel (Nguru), and sudan savanna (Katsina and Potiskum). The higher relative humidity in the rainforest region could be attributed to the influence of the prevalent rain bearing tropical maritime (mT) airmass. The effect of the mT airmass is weakened as it blows northwards by another prevailing northeast continental tropical (cT) airmass. The alternating effect of the airmass suggests that the overriding impact of the influence of any of the air masses on its affected region could be dynamic. Therefore, the monthly variation of the temperature and relative humidity is therefore reported in the next section (4.2). When compared, the 1981-2009 geoinformation based map of mean relative humidity of Nigeria showed that relative humidity has significantly reduced than what occurred in 1951-1980 period (Figures 4.12a and 4.12b). Figure 4.12a shows that some region in northern Nigeria, including Katsina, Nguru, Potiskum and Maiduguri are gradually becoming ‘dryland’ (according to the classification by Hulme et al., 1992) based on their less than 40% mean relative humidity values.



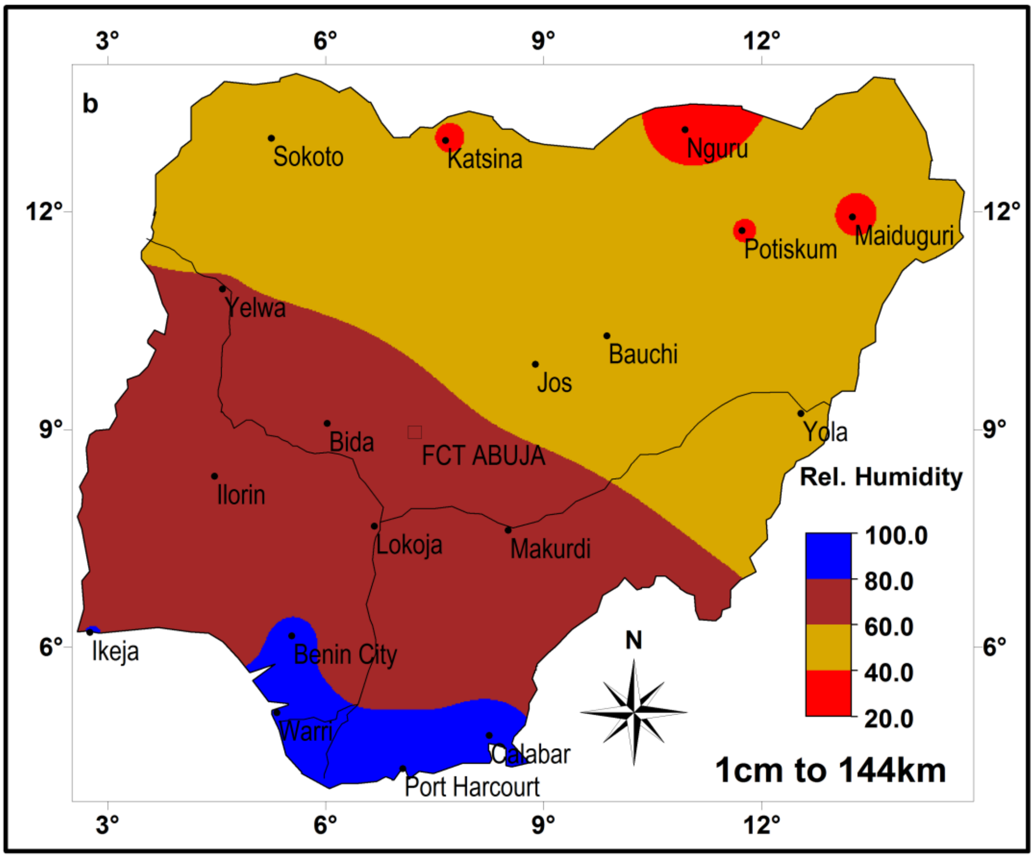


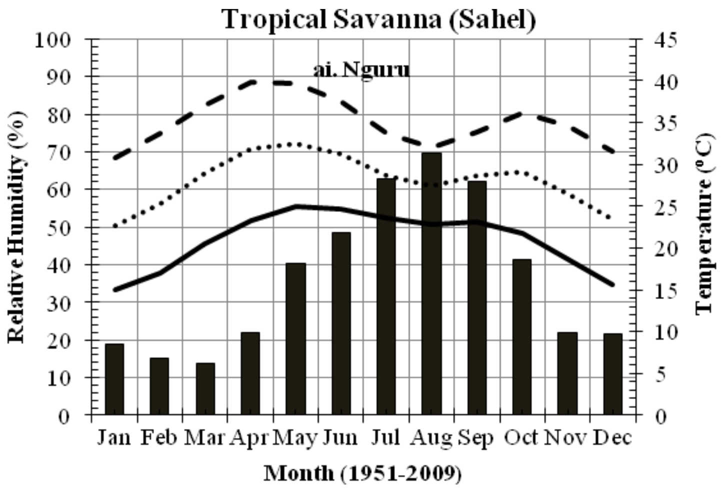
Figure 4.12a-b: Mean Relative Humidity over Nigeria in (a) 1951-1980 and (b) 1981- 2009

4.2. Monthly Variations in the Temperature and Relative Humidity at Different Eco-climatic Regions of Nigeria

The monthly distribution of the minimum, maximum and mean temperatures with relative humidity for 1951-2009 is presented in Figures 4.13a-d for different climate regions. Stations in the sudano-sahelian savanna and montane regions exhibited similar pattern with the peak relative humidity in August after a rise from April. This was followed by a cycle of decline from September till March (Figure 4.13a-b). The peak of relative humidity in August coincides with the peak of rainy season in the northern region (Iloeje, 2001). Temperature in the sahel and sudan savanna regions also peaked in March or April, with maximum temperature ranging between 35 and 40^oC. A lower (30-35^oC maximum temperature) temperature peak also occur between October and November. Months when temperature peaked were also characterised with lower relative humidity, suggesting an inverse relationship between temperature and relative humidity in this region. The montane region, on the other hand, is characterised by generally lower temperature (minimum and maximum temperature being lower than 23^oC and 30^oC, respectively) throughout the year (Figure 4.13aii).

Relative humidity in the guinea savanna was higher than either the sudano-sahelian or montane climate region in most months. Temperature in the guinea savanna was also high (maximum and minimum temperature being around 33-38^oC and 18-22^oC, respectively at all the stations) in the early part of the year (January-April) and declined between June and October, when relative humidity was high, being more than 70% in most stations (Figure 4.13c). The rainforest region (Tropical wet and dry climate, Figure 4.13d and Tropical wet climate, Figure 4.13e) is characterised by more than 75% mean monthly relative humidity, 30-35^oC maximum temperature and 20-25^oC of minimum temperature throughout the year. In addition, minimum, maximum and mean temperature exhibited similar patterns at all the stations, except for the variations in the periods of the peak among the stations from different regions. For example, peaks of the minimum, maximum and mean temperature within the tropical rainforest (Figures 4.13d-e) occurred in February, March in the guinea savanna (Figure 4.13c), April in sudan savanna (Figure 4.13b), and May in the sahel savanna (Figure

4.13ai). This is observed to occur at the peak of the dry season in each of the climate regions when the cT airmass blows over the region.



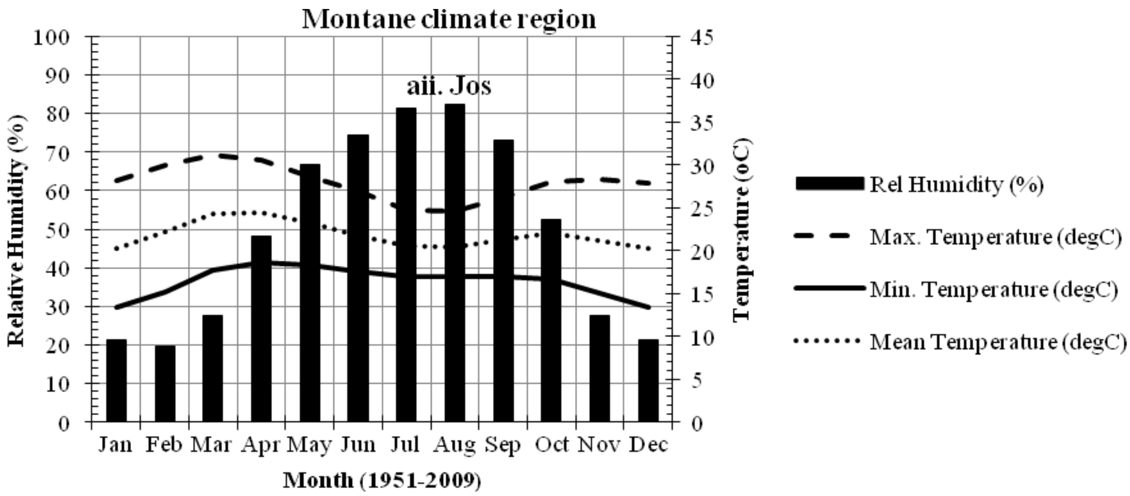


Figure 4.13a: Relative Humidity-Temperature Graph for Selected Station within the Sahel Savanna and Montane Regions (1951-2009)

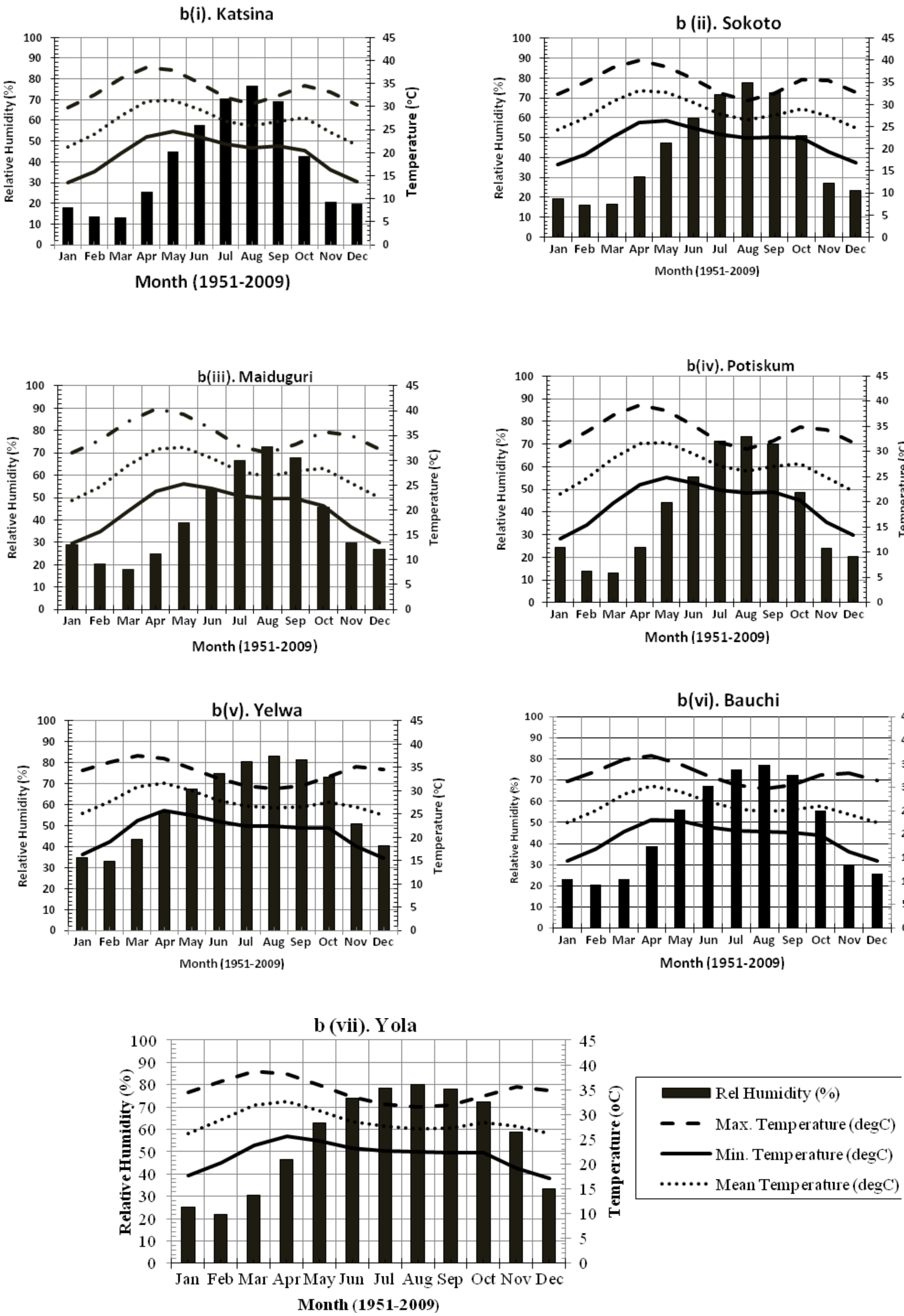


Figure 4.13b: Relative Humidity-Temperature Graphs for Selected Stations within the Tropical Savanna (Sudan) Regions (1951-2009)

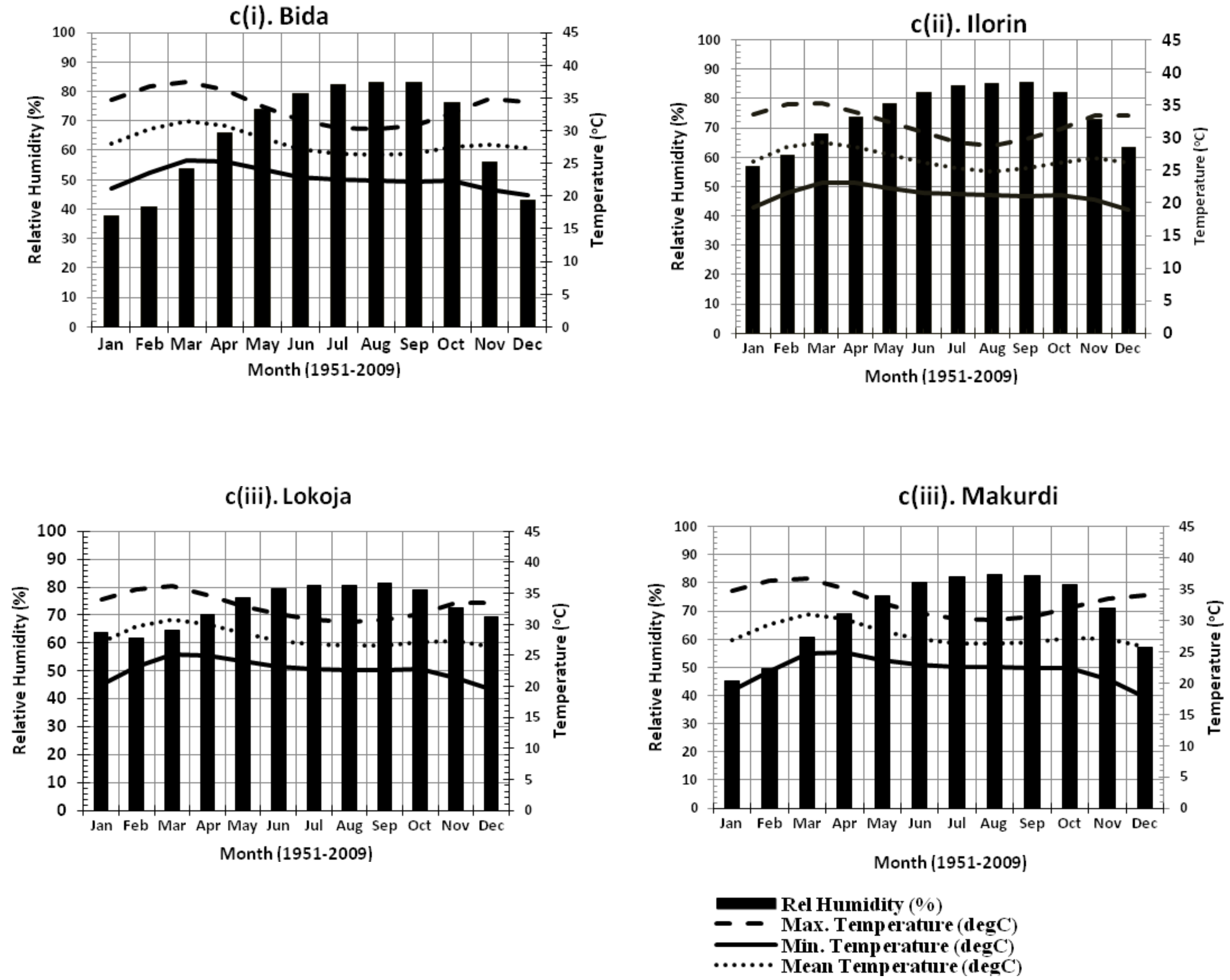


Figure 4.13c: Relative Humidity-Temperature Graphs for Selected Stations within the Tropical Savanna (Guinea) Regions (1951-2009)

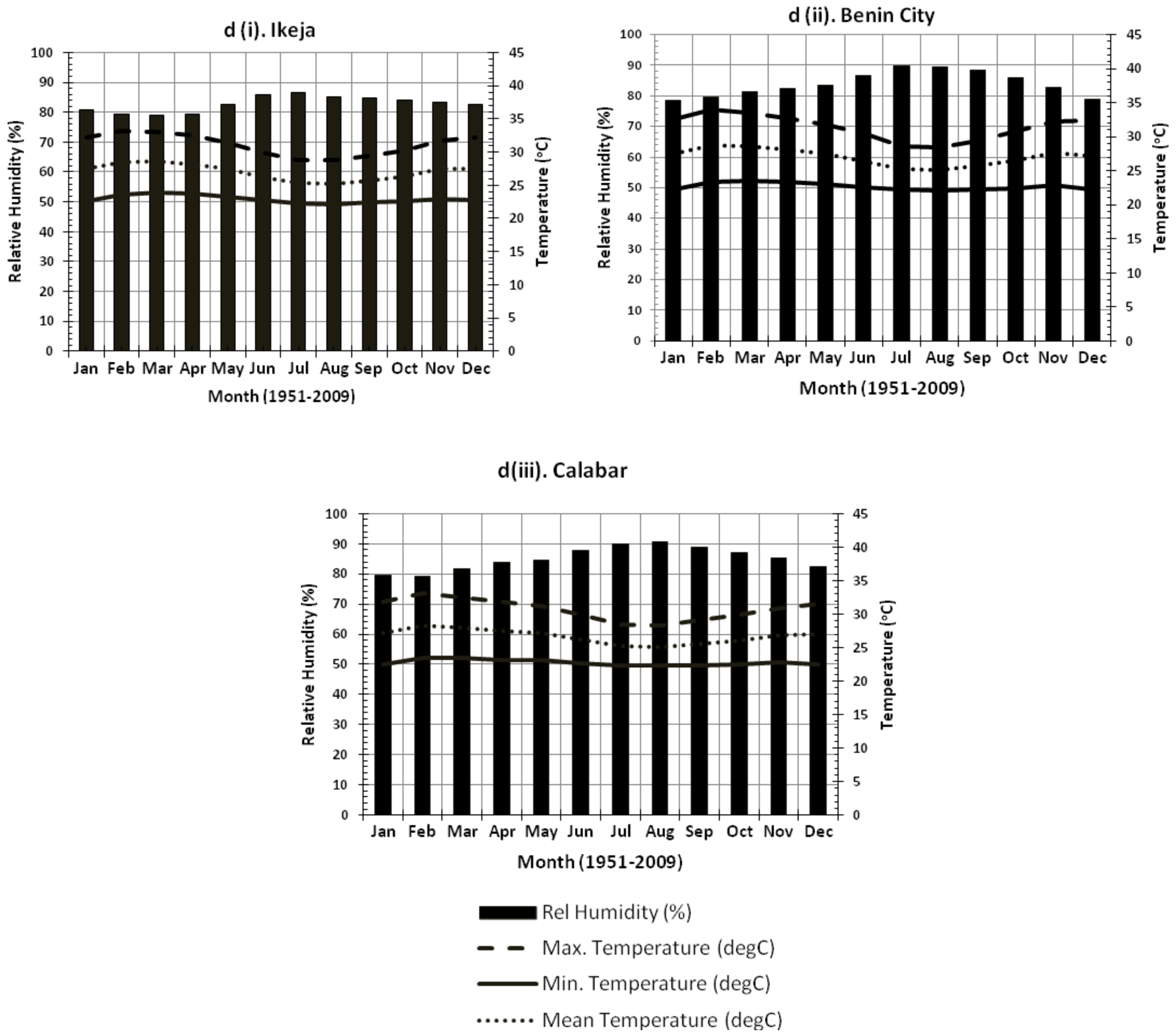


Figure 4.13d: Relative Humidity-Temperature Graphs for Selected Stations within the Tropical Wet And Dry Region (1951-2009)

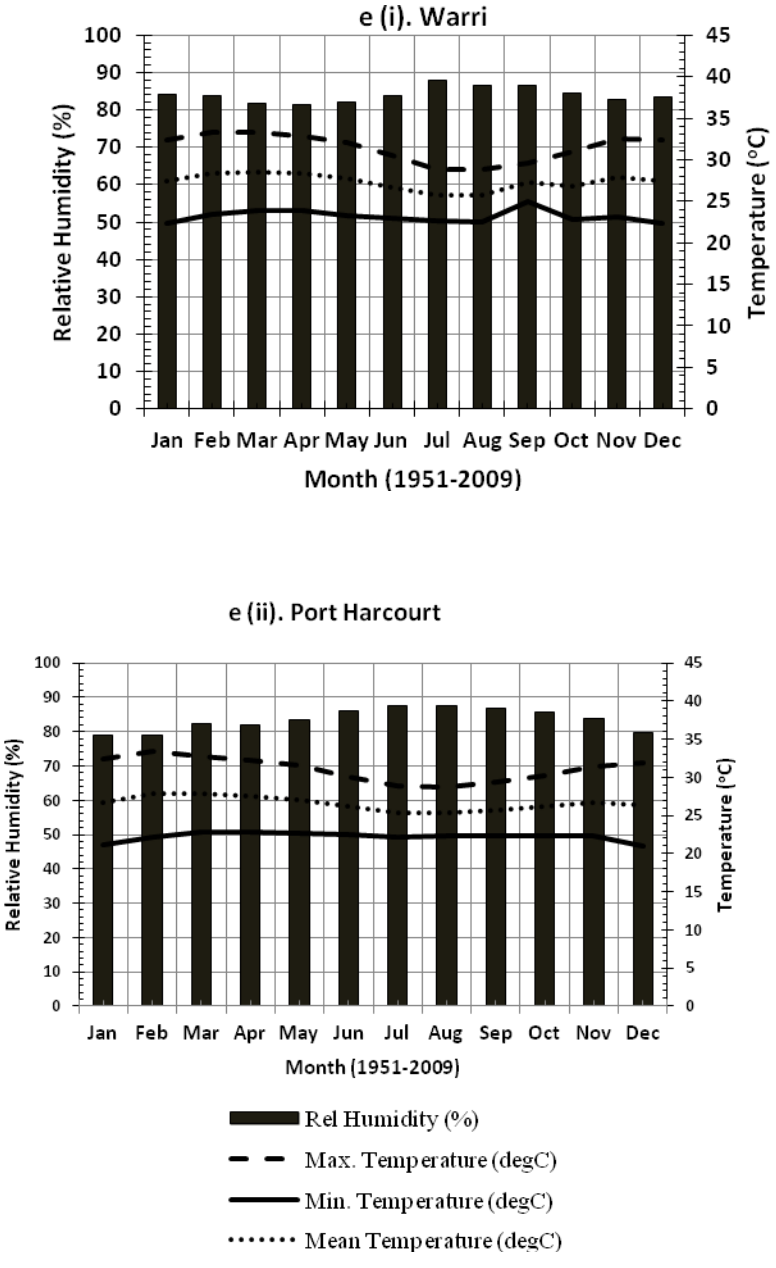


Figure 4.13e: Relative Humidity-Temperature Graphs for Selected Stations within the Tropical Wet Region (1951-2009)

4.3. Effective Temperature Index (ETI)

4.3.1. Mean annual variations in ETI

Effective temperature index (ETI) defined as the temperature of still air saturated with water vapour in which subjects experience a subjectively equivalent sensation of comfort (Smith, 1974), is described in terms of its means, range and linear trend between 1951 and 2009 (see Appendix 4.5). The lowest and highest mean annual ETI occurred at Jos (19.4±0.33^{o}C) and Warri (26.1±0.36^{o}C), in the montane and tropical wet and dry regions, respectively. The overall average of all the stations is 24.3±1.85^{o}C. Converse to the pattern obtained with temperature, ETI at most stations in the sudano-sahelian (Bauchi, Katsina, Maiduguri, Nguru and Potiskum) and montane (Jos) regions was below the overall mean while the rainforest region exhibited ETI means that are above the overall mean (Appendix 4.5). The variability, as measured by coefficient of variation at the investigated stations was generally low, but lower in the southern than the northern stations. The results of the trend analysis suggests increasing ETI at most stations in the sahel, sudan savanna and tropical rainforest regions, while stations within the guinea savanna and montane (Jos) regions did not exhibit significant trend. Figure 4.14, which presents the mean annual variations in ETI between 1951 and 2009, suggests relative increase at all but guinea savanna and montane regions.

The geoinformation based maps for ETI means and its coefficient of variation for 1951-2009 from interpolated values of the meteorological means are presented as Figures 4.15a and 4.15b. Figure 4.15a suggests that the rainforest region, north-western Nigeria, and area around Yola station exhibited higher ETI than the north-eastern part. The montane region and its neighbouring Bauchi station exhibited the lowest ETI (18-22^{o}C) between 1951 and 2009. Figure 4.15b, on the other hand, shows that temporal variability was lowest in the southern coastal and montane regions. Variability was, however, highest around the Nguru-Potiskum section of the north-eastern Nigeria. The maps drawn to compare the 1951-1980 and 1981-2009 annual average patterns (Figure 4.16a and 4.16b) show that ETI has generally increased in Nigeria in 1981-2009 period by 2^{o}C (from 1951-1980 means), except in the montane region and Ilorin, in the guinea savanna.

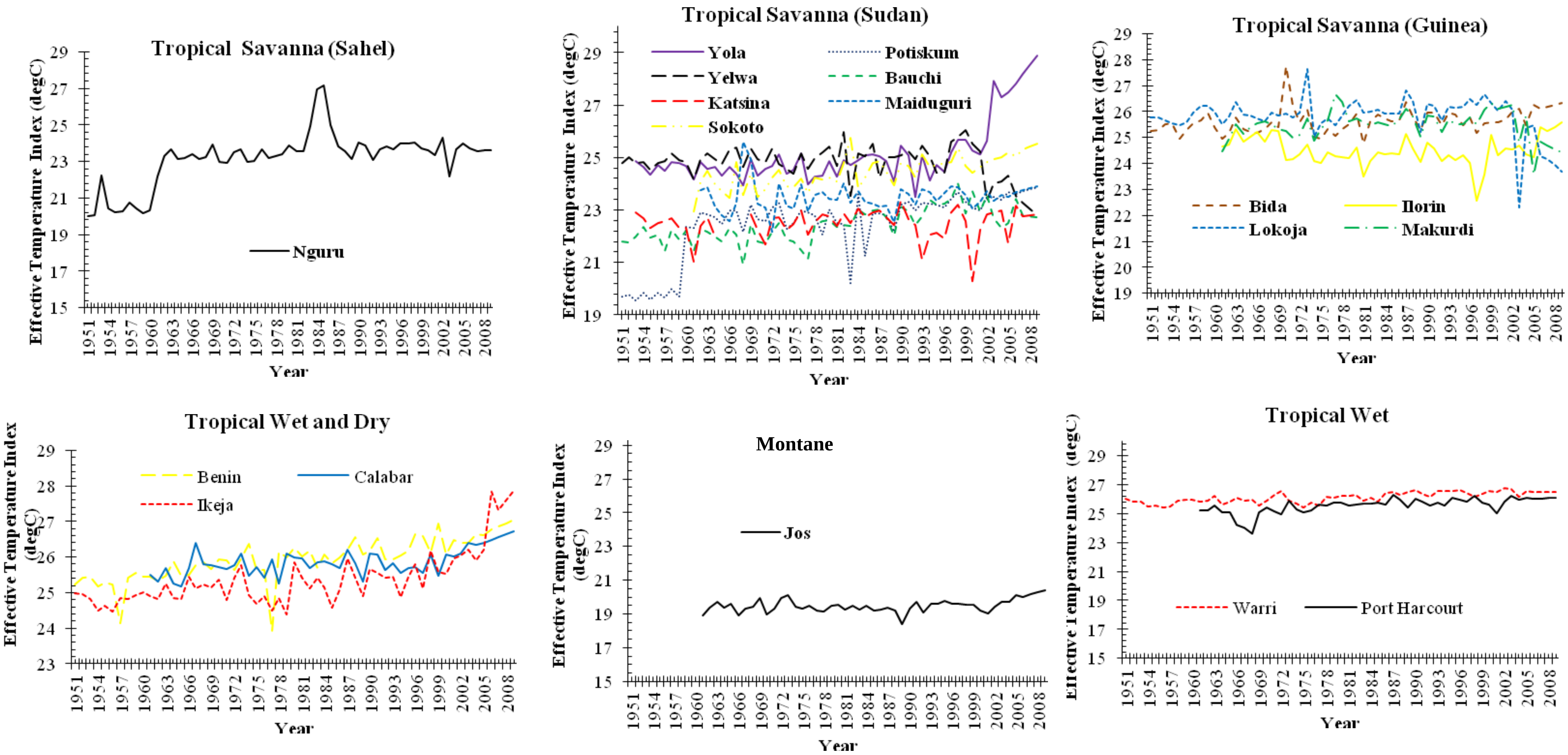
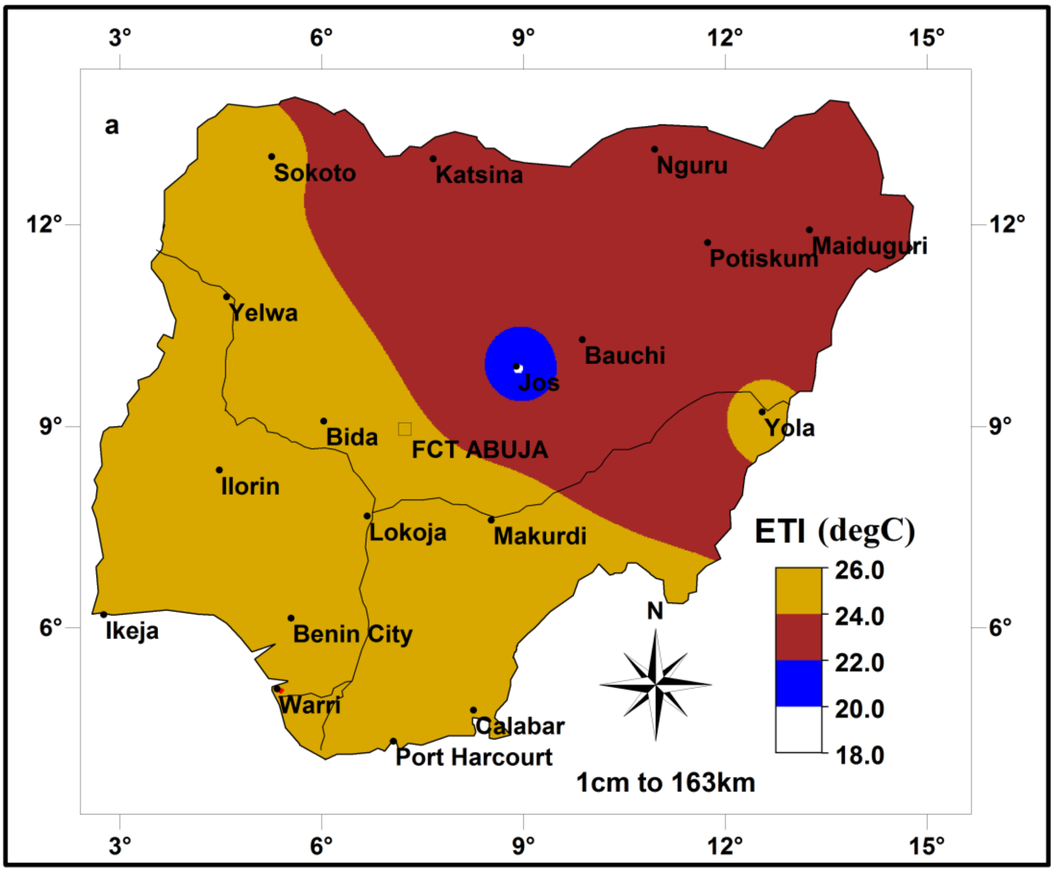


Figure 4.14: Annual Variations in Effective Temperature Index at different Eco-Climatic Regions (1951-2009)



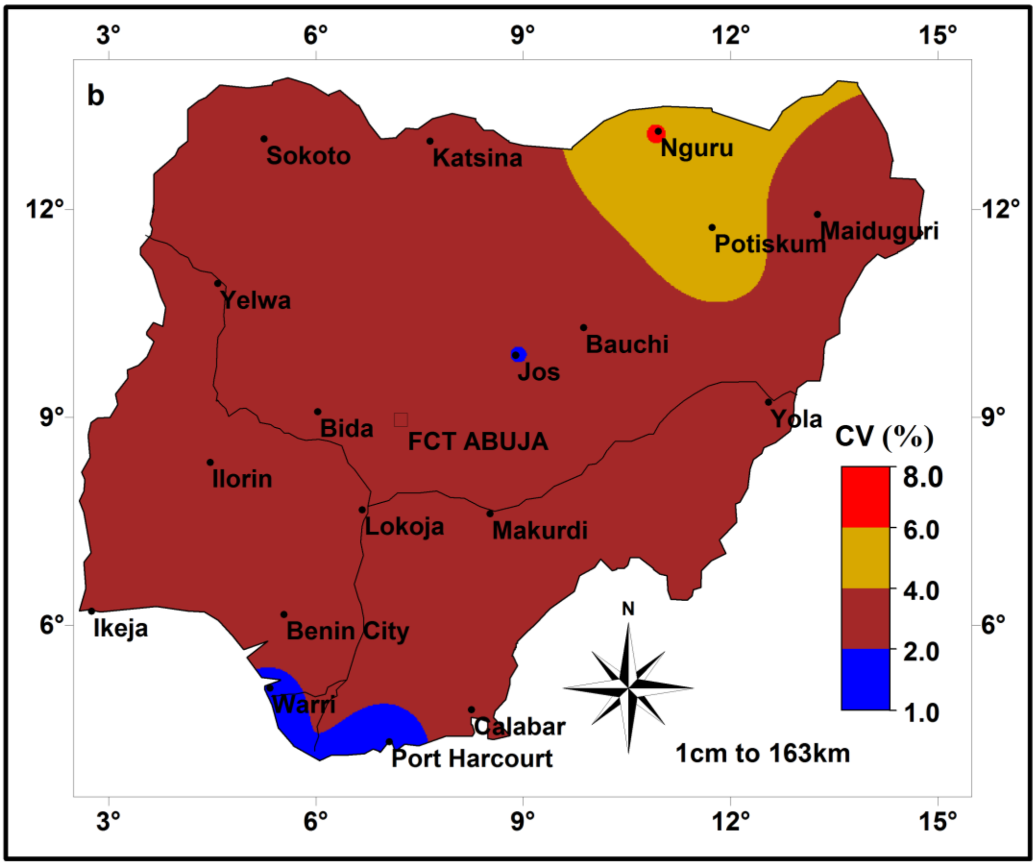


Figure 4.15a-b: (a) Mean Effective Temperature Index – ETI (°C) and (b) Coefficient of Variation in ETI (%) for the Period of 1951- 2009 over Nigeria

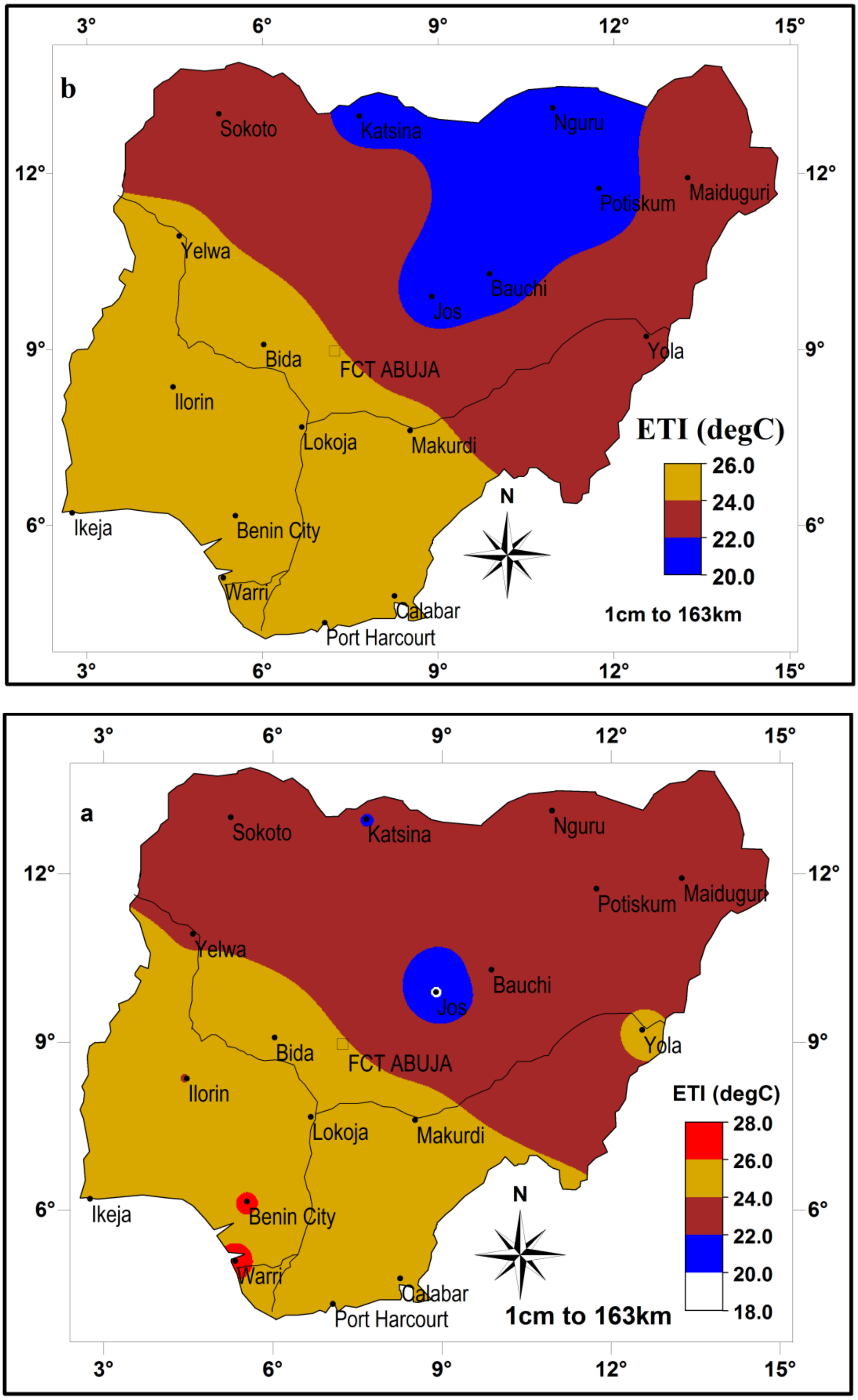


Figure 4.16a-b: Mean Effective Temperature Index (^oC) over Nigeria in (a) 1951-1980 and (b) 1981-2009

Table 4.1 presents the result of the analysis of variance (ANOVA) which shows significant increase in ETI in 1981-2009 at most stations in the rainforest and the sudano-sahelian regions, while few stations (Jos and Lokoja) in guinea savanna exhibited significant reduction in mean ETI. Based on the interpretation of ETI, which puts 18.9-25.6^{o}C as the comfortable range for tropical countries (Nieuwolt, 1977; Ayoade, 1978), Figure 4.17 classifies Benin-Warri axis of the southern Nigeria and Lokoja at the confluence of Rivers Niger and Benue as physiologically uncomfortable due to heat stress. Investigation into the 1951-1980 and 1981-2009 variations (Figures 4.18a and 4.18b) suggests that the identification of the Benin-Warri axis is probably recent, based on the 1981-2009 buffering of a larger sphere than the 1951-1980 (Figure 4.18b) while the situation at Lokoja can be linked to the retreat in the ETI in 1951-1980.

Table 4.1. Comparison between 1951-1980 and 1981-2009 Values of Effective Temperature Index (ETI) for Selected Stations across different Eco-climatic Regions in Nigeria

Eco- Climatic region	**Station**	**Values for 1951-1980**		**Values for 1981-2009**		**Analysis of variance to identify significant difference**	
		Mean	CV (%)	Mean	CV (%)	F-Stat	P-value
Tropical Savanna (Sahel)	Nguru^{SI}	21.6	5.6	23.2	4.7	27.9	0.00*
Tropical Savanna (Sudan)	Katsina	21.5	2.8	21.9	4.1	3.3	0.07
	Sokoto^{SI}	23.1	1.7	24.0	2.5	57.6	0.00*
	Maiduguri^{SD}	23.2	3.9	22.7	2.2	7.7	0.01*
	Potiskum^{SI}	21.1	5.7	22.1	3.2	16.5	0.00*
	Yelwa	24.4	1.2	24.0	4.6	3.3	0.07
	Bauchi^{SI}	21.4	2.3	22.5	3.1	48.9	0.00*
	Yola^{SI}	24.0	1.7	24.8	4.0	18.5	0.00*
Montane	Jos^{SD}	20.0	7.0	19.2	3.1	8.5	0.01*
Tropical Savanna (Guinea)	Bida	25.4	2.0	25.1	4.0	1.4	0.24
	Ilorin^{SD}	24.9	2.8	23.9	3.8	21.1	0.00*
	Lokoja	25.9	1.5	25.6	4.7	2.1	0.15
	Makurdi	24.7	3.6	25.0	5.6	0.8	0.37
Tropical Wet and Dry	Ikeja^{SI}	25.0	1.6	25.6	2.3	21.4	0.00*
	Benin^{SI}	25.7	1.9	26.4	1.5	36.3	0.00*
	Calabar	25.2	4.0	25.6	4.7	2.5	0.12
Tropical Wet	Warri^{SI}	26.0	1.2	26.4	1.5	15.7	0.00*
	Port Harcourt^{SI}	24.9	2.8	25.4	4.3	4.7	0.04*
Overall (monthly data) mean		23.8	2.0	24.1	3.6	6.3	0.01*

Variation for all asterisked (*) rows are significant at 95% confidence level (i.e. $p \leq 0.05$).

Superscripts SI and SD ($^{SI, SD}$) are used to identify station that exhibits significant mean increase (SI) or significant mean decrease (SD) in Effective Temperature Index between 1951-1980 and 1981-2009 values

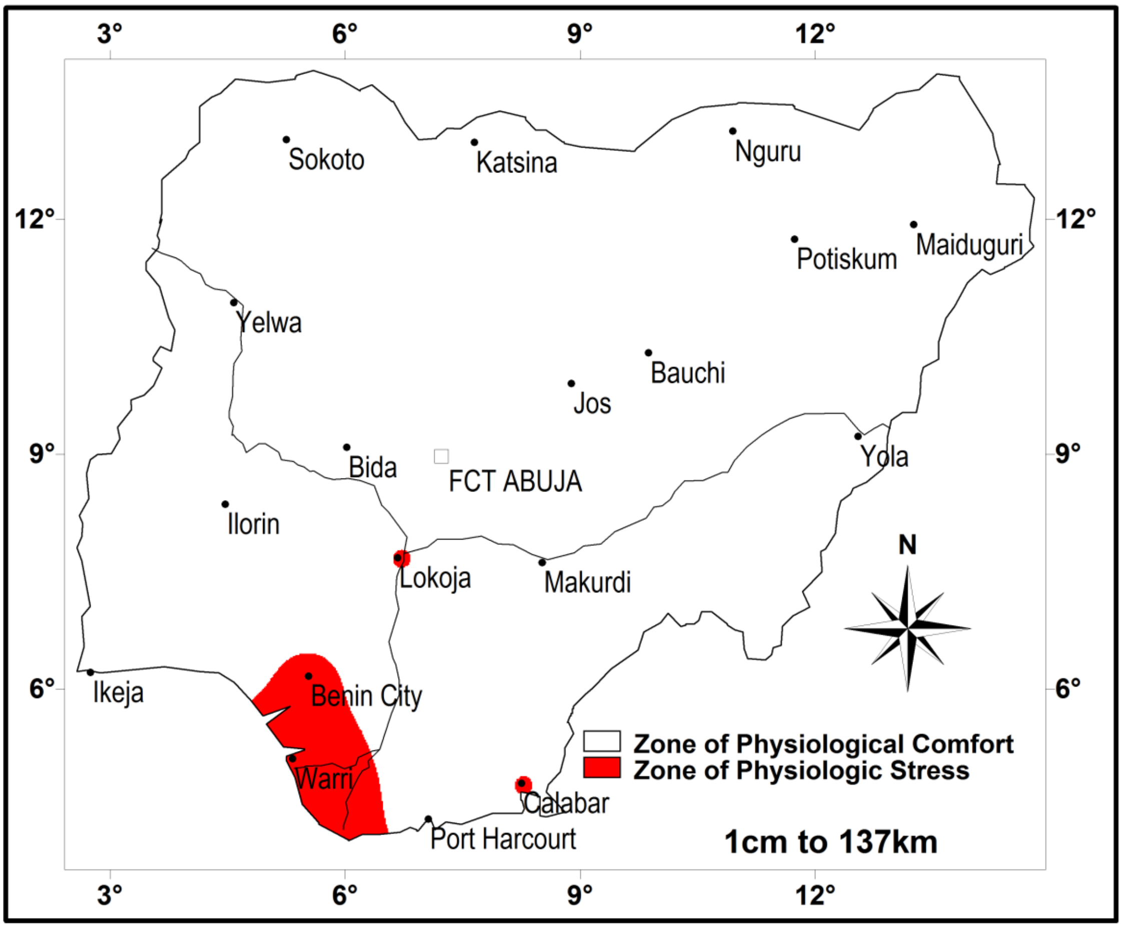
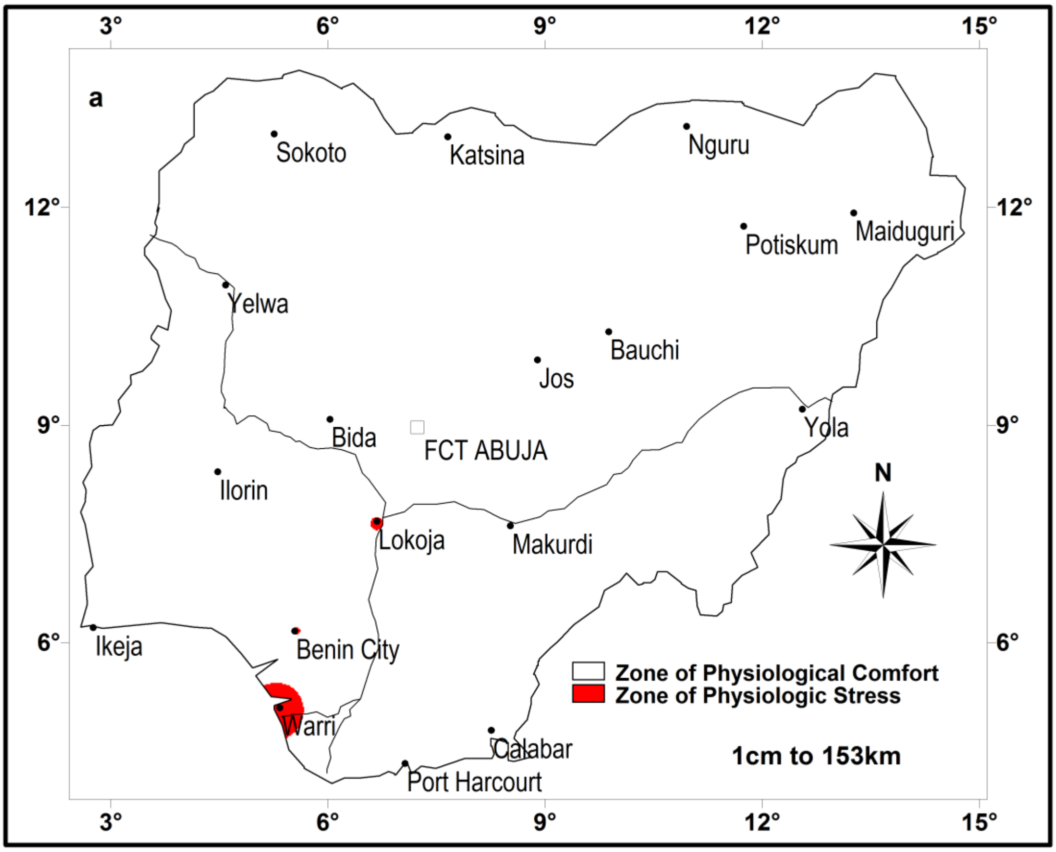


Figure 4.17: Annual Pattern of Physiologic Comfort in Nigeria, derived from Effective Temperature Index (1951-2009)



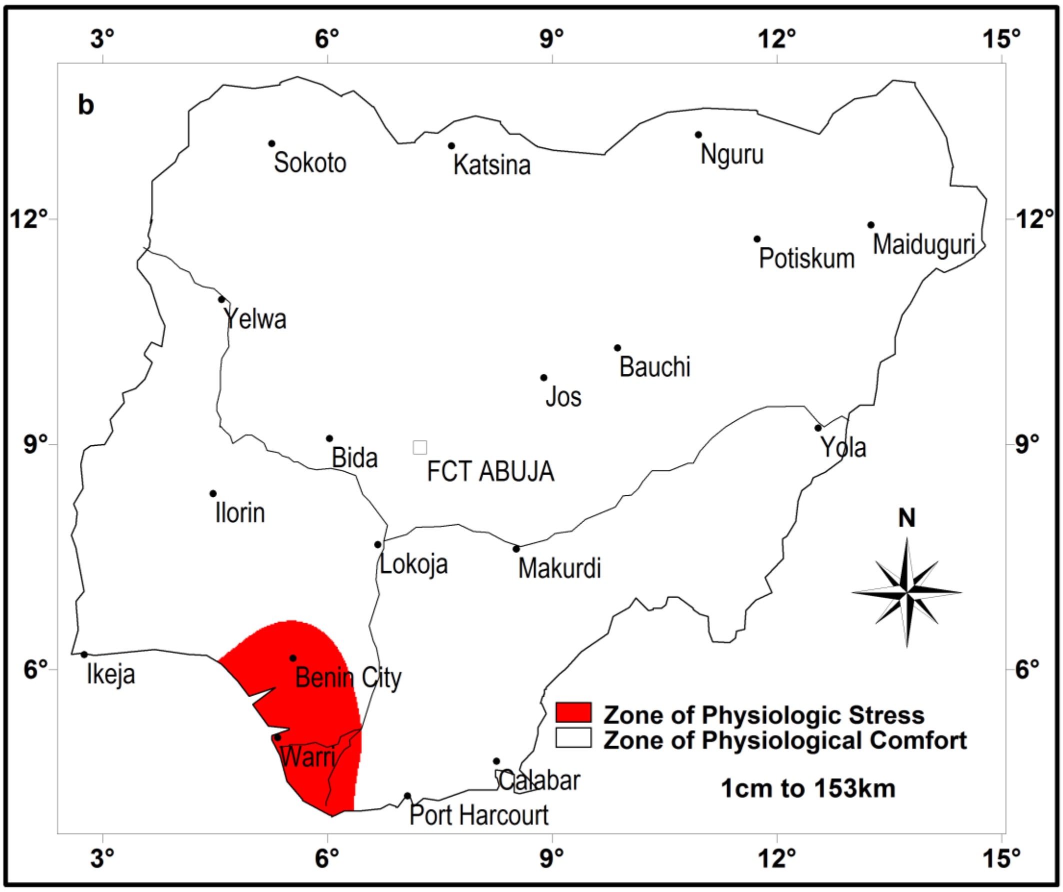


Figure 4.18: Annual Pattern of Physiologic Comfort in Nigeria in 1951-1980 (a) and 1981-2009 (b) Periods as derived from Effective Temperature Index

The reversal of the hitherto physiologic stress around the middle belt area of Nigeria (especially around Lokoja) (see also Ayoade, 1978; Komolafe and Agarwal, 1987) is probably one of the signs of climate variability or change in the region. Such climate change have been reported in the study of the rainfall in the region by Odekunle (2010), which recorded that the part of the savanna region is presently wetter than what it used to be few decades ago. A wetter atmospheric condition suggests higher relative humidity, which is a principal component of ETI. Therefore, a change may occur in the ETI for this part of Nigeria. Meanwhile, a better understanding of this phenomenon is expected when the seasonal and diurnal patterns are examined, later in this section. Secondly, recent studies of the Niger Delta region (e.g. Ogundare and Sidiq, 2010) have shown increase in ETI as a possible consequence of gas flaring in the region.

4.3.2. Decadal variations

The summary of the decadal ETI means in Nigeria (see appendix 4) showed a steady increase from 23.7°C in 1951-1960 to about 24.5°C in 2001-2009. Result of the linear regression showed that the mean decadal value of the ETI exhibited significant increase (R^2=0.97; $p<0.05$) (Figure 4.30). Variation in ETI per decade can therefore be estimated using equation 4.1, $y\ (°C) = 0.17x + 23.73$ 4.1

Where:

$y\ (°C) =$ the mean ETI in a decade; and $x =\ n^{th}$ decade from $1951 - 1960$ (The value for *x* for the 2011-2020 decade for example is 6 or 8 for 2031-2040).

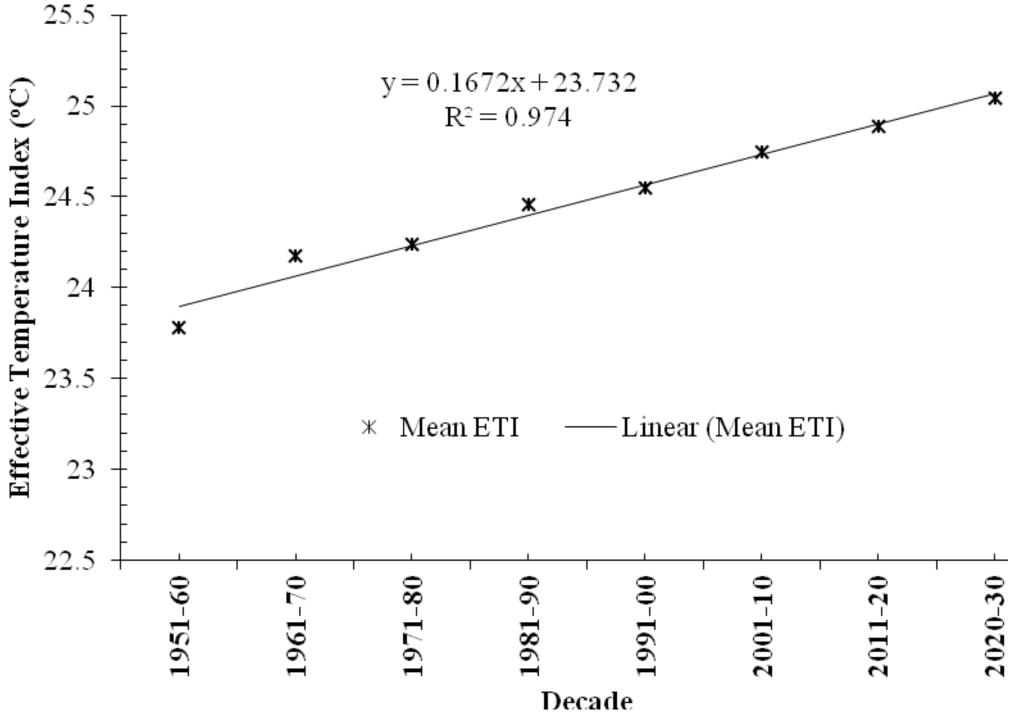


Figure 4.19: Trend of Decadal Mean Effective Temperature Index in Nigeria

Figure 4.20 shows the spatial variations in the mean ETI, in recognition of the spatial differences in Nigeria, for 1951-1960, 1961-1970, 1971-1980, 1981-1990, 1991-2000, 2001-2010, and the predicted patterns (based on equation 4.1) for 2011-2020 and 2021-2030. Earlier studies undertaken on Nigeria (e.g. Ayoade, 1978; Olaniran, 1982) classified ETI values between 18.9 and 25.6 ^{o}C as comfortable, and values above 25.6^{o}C as thermally stressful for a significant proportion (75%) of people. Figure 4.20 shows that thermal stress has increased from Warri in the southern Nigeria, and spread towards the Niger Delta region and Lokoja between 1961 and 2000. The projected figures indicated that there will be further spread towards the western and eastern regions between 2010 and 2030.

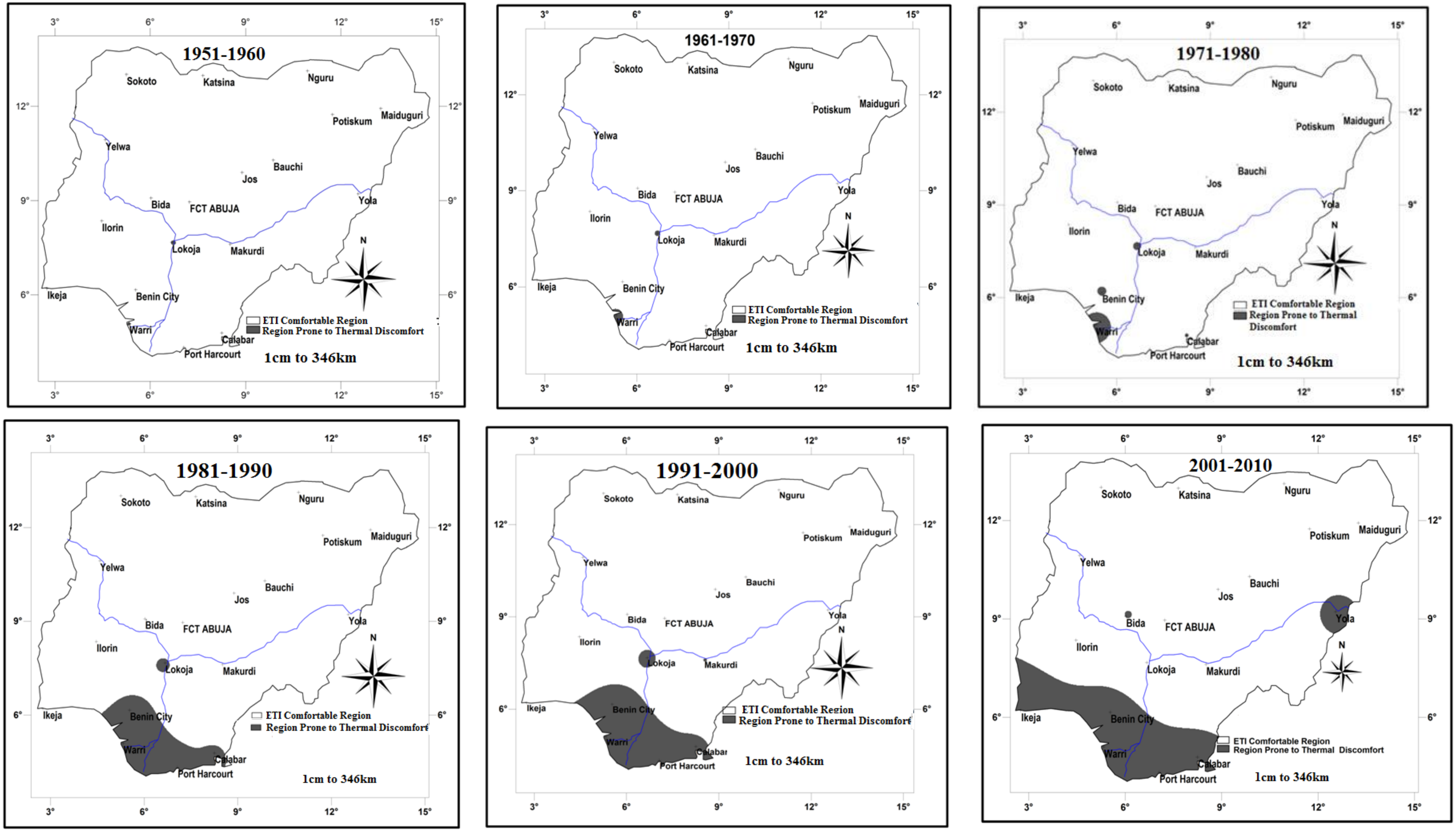


Figure 4.20a: Decadal Variations in the Distribution of Thermal Comfort and Discomfort, derived from Effective Temperature Index (ETI) for Nigeria

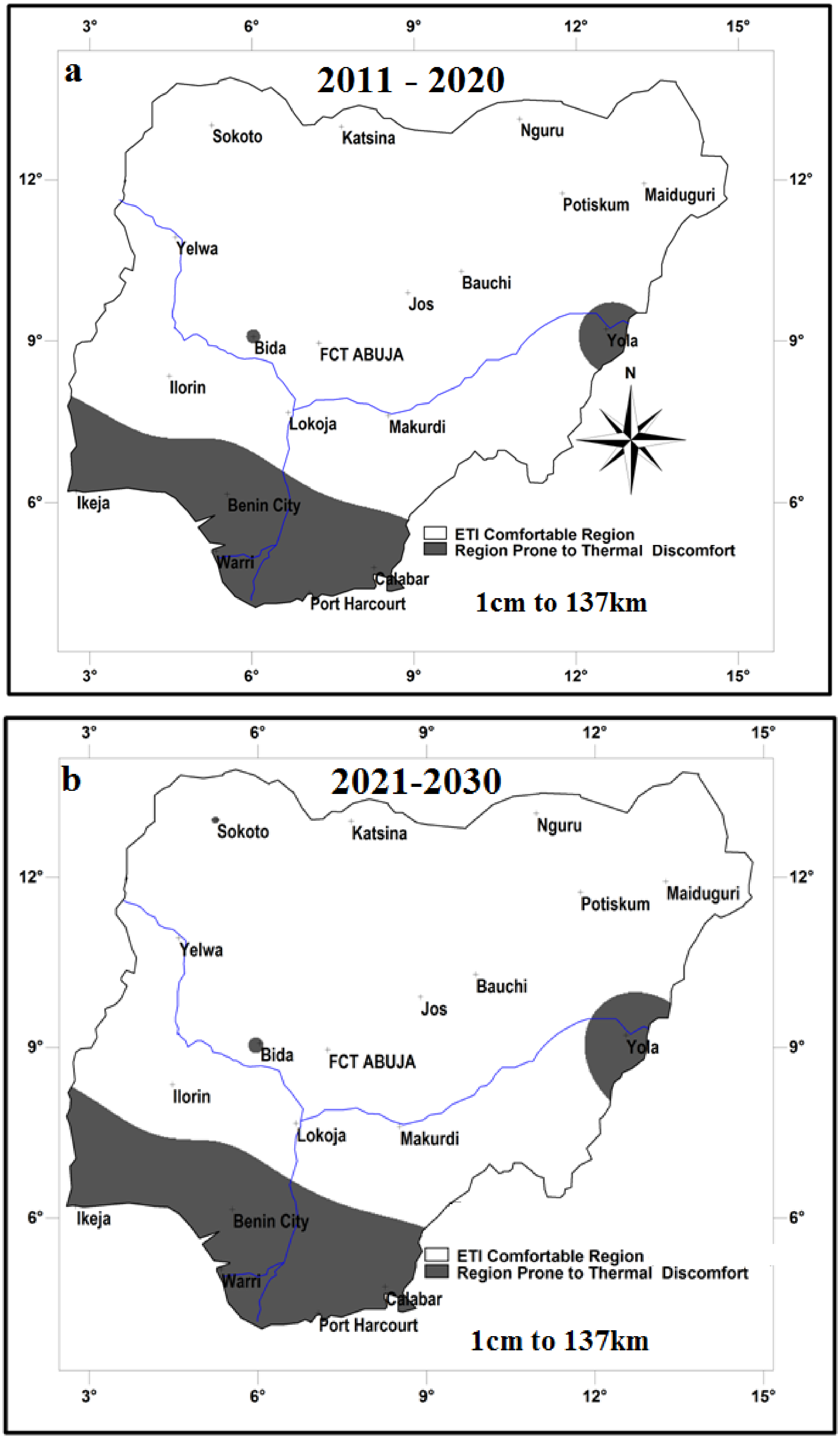


Figure 4.20b: Projected Distribution of Effective Temperature Index- ETI over Nigeria for the period of 2011-2030

4.3.3. Seasonal variations

The mean and range (minimum-maximum) distribution of effective temperature index (ETI) in rainy and dry seasons, and harmattan period for 1951-2009 at the selected stations is presented in Table 4.2. Higher values of ETI occurred in the dry season at stations in the rainforest, but the values in the rainy season were higher in the savanna. Effective temperature index in the savanna region was lower in both dry season and Harmattan period than in the rainforest region.

The maps generated from the seasonal mean ETI (Figure 4.21a-c) show distinguishable characteristics in ETI across Nigeria. For example, the harmattan distribution of ETI exhibited a northeast-south increase, similar to the dry season's condition. Conversely, the rainy season's pattern shows a radial pattern of increase from the montane region. When interpreted for physiologic comfort or discomfort (ETI classifies 18.9-25.6^oC as comfortable), Figure 4.22a-c show that the north-western region and some areas in the northeast, including Maiduguri and Yola are among the regions prone to physiologic stress in the rainy season. The harmattan condition shows that some regions in the north, including the montane region, Katsina and Nguru-Potiskum section of the northeast are prone to cold stress (ETI being less than 18.9^oC) while heat stress (ETI > 25.6^oC) is recorded for the Benin-Warri, Port Harcourt and Calabar coastal area. The dry season's condition shows a significant part of the Niger-Delta region and Lokoja, the confluence of Rivers Niger and Benue as under heat stress (Figure 4.22b). The results of the analysis of the diurnal patterns of ETI with other investigated indices (temperature, relative humidity, temperature-humidity index and relative strain index) are discussed after the interpretation of the monthly means of the integrative indices (ETI, THI and RSI) in Section 4.7.

Table 4.2: Seasonal Values of the Effective Temperature Index (ETI ^{o}C) for Selected Stations in Different Eco-Climatic Region in Nigeria

Eco-Climatic Regions	**Stations**	**Rainy season (April-October) (1951-2009)**		**Dry season (Nov-March) (1951-2009)**		**Harmattan period (1951-2009) (Dec-Feb)**	
		Mean (^{o}C)	Range (^{o}C) (min-max)	Mean (^{o}C)	Range (^{o}C) (min-max)	Mean (^{o}C)	Range (^{o}C) (min-max)
Tropical Savanna (Sahel)	Nguru	25.3	20.9-29.0	20.9	18.7-25.5	19.1	16.8-24.8
Tropical Savanna (Sudan)	Katsina	24.9	21.6-26.5	20.1	18.3-21.0	18.0	16.4-19.4
	Sokoto	26.4	25.3-27.4	22.4	20.6-23.7	20.4	18.6-22.3
	Maiduguri	25.9	24.9-27.2	21.2	19.5-25.8	19.0	17.1-20.7
	Potiskum	24.4	20.1-26.3	20.2	18.7-21.6	18.3	17.0-19.8
	Yelwa	25.9	25.0-26.8	23.8	20.8-25.9	21.9	18.4-24.4
	Bauchi	24.0	22.0-25.9	20.9	18.7-23.0	19.1	17.6-21.9
	Yola	26.1	24.0-30.6	23.7	21.8-26.5	21.8	20.2-26.1
Montane	Jos	20.3	19.5-21.0	18.5	17.1-19.5	17.3	15.3-18.8
Tropical Savanna (Guinea)	Bida	25.6	20.9-30.3	25.4	22.3-27.3	24.1	21.6-27.9
	Ilorin	24.6	22.8-25.6	24.3	21.5-25.9	23.3	20.3-25.9
	Lokoja	25.7	23.2-28.4	26.0	19.6-26.9	25.2	19.0-26.7
	Makurdi	25.5	20.4-27.3	25.3	21.5-27.0	23.9	20.6-26.2
Tropical Wet and Dry	Ikeja	25.0	20.1-28.4	25.6	24.1-27.3	24.5	22.5-27.0
	Benin	25.2	22.8-26.1	26.5	23.8-27.9	26.3	25.1-27.9
	Calabar	25.1	19.7-25.9	26.2	20.6-26.9	26.1	21.0-27.0
Tropical Wet	Warri	25.4	24.5-26.2	26.8	25.9-27.7	26.6	24.4-27.6
	Port Harcourt	25.2	24.5-25.9	26.0	23.4-26.8	25.7	23.5-27.0

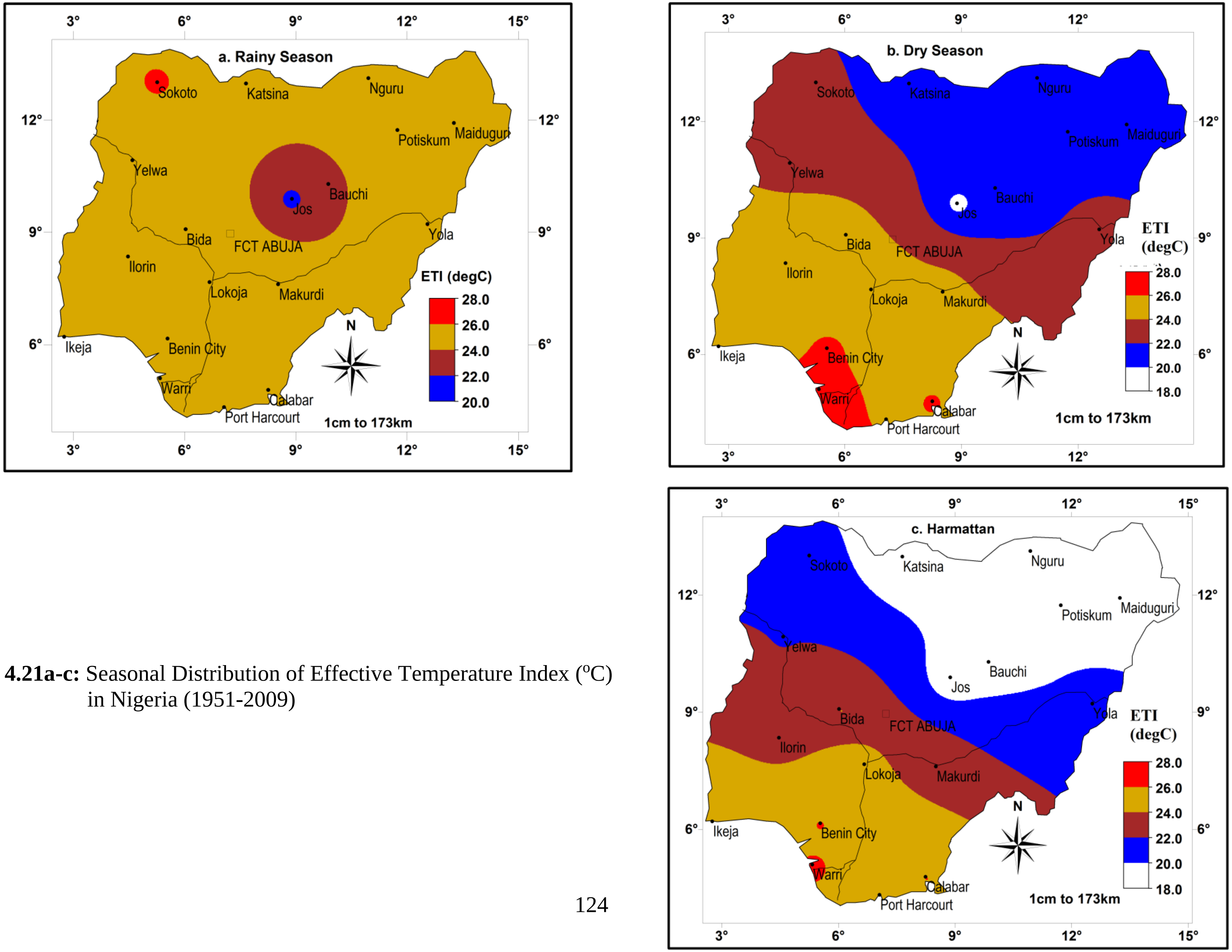
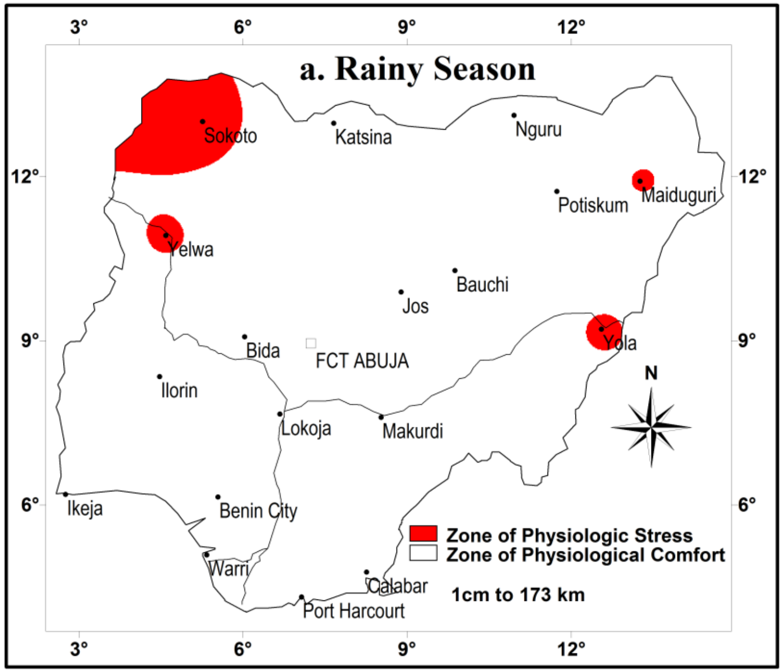


Figure 4.21a-c: Seasonal Distribution of Effective Temperature Index (^{o}C) in Nigeria (1951-2009)



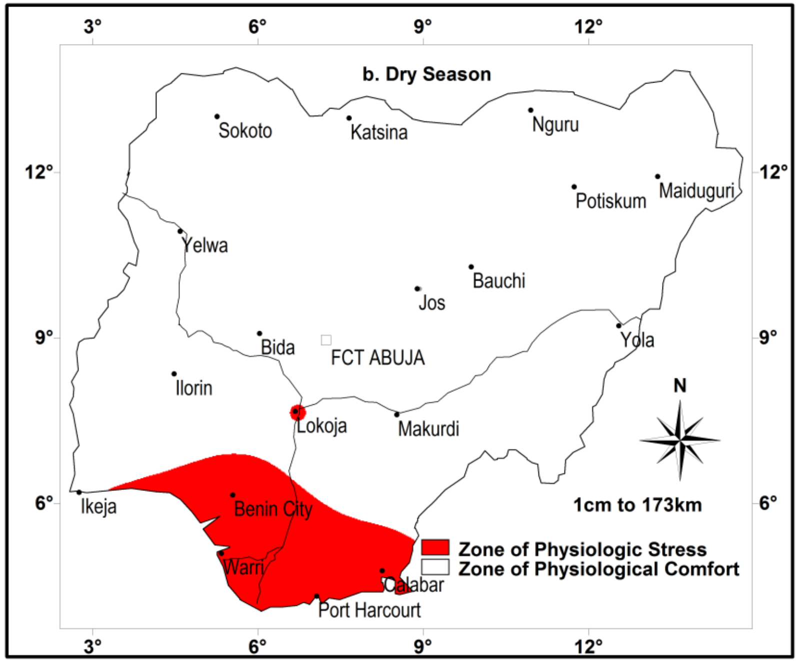
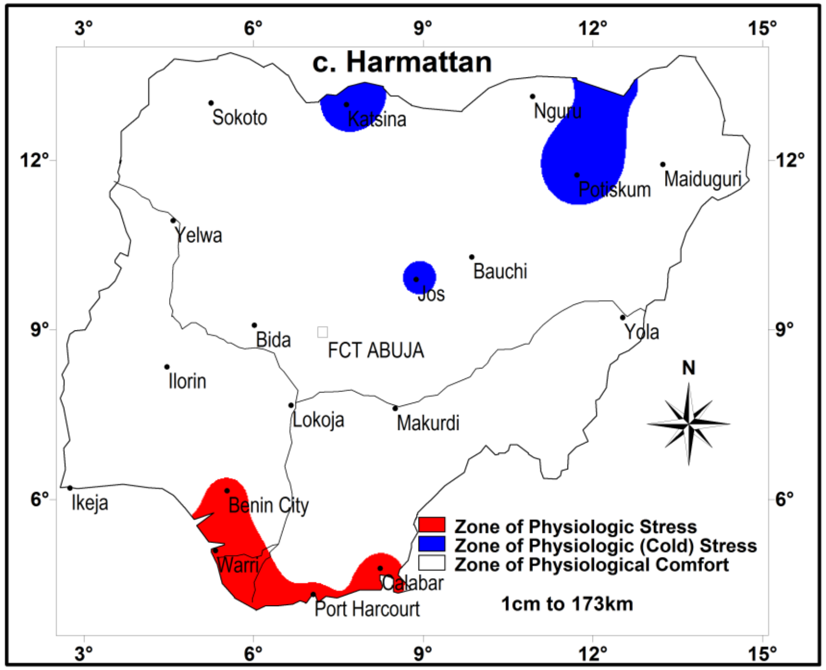


Figure 4.22a-c: Seasonal Pattern of Physiologic Comfort in Nigeria as derived from Effective Temperature Index (°C) in Nigeria (1951-2009)



4.4. Temperature-Humidity Index (THI)

4.4.1. Annual variations

The temperature-humidity index, described as an expression of physiological temperature in terms of temperature and humidity of the air (Smith, 1974), is presented in terms of its mean, range (minimum-maximum), variability, and linear trend at the selected meteorological stations in Nigeria (Appendix 4.6). Highest mean THI (26.3±0.62 ^{o}C) occurred in Lokoja (guinea savanna) while Jos, a station in the montane region, exhibited the lowest (19.6±0.39 ^{o}C). The overall average was 24.8±1.83^{o}C. Most stations in the rainforest and guinea savanna regions exhibited higher mean (24.8-26.3^{o}C) than this overall mean while stations in the montane and sudano-sahelian regions (except Sokoto, Yelwa and Yola) exhibited lower means (19.6-24.2^{o}C) below this average. Generally, most stations in the guinea savanna, montane and rainforest regions (except Port Harcourt) exhibited lower coefficient of variation (less than 3.0%) than most stations in the sudano-sahelian region (2.5-6.1%). Except for Ilorin in the guinea savanna, stations (Nguru, Sokoto, Potiskum, Bauchi, Yola, Ikeja, Benin, Warri and Port Harcourt) that exhibited significantly rising trend with ETI also exhibited significant rise with THI. Ilorin in the guinea savanna, however, exhibited a significant decline ($b = -0.006$; $p \leq 0.05$) with THI but was not significant with ETI. The temporal (annual) patterns of THI (Figure 4.23) also show similar patterns for most regions, although closer observation reveals differences at some stations, especially Lokoja and Ilorin in the guinea savanna. The similar pattern in the trends of THI and ETI at many of these stations may have informed conclusions of previous studies, including Olaniran (1982), that these two indices (ETI and THI) can be ‘equated’. The situation with Ilorin will probably be better understood with the consideration of the diurnal and seasonal distribution. The time graph also showed that THI only increased at the rainforest region and parts of savanna (Yola and Nguru) (Figure 4.23).

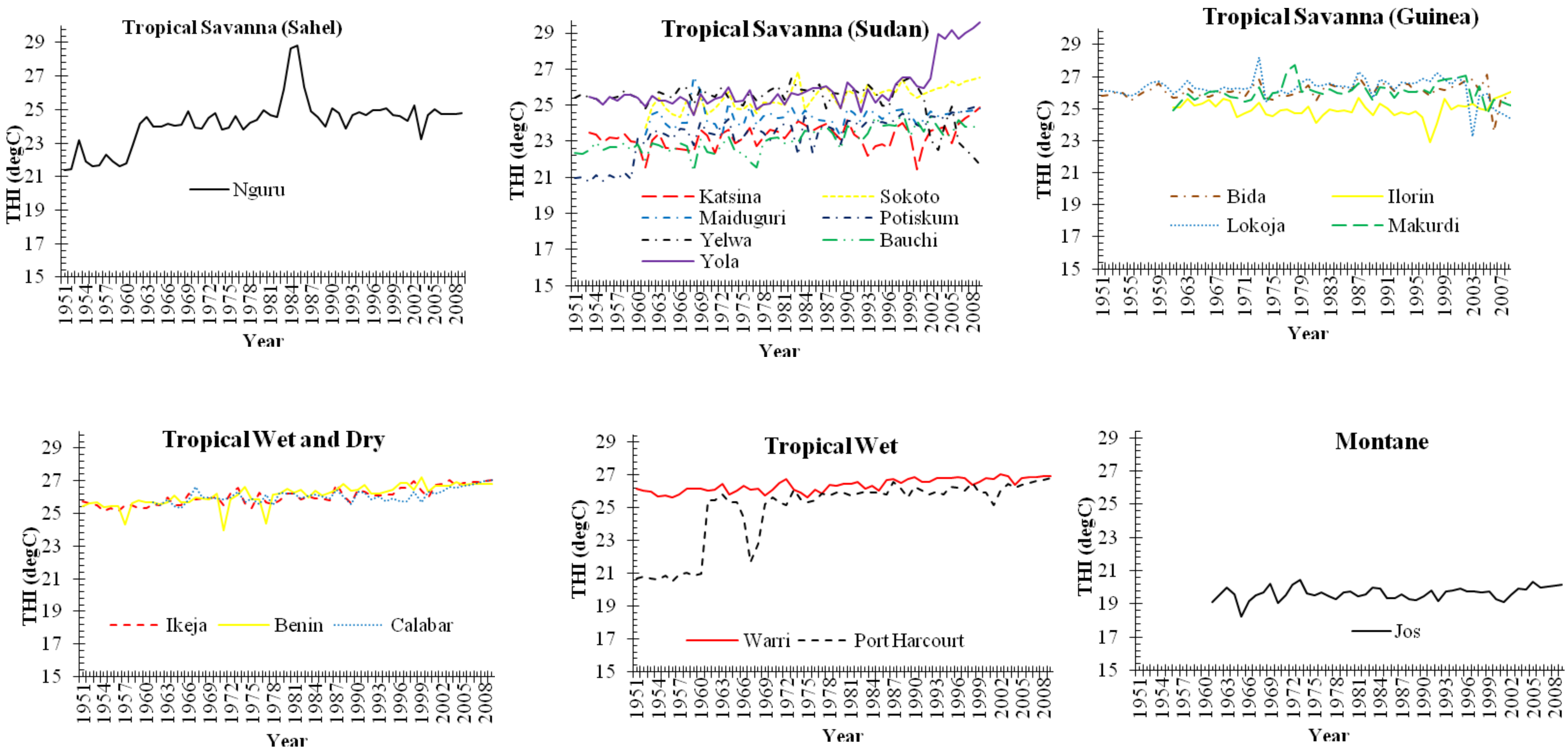


Figure 4.23. Annual Variations in Temperature-Humidity Index at different Eco-climatic Regions (1951-2009)

Figures 4.24a and 4.24b are maps generated by interpolating the 1951-2009 means and coefficient of variations of THI for the 18 selected meteorological stations in Nigeria. Figure 4.24a shows that like ETI and minimum temperature, north central region exhibits lower THI than other parts of Nigeria. THI was also distinctly higher (26-28^{o}C) around Lokoja, Ikeja, Benin and Warri. In the savanna region, THI in the northwest and north eastern parts were higher than the north-central region, while the montane station (Jos) exhibited the lowest THI in Nigeria. Coefficients of variations were relatively lower in the west (<3.0%), and increased towards the east, except Maiduguri in the northeast which recorded the lowest variability, and Port Harcourt, in the southeast, which recorded the highest variability (8.3%) for 1951-2009. Comparison of the 1951-1980 and 1981-2009 average (Table 4.3) suggests higher THI at most stations, except Jos and few stations in guinea savanna (Maiduguri, Lokoja.). The montane station (Jos) and few stations in the guinea (Ilorin) and sudan (Yelwa) savanna, however, exhibited significant decline in 1981-2009.

On the THI scale, the north central region (montane and northern part of the sudano-sahelian savanna) were comfortable while the regions around Lokoja- the confluence town of River Niger and Benue, and Benin and Warri in the rainforest climate exhibited severe physiologic discomfort; a similar pattern with ETI for the regions. Unlike ETI, however, THI also classified Ikeja, in the southwest as an area that is vulnerable to heat stress (Figure 4.25). The maps for the 1951-1980 and 1981-2009 means (Figures 4.26a and 4.26b) suggest that the northeast was the most comfortable region in Nigeria. There is, however, a limit to which this can be asserted based on the results of temperature (Section 4.1) that showed that the northeastern is equally characterised by high maximum temperature and low minimum temperature.

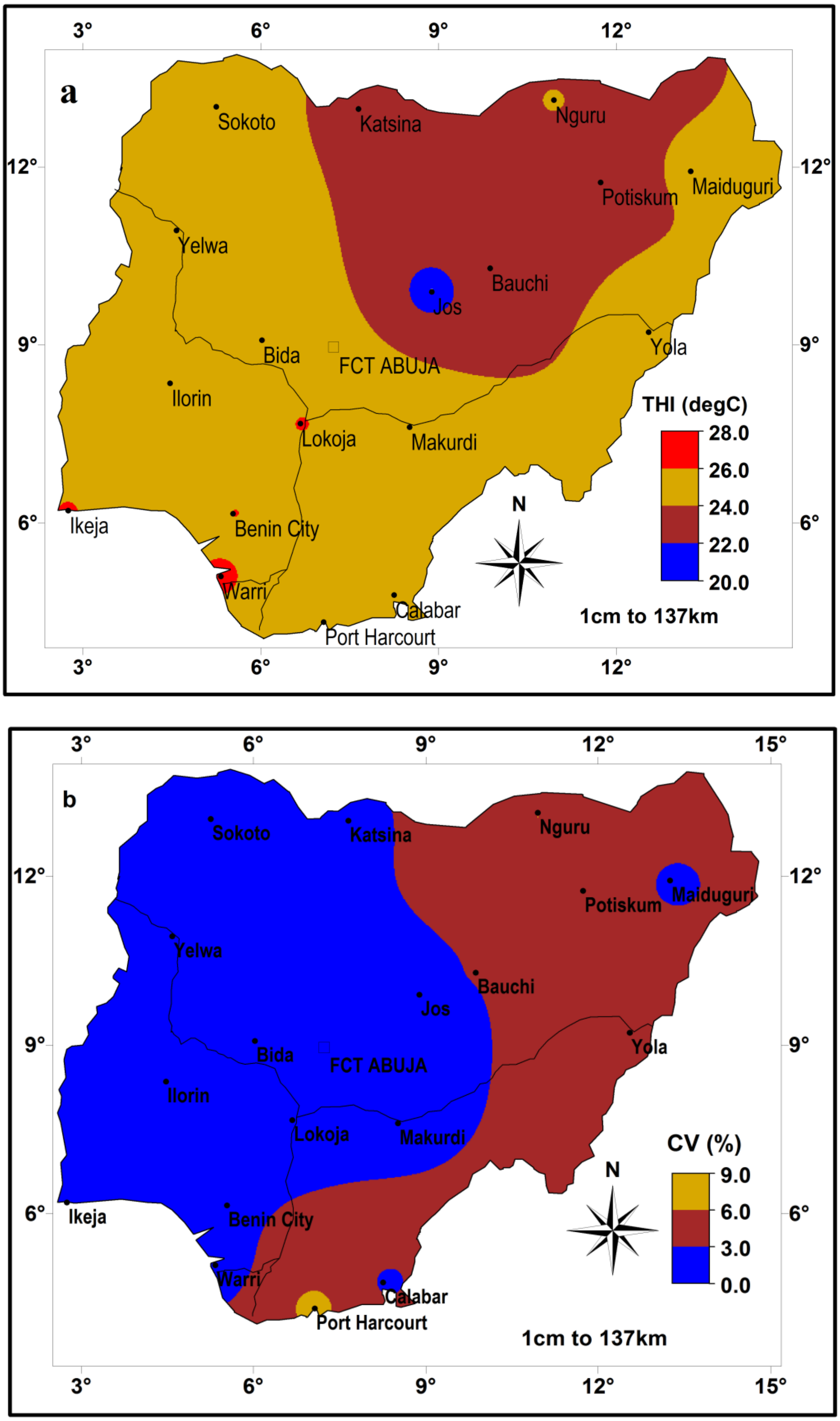


Figure 4.24: (a) Mean Temperature-Humidity Index (ºC) and (b) Coefficient of Variation (%) for the Period of 1951-2009 over Nigeria

Table 4.3: Comparison between 1951-1980 and 1981-2009 Values of Temperature-Humidity Index (THI) for Selected Stations across different Eco-Climatic Regions in Nigeria

Eco-Climatic region	**Station**	**Values for 1951-1980**		**Values for 1981-2009**		**Analysis of variance to identify significant difference**	
		Mean	CV (%)	Mean	CV (%)	F-value	P-value
Tropical Savanna (Sahel)	Nguru SI	22.6	4.4	23.9	5.9	17.7	0.00*
Tropical Savanna (Sudan)	Katsina SI	22.1	3.2	22.6	3.5	5.1	0.03*
	Sokoto SI	23.9	1.7	25.0	2.0	64.1	0.00*
	Maiduguri	23.8	2.9	23.6	2.1	2.1	0.16
	Potiskum SI	21.9	4.6	23.0	2.6	25.0	0.00*
	Yelwa SD	25.1	1.2	24.5	4.9	4.9	0.03*
	Bauchi SI	21.9	2.3	23.1	3.0	48.6	0.00*
	Yola SI	24.9	1.6	25.8	4.3	19.3	0.00*
Montane	Jos SD	20.2	6.9	19.5	2.6	8.3	0.05*
Tropical Savanna (Guinea)	Bida	25.9	1.2	26.0	2.7	0.1	0.72
	Ilorin SD	25.4	3.2	24.4	3.7	18.3	0.00*
	Lokoja	26.3	1.9	26.1	4.6	1.5	0.23
	Makurdi	25.3	3.6	25.7	4.3	1.9	0.17
Tropical Wet and Dry	Ikeja SI	25.9	1.2	26.5	2.3	25.8	0.00*
	Benin SI	25.9	1.9	26.7	1.5	35.0	0.00*
	Calabar	25.6	2.3	25.9	3.5	2.1	0.16
Tropical Wet	Warri	26.2	0.8	24.9	18.9	2.2	0.14
	Port Harcourt SI	23.8	9.7	25.8	3.5	17.9	0.00*
Overall (monthly data) mean SI		24.3	3.0	24.6	4.2	6.5	0.01*

Variation for all asterisked (*) rows are significant at 95% confidence level (i.e. $p \leq 0.05$).

Superscripts SI and SD ($^{SI, SD}$) are used to identify station that exhibits significant mean increase (SI) or significant mean decrease (SD) in Temperature-Humidity Index between 1951-1980 and 1981-2009 values

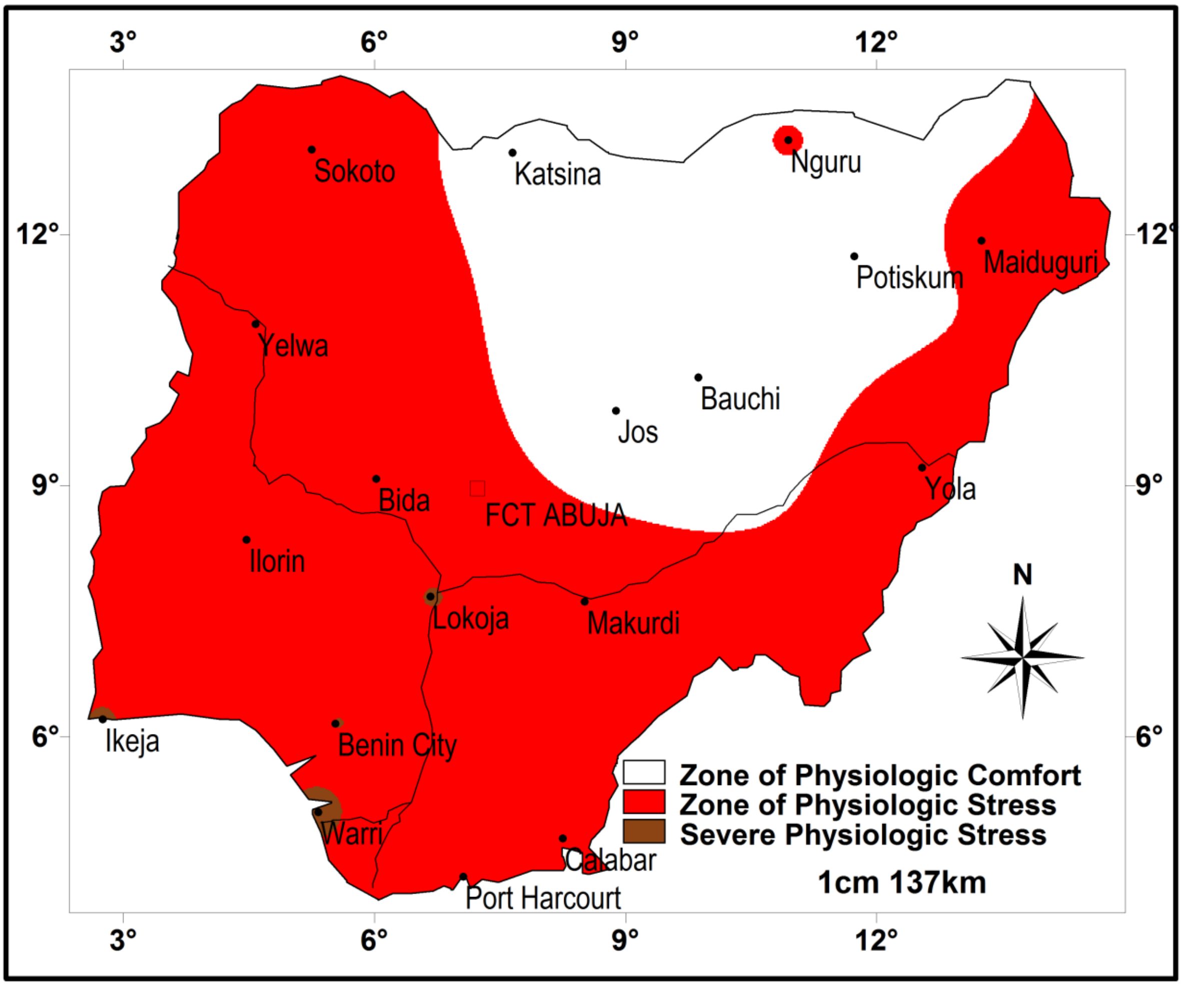


Figure 4.25: Annual Pattern of Physiologic Comfort in Nigeria Based on Temperature-Humidity Index (THI ^{o}C) (1951-2009)

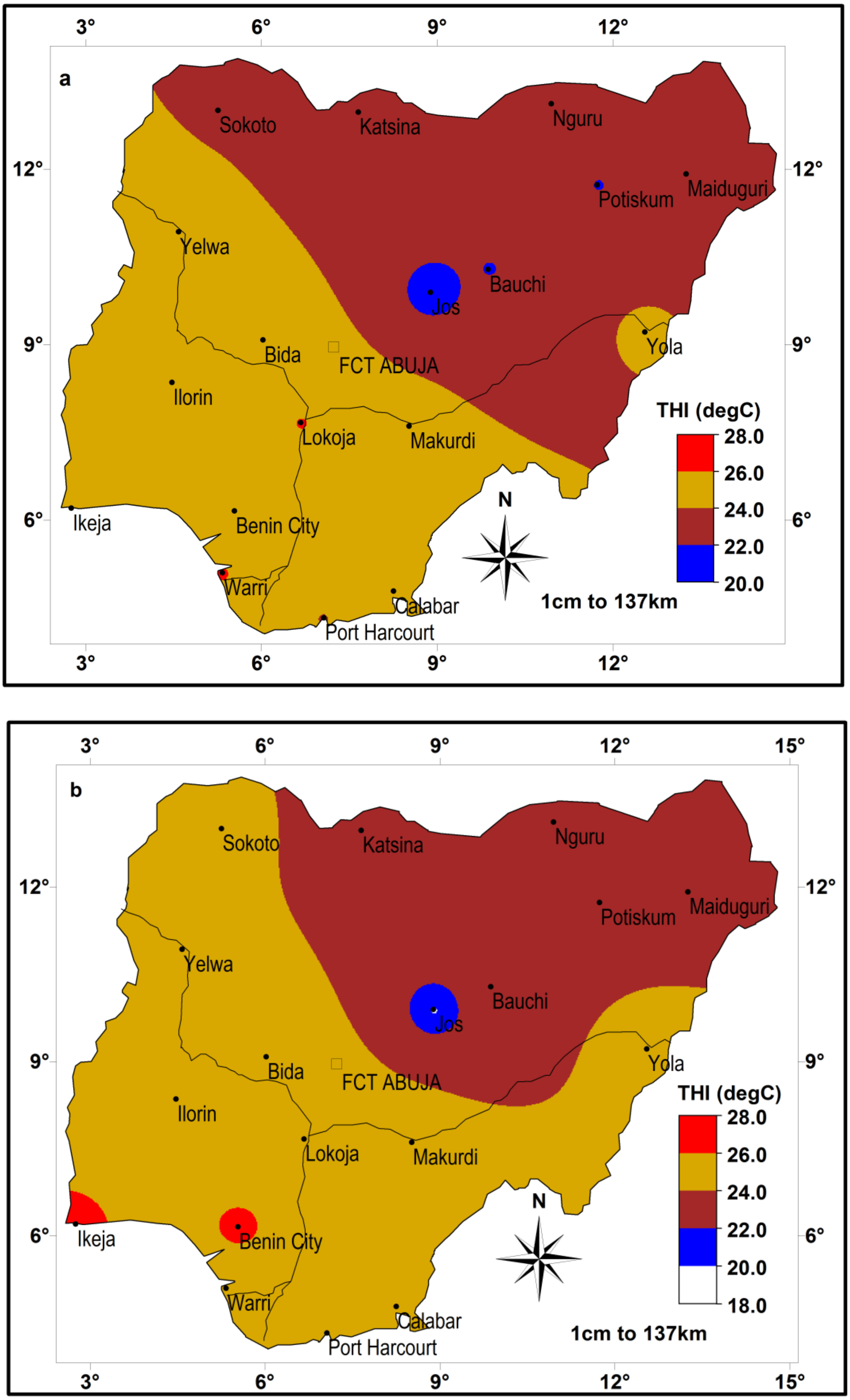


Figure 4.26a-b: Mean Temperature-Humidity Index (°C) over Nigeria in (a) 1951-1980 and (b) 1981-2009.

Interpretation of the 1951-1980 and 1981-2009 mean THI (Figures 4.27a and 4.27b) suggests that regions prone to heat stress have increased in the latter (1981-2009) period. Benin City was recognised by both THI and ETI to be vulnerable to heat stress (severe by THI) while the major difference in the classification is with Warri and Ikeja, both in the southern coastal region. While Warri, alongside with Benin constituted area of physiological discomfort with the mean annual THI in 1981-2009, it was Ikeja and Warri that THI classified to be vulnerable to severe heat stress in the period (1981-2009).

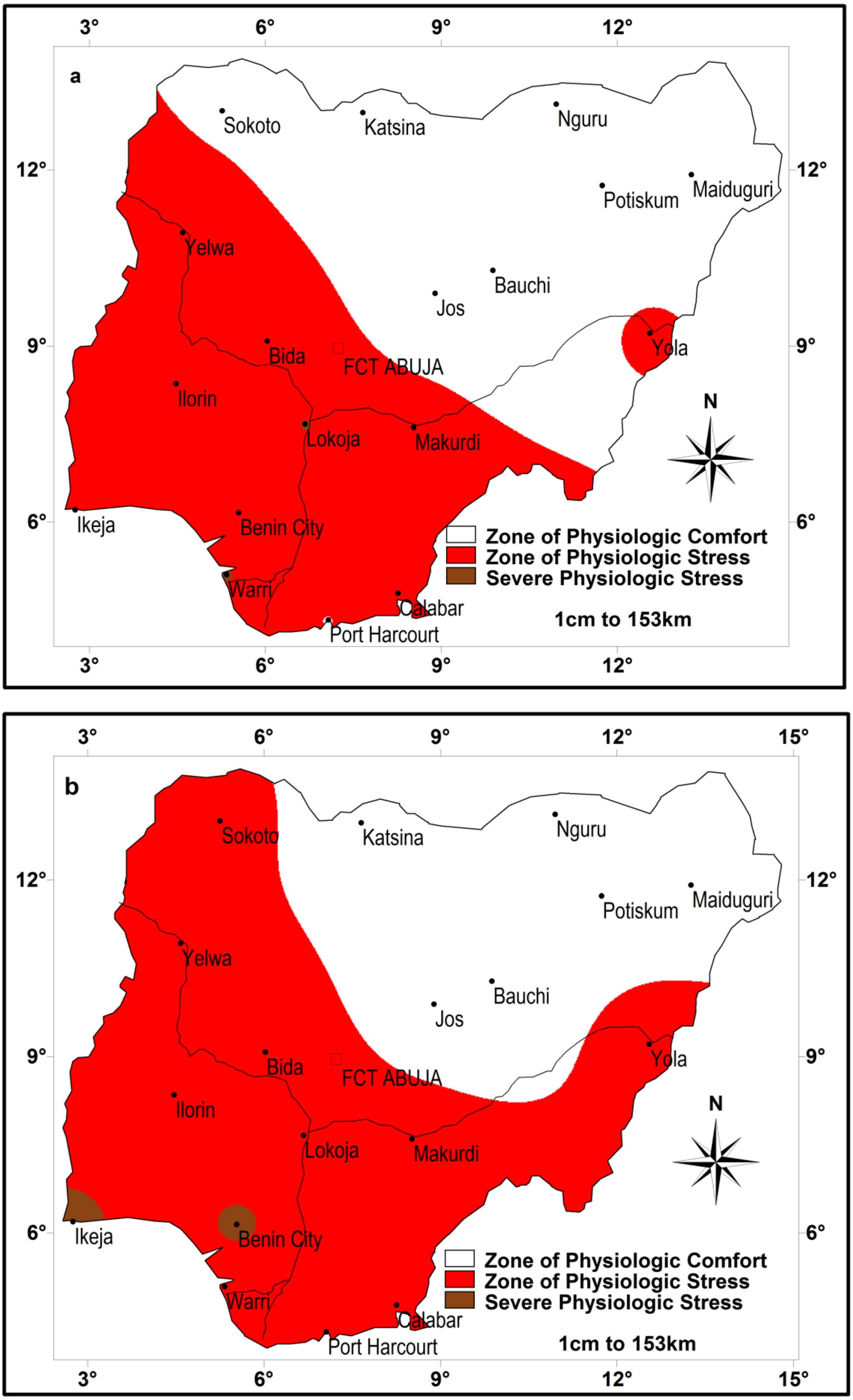


Figure 4.27: Physiologic Comfort and Discomfort Region derived from Annual Temperature-Humidity Index in (a) 1951-1980 and (b) 1981-2009

4.4.2. Decadal variations

The mean THI values exhibited an increasing trend from 1951, with the results of the linear regression model in equation 4.2.

$$y\ (°C) = 0.19x + 24.17 \qquad 4.2$$

Where

$y\ (°C) =$ the mean THI in a decade; and $x = n^{th}$ decade from $1951 - 1960$ (such that the n^{th} for the decade 2011-2020 is 6 and it is 8 for 2031-2040).

The mean value of THI has increased from 1951, and it is predicted to increase with time. The spatial distribution of mean THI values for 1951-1960 to 2001-2010, and the predicted patterns for 2011-2020 and 2021-2030 are presented in Figure 4.28. Using the 15-24°C threshold for comfortable climate suggested for Nigeria and the tropics in general (Nieuwolt, 1977; Olaniran, 1982; Ogbonna and Harris, 2008), Figure 4.29 showed that thermal stress has increased from 1951, and will extend to most parts of Nigeria, except Jos, Katsina and Yelwa by 2030. The apparent persistent thermal comfort in Jos area is most likely linked with the high elevations (above 1285 m above the mean sea level) around this region. The thermal comfort situation around Yelwa and Katsina could however not be ascertained in this study, hence an intensive microclimate study of these settlements will be required for a better understanding of the physiologic climate system.

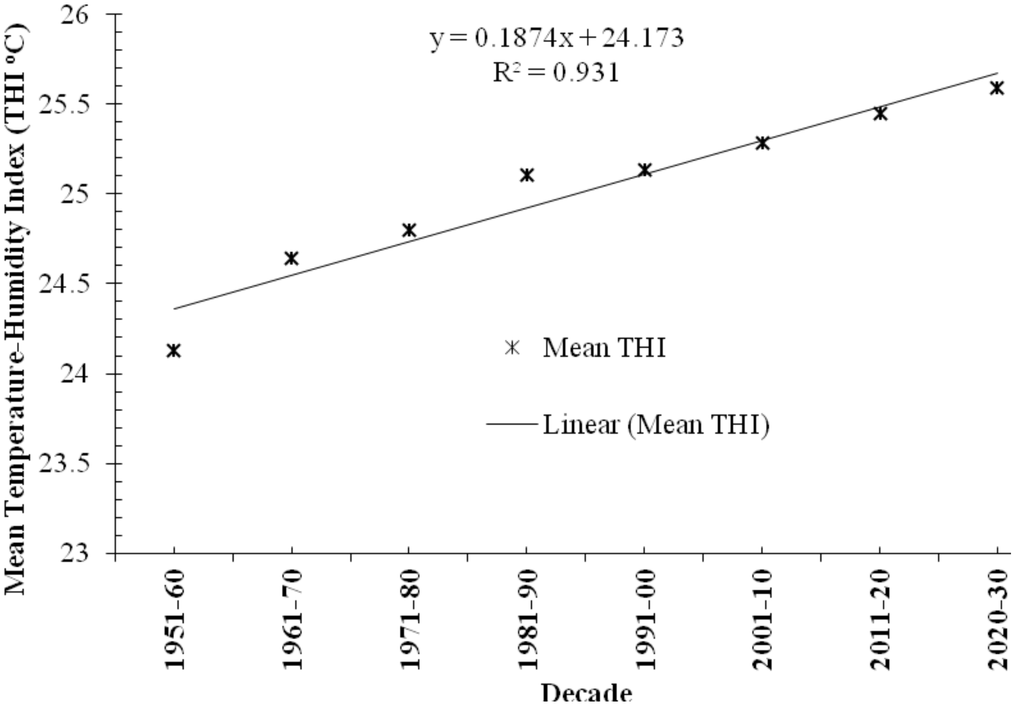


Figure 4.28: Trend of Decadal Mean Temperature-Humidity Index in Nigeria

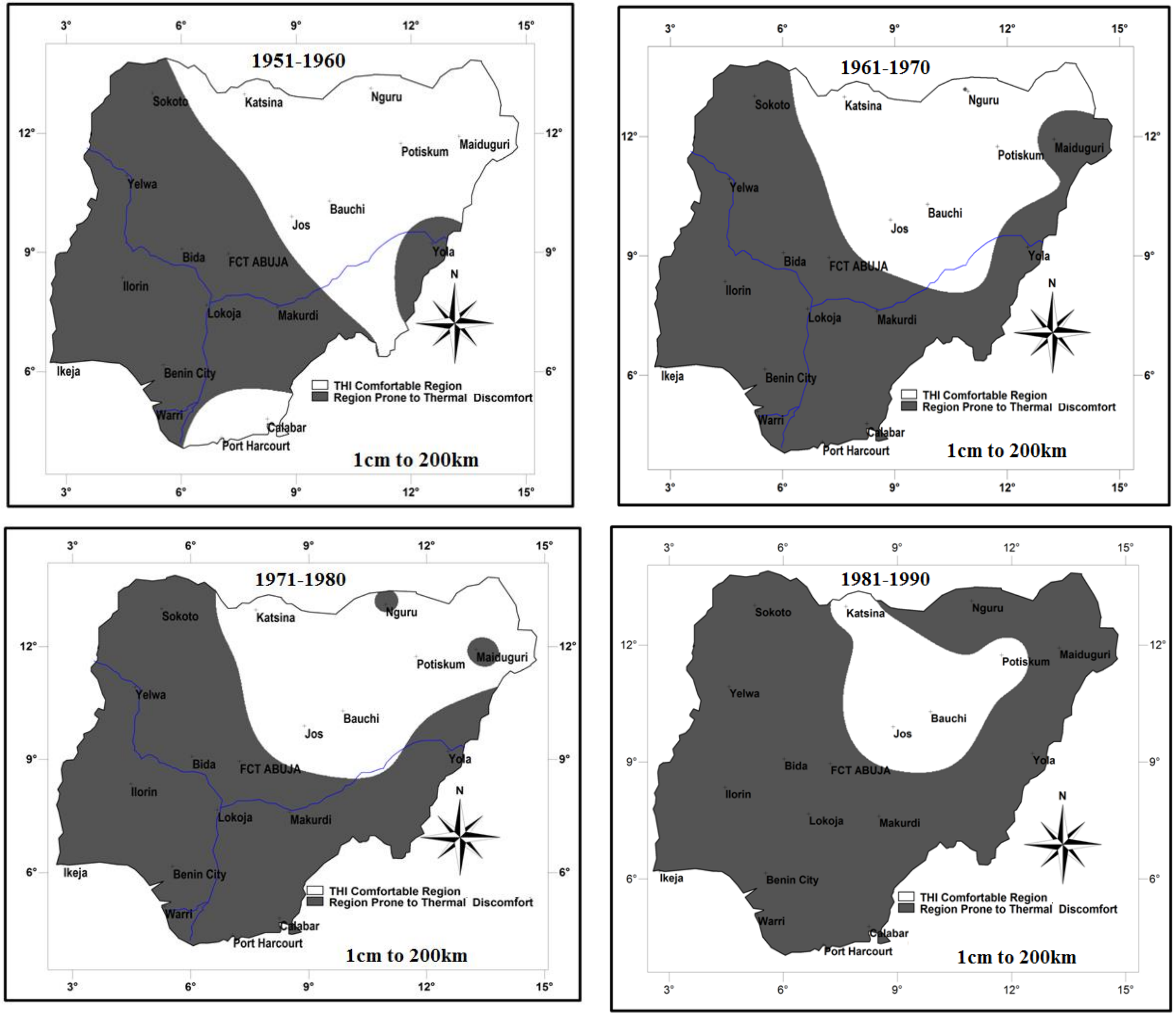


Figure 4.29: Decadal Variations in the Distribution of Thermal Comfort and Discomfort derived from Temperature Humidity Index (THI) for Nigeria.

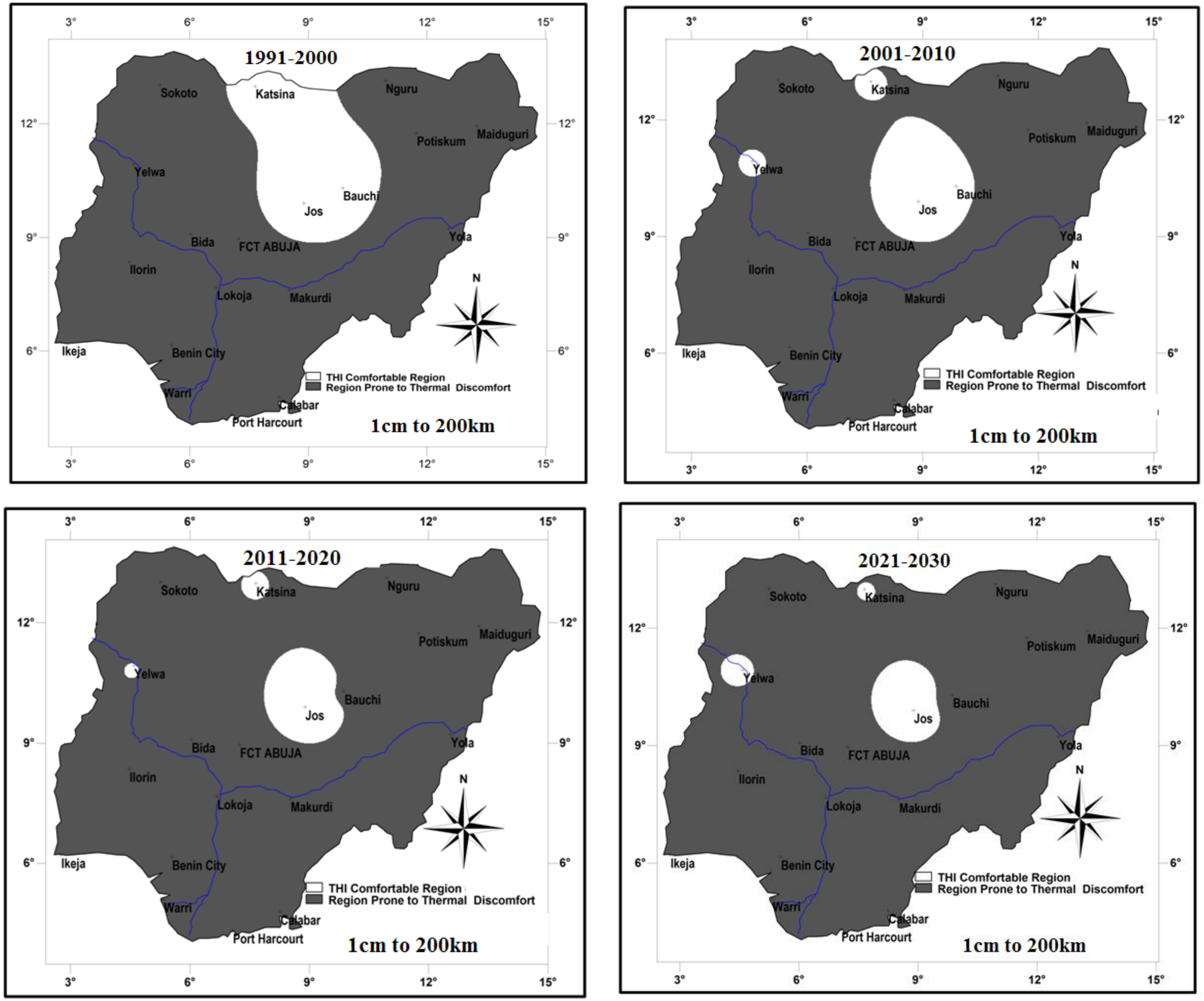


Figure 4.29 (contd.): Decadal Variations in the Distribution of Thermal Comfort and Discomfort derived from Mean Temperature Humidity Index (THI) for Nigeria. (Maps for 2011-2020 and 2021-2030 are projected).

4.4.3. Seasonal variations

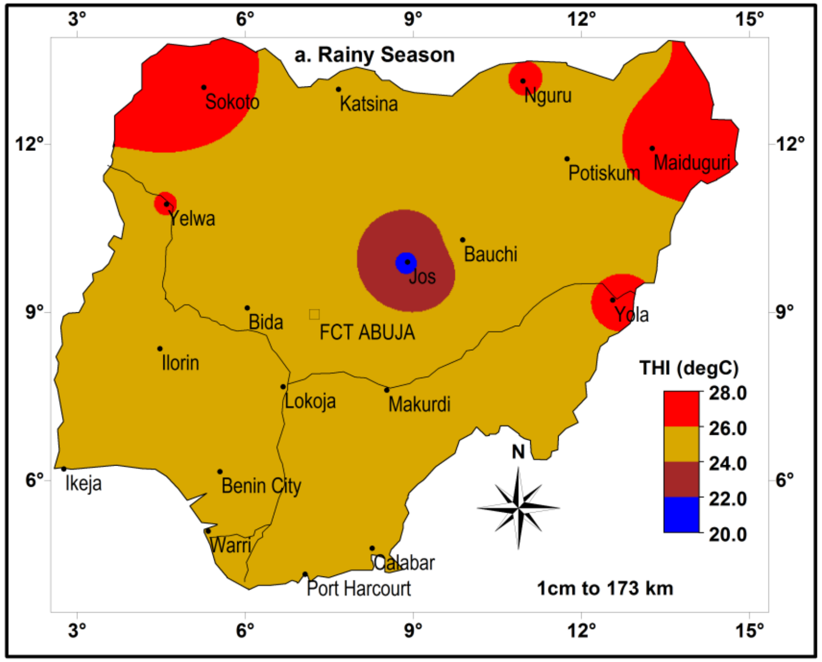
The seasonal distribution of the mean and range values of THI at the investigated meteorological stations are presented as Table 4.4. Table 4.4 shows that the Harmattan means were generally lower in the sudano-sahelian (18.4-22.8^{o}C) and montane (17.3^{o}C) regions than the rainforest and (25.0-26.8^{o}C) and guinea savanna (24.0-25.7^{o}C). This is similar to the pattern observed for dry season. Conversely, the rainy season means were generally higher in the sudano-sahelian region, except at Bauchi (24.5^{o}C) than the rainforest (24.4-25.9^{o}C) or guinea savanna region (24.8-26.0^{o}C). Jos, in the montane region exhibited the lowest mean THI in all the season.

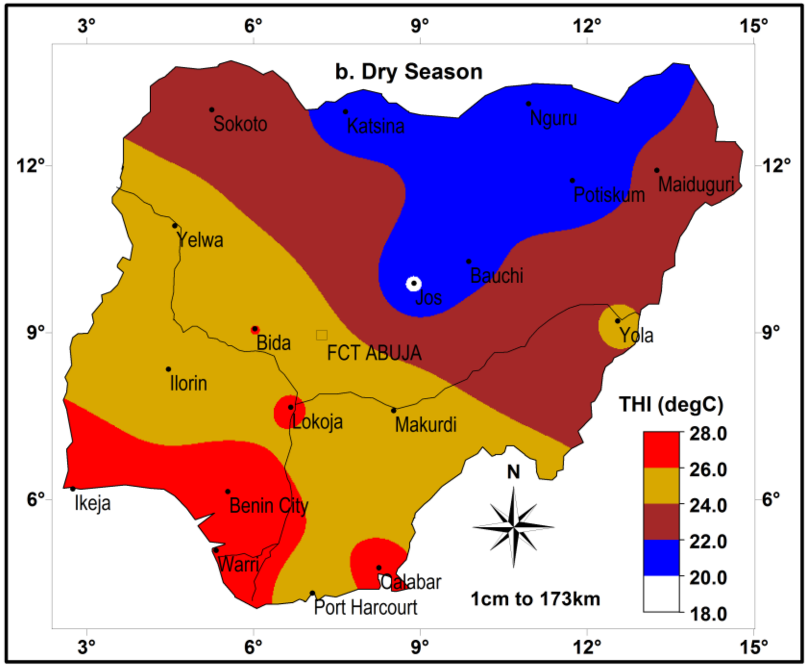
The maps showing the interpolated means for Nigeria (Figure 4.30a-c) suggest that the northeastern region, through which the dry, dust-laden harmattan blows in the Harmattan period, into Nigeria, exhibited the lowest THI range (18-20^{o}C) in this period. The patterns for the other seasons show that northern stations exhibited higher THI in the rainy season than the southern stations, but lower in the dry season. This seasonal pattern is similar to the pattern observed with ETI (explained in section 4.3), and it shows that the seasonal pattern in the physiologic indices are linked with the pattern of flow of the two main air masses (i.e. tropical maritime, mT and tropical continental, cT) controlling the climate of Nigeria. For example, the prevalence of mT in the southern Nigeria in the rainy season appears to coincide with the low values of the physiologic indices (ETI and THI) in the southern region. High rainfall may have caused a cooling effect in the area, accounting for the lower means.

Table 4.4: Seasonal Values of Temperature-Humidity Index (THI°C) for Selected Stations in different Eco-Climatic Regions in Nigeria

Eco-Climatic Region	Stations	Rainy season (April-October) (1951-2009)		Dry season (Nov-March) (1951-2009)		Harmattan period (1951-2009) (Dec-Feb)	
		Mean (°C)	Range (°C) (min-max)	Mean (°C)	Range (°C) (min-max)	Mean (°C)	Range (°C) (min-max)
Tropical Savanna (Sahel)	Nguru	26.4	22.6-30.4	22.0	19.6-27.5	19.7	17.1-26.5
Tropical Savanna (Sudan)	Katsina	25.6	23.1-27.7	20.9	18.7-21.9	18.4	16.3-20.0
	Sokoto	27.1	26.0-28.2	23.6	21.5-25.2	21.3	19.1-23.5
	Maiduguri	26.7	25.7-28.6	22.2	20.2-26.6	19.5	17.2-21.5
	Potiskum	25.3	21.5-27.0	21.2	19.5-22.8	18.8	17.1-20.6
	Yelwa	26.2	25.3-27.3	24.7	20.6-26.6	22.6	19.2-25.1
	Bauchi	24.5	23.0-26.6	21.7	19.2-23.9	19.6	17.7-22.7
	Yola	26.6	24.9-31.2	24.9	22.9-28.0	22.8	21.0-27.7
Montane	Jos	20.4	19.7-21.1	18.8	16.0-20.1	17.3	12.2-19.3
Tropical Savanna (Guinea)	Bida	25.9	22.5-27	26.3	24.4-27.6	25.0	22.5-27.0
	Ilorin	24.8	23.3-25.9	25.0	22.0-26.4	24.0	20.8-26.3
	Lokoja	26.0	24.1-28.9	26.6	20.8-27.8	25.7	20.0-27.4
	Makurdi	25.9	21.8-27.9	26.0	23.3-27.7	24.6	22.1-27.0
Tropical Wet and Dry	Ikeja	25.3	24.2-28.7	26.9	25.9-28.9	26.7	24.5-29.0
	Benin	25.4	23.3-26.3	26.8	22.6-28.2	26.5	17.9-28.2
	Calabar	25.2	20.9-26.1	26.5	22.1-27.3	26.4	22.6-27.3
Tropical Wet	Warri	25.6	24.8-26.4	27.1	26.4-28.0	26.8	25.1-28.0
	Port Harcourt	24.4	20.1-26	25.2	20.9-27.1	25.0	20.5-27.2

Seasonal relationship (r) is significant at $p \leq 0.05$ (*) and $p \leq 0.01$ (**)





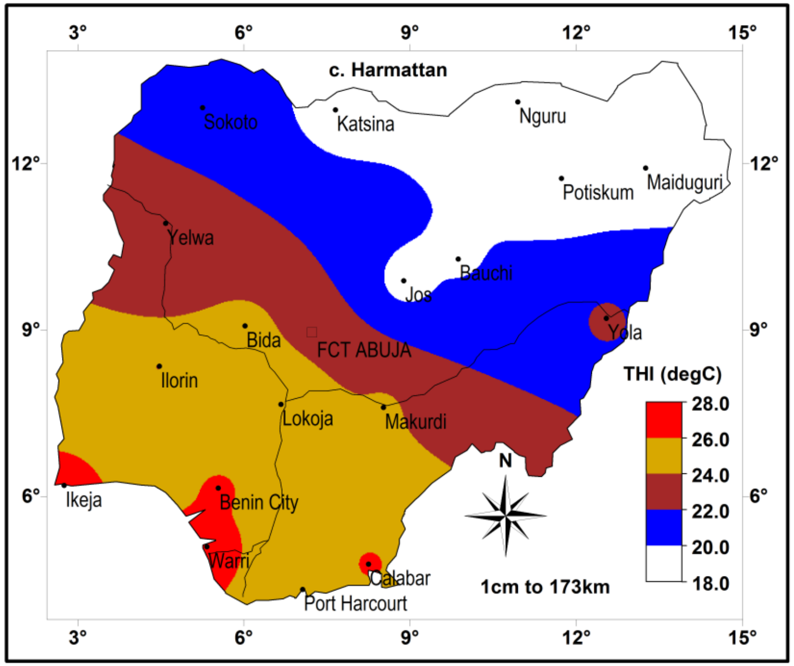
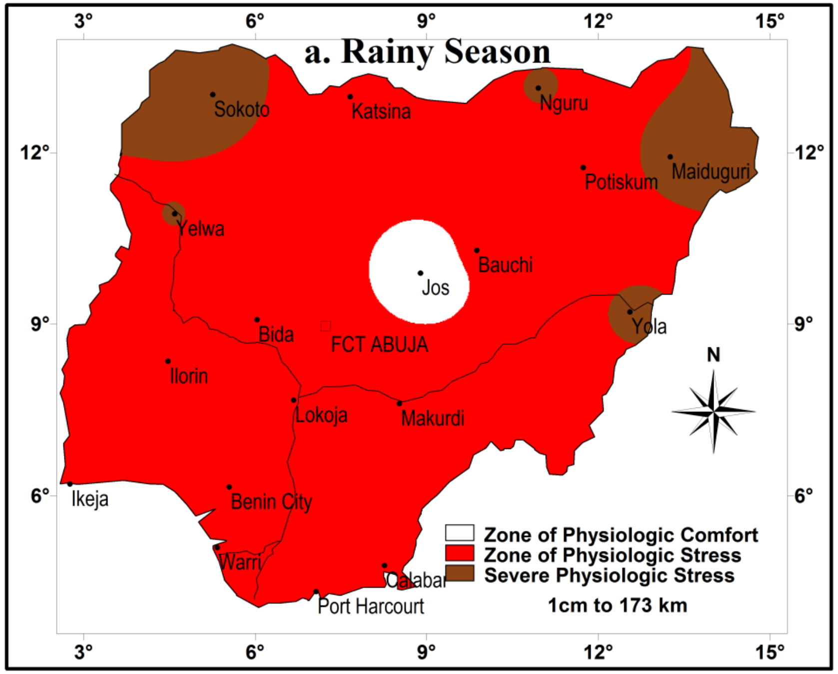
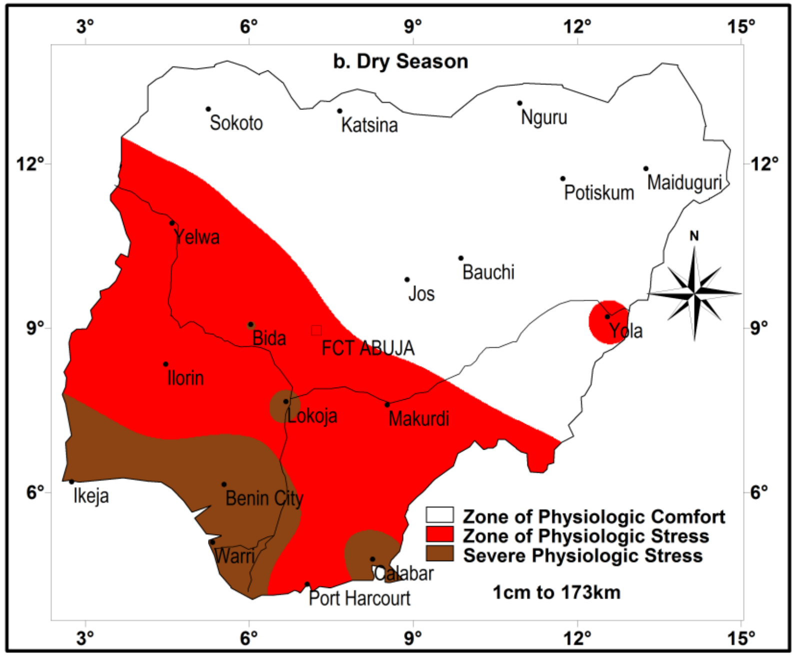


Figure 4.30a-c: Seasonal Distribution of Temperature-Humidity Index (THI °C) in Nigeria (1951-2009)

On the other hand, the prevalence of the dry, dust-laden Harmattan across the northeastern Nigeria in the Harmattan period may have caused these physiologic stress to reduce, especially given the ability of dust, air molecules and clouds to reflect back into the space more than 30% of the radiant energy from the sun (Adeleke and Leong, 1978; Strahler and Strahler, 1994). The harmattan is characterised by large amount of dust haze and smog in Nigeria (Miller, 1952; Adefolalu, 1984).

With the classification of temperature-humidity index into physiologic comfort or discomfort in Nigeria, the seasonal pattern (Figure 4.31a-c) show severe stress in some part of northern Nigeria in the rainy season, leaving the montane as the only physiologically comfortable region. The situation in the dry season showed a converse situation with the southern region, especially Ikeja, Benin-Warri axis, Calabar and Lokoja, exhibiting intense heat (physiologic) stress during the period. Harmattan period was considered more conducive in the north but less conducive in the south, the coastal areas of Calabar, Benin, Warri and Ikeja exhibiting severe physiological stress.





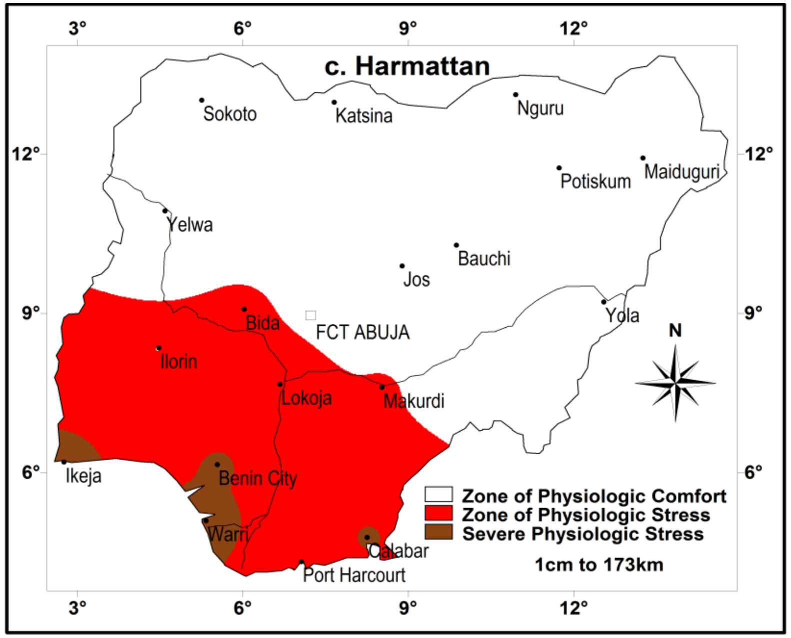


Figure 4.31a-c: Physiologic Comfort and Discomfort Zones Derived from Temperature-Humidity Index (THI ^{o}C) in Nigeria (1951-2009)

4.5. Relative Strain Index (RSI)

4.5.1. Annual variation

The relative strain index, defined as the ratio of the evaporative cooling required by a subject to the maximum evaporative cooling possible (Giles et al., 1990) is described in terms of its means, ranges (minimum-maximum) and linear trend between 1951 and 2009 in 18 selected stations in Nigeria in Appendix 4.9. Highest RSI ratio (0.22±0.04) occurred at Warri in the Tropical wet climate while the montane region exhibited the lowest ratio (0.01±0.01). The overall mean of RSI in the investigated 18 meteorological stations is 0.20±0.18. Most stations in the rainforest and guinea savanna regions (except Calabar and Ilorin) exhibited higher RSI ratio than the overall average while most stations in the sudano-sahelian (except Yola) and montane regions showed lower RSI ratio. The coefficient of variations at stations in the neighbourhood of the montane climate region (Potiskum, Bauchi and Jos) were significantly higher (>70%) than other stations. Stations with very low means and correspondingly low deviation statistically results into large (close to 100%) coefficients of variation (Wheeler et al., 2010). Mean variability was also low (≤20%) at most stations in the rainforest, except Calabar, and the northern region, except Yelwa, Yola, Nguru (where variability was 47.4, 33.3, 23.8 and 29.4%, respectively). Figure 4.32 showed that the RSI values exhibited linear increase especially in the rainforest, sudan and sahelian savanna.

Furthermore, the maps generated to show the mean annual RSI and its coefficient of variation in Nigeria for 1951-2009 (Figures 4.33a and 4.33b) show that the region around the southwest coastline and the confluence area of Rivers Niger and Benue exhibited the highest means (0.2-0.3) while the montane and neighbouring Bauchi regions recorded the lowest mean ratio (0.00-0.01). Variability was, however, relatively low (≤ 20%) at Warri-Port Harcourt axis of the southern Nigeria, and at some stations (Lokoja, Sokoto, Katsina and Maiduguri) in the savanna region (Figure 4.33b). The montane and the surrounding area in the northeast exhibited the highest mean variability (≥60%) in RSI in 1951-2009.

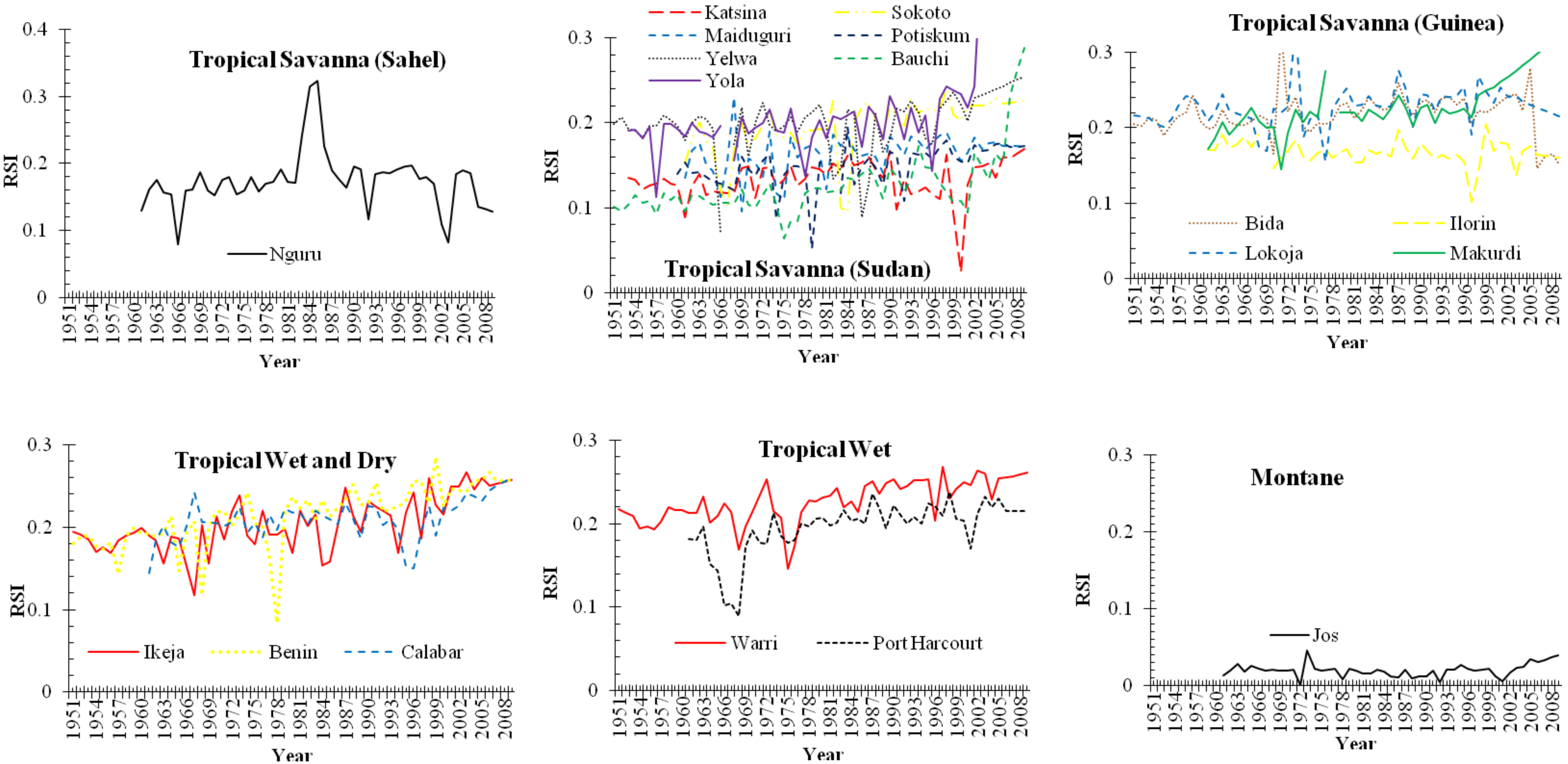


Figure 4.32: Annual Variations in Relative Strain Index (RSI ratio) at different Eco- Climatic Regions (1951-2009)

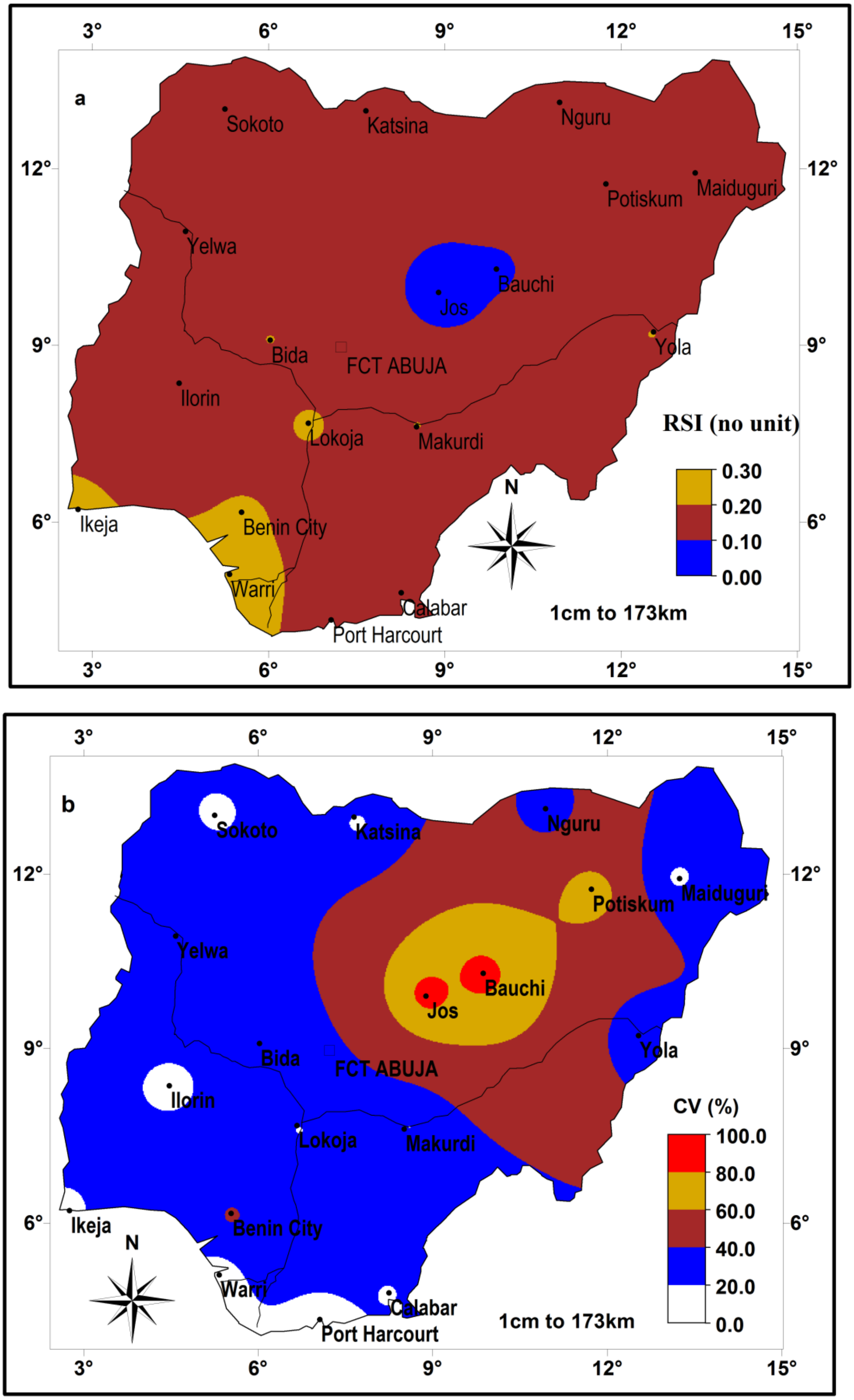


Figure 4.33: (a) Mean Annual Relative Strain Index- RSI, and (b) Coefficient of Variation of RSI over Nigeria for the Period of 1951-2009

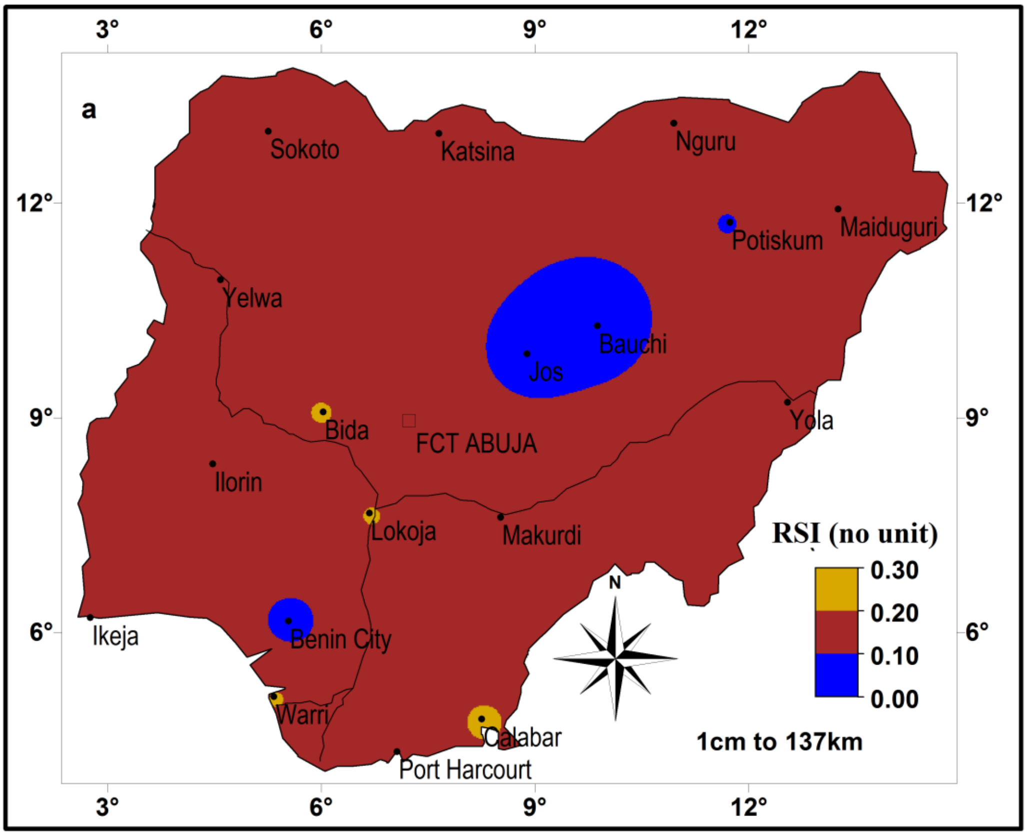
The 1951-1980 and 1981-2009 distributions of mean RSI across selected stations (Table 4.5) show that significant increase has occurred in the rainforest (except Calabar) and at few stations in the savanna (Ilorin in the guinea region; Yelwa, Yola, Sokoto and Nguru in the sudano-sahelian region). The montane climate region, Ilorin and Yelwa have exhibited significant decline, however. The maps showing the 1951-1980 and 1981-2009 RSI patterns for Nigeria which were obtained from interpolating the means of the 18 selected stations (Figure 4.34a and 4.34b) suggest a general increase in RSI in Nigeria, especially in the southern (southwest and south-south) regions, Yola and areas close to the montane climate region.

Interpretations of the RSI ratio into physiologically comfortable regions (0.1-0.2 RSI is regarded as the physiologically comfortable range) are presented for the annual means of 1951-2009, 1951-1980 and 1981-2009 as Figures 4.35, 4.36a and 4.36b, respectively. Figure 4.35 suggests that Warri-Benin axis, Ikeja and Lokoja exhibited significant vulnerability to heat stress in 1981-2009. Effective temperature index and temperature-humidity index have also identified these regions as being vulnerable to heat stress in the 1981-2009 period.

Table 4.5: Comparison between 1951-1980 and 1981-2009 Values of Relative Strain Index (RSI, ratio) for Selected Stations across different Eco-Climatic Regions in Nigeria

Eco-Climatic region	Station	Values for 1951-1980		Values for 1981-2009		Analysis of variance to identify significant difference	
		Mean	CV (%)	Mean	CV (%)	F-value	P-value
Tropical Savanna (Sahel)	Nguru^{SI}	0.14	14.3	0.16	37.5	5.09	0.03*
Tropical Savanna (Sudan)	Katsina	0.11	18.2	0.12	25.0	1.89	0.18
	Sokoto^{SI}	0.15	20.0	0.18	22.2	11.49	0.00*
	Maiduguri	0.14	28.6	0.15	6.7	0.70	0.41
	Potiskum	0.10	96.0	0.13	15.4	2.13	0.15
	Yelwa^{SD}	0.18	16.7	0.14	50.0	7.54	0.01*
	Bauchi	0.07	97.0	0.10	80.0	2.59	0.11
	Yola^{SI}	0.17	11.8	0.22	22.7	19.53	0.01*
Montane	Jos^{SD}	0.04	97.0	0.02	87.0	6.17	0.02*
Tropical Savanna (Guinea)	Bida	0.22	18.2	0.20	40.0	0.56	0.46
	Ilorin^{SD}	0.20	20.0	0.16	18.8	18.86	0.01*
	Lokoja	0.22	13.6	0.21	33.3	0.37	0.53
	Makurdi	0.19	15.8	0.20	25.0	0.19	0.06
Tropical Wet and Dry	Ikeja^{SI}	0.20	10.0	0.24	16.7	22.60	0.01*
	Benin^{SI}	0.20	15.0	0.25	8.0	52.88	0.01*
	Calabar	0.20	15.0	0.20	60.0	0.04	0.84
Tropical Wet	Warri^{SI}	0.22	13.6	0.25	8.0	40.23	0.00*
	Port Harcourt^{SI}	0.18	16.7	0.21	9.5	25.16	0.01*
Overall (monthly data) mean^{SI}		0.16	35.3	0.18	32.2	8.23	0.01*

Variation for all asterisked (*) rows are significant at 95% confidence level (i.e. $p \leq 0.05$).
Superscripts SI and SD ($^{SI, SD}$) are used to identify station that exhibits significant mean increase (SI) or significant mean decrease (SD) in Relative Strain Index between 1951-1980 and 1981-2009 values



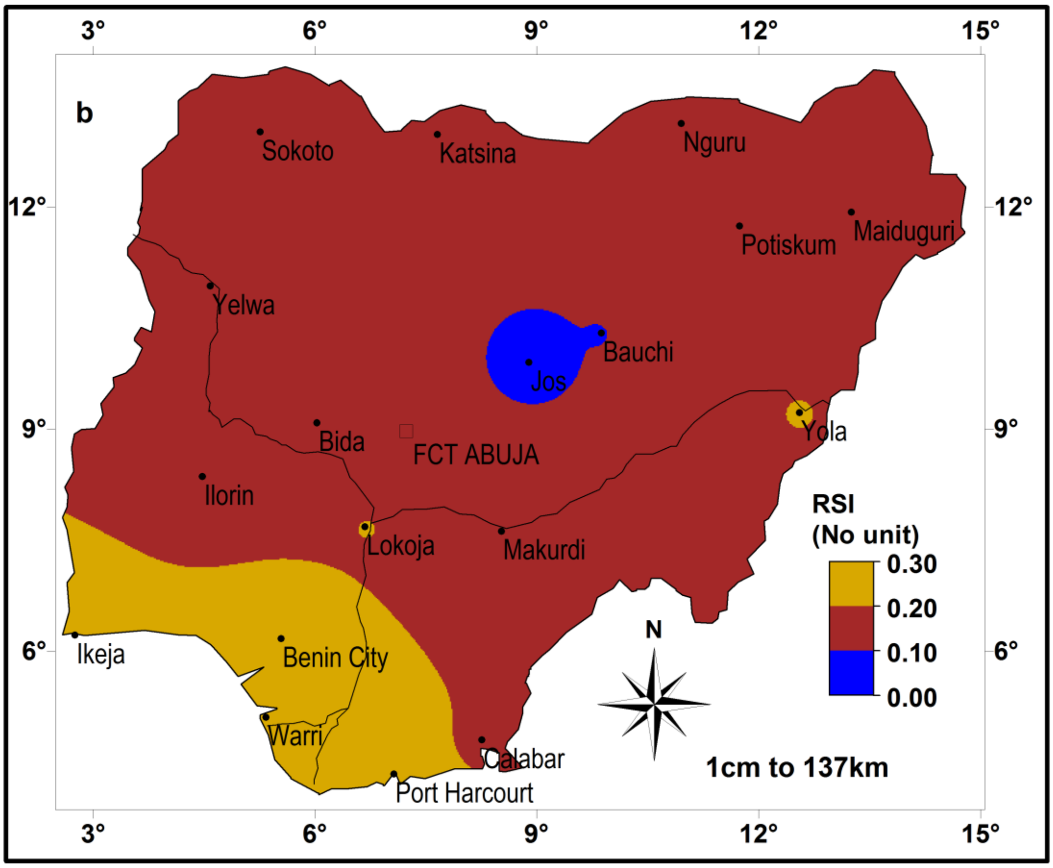


Figure 4.34: Mean Relative Strain Index over Nigeria in (a) 1951-1980 and (b) 1981-2009

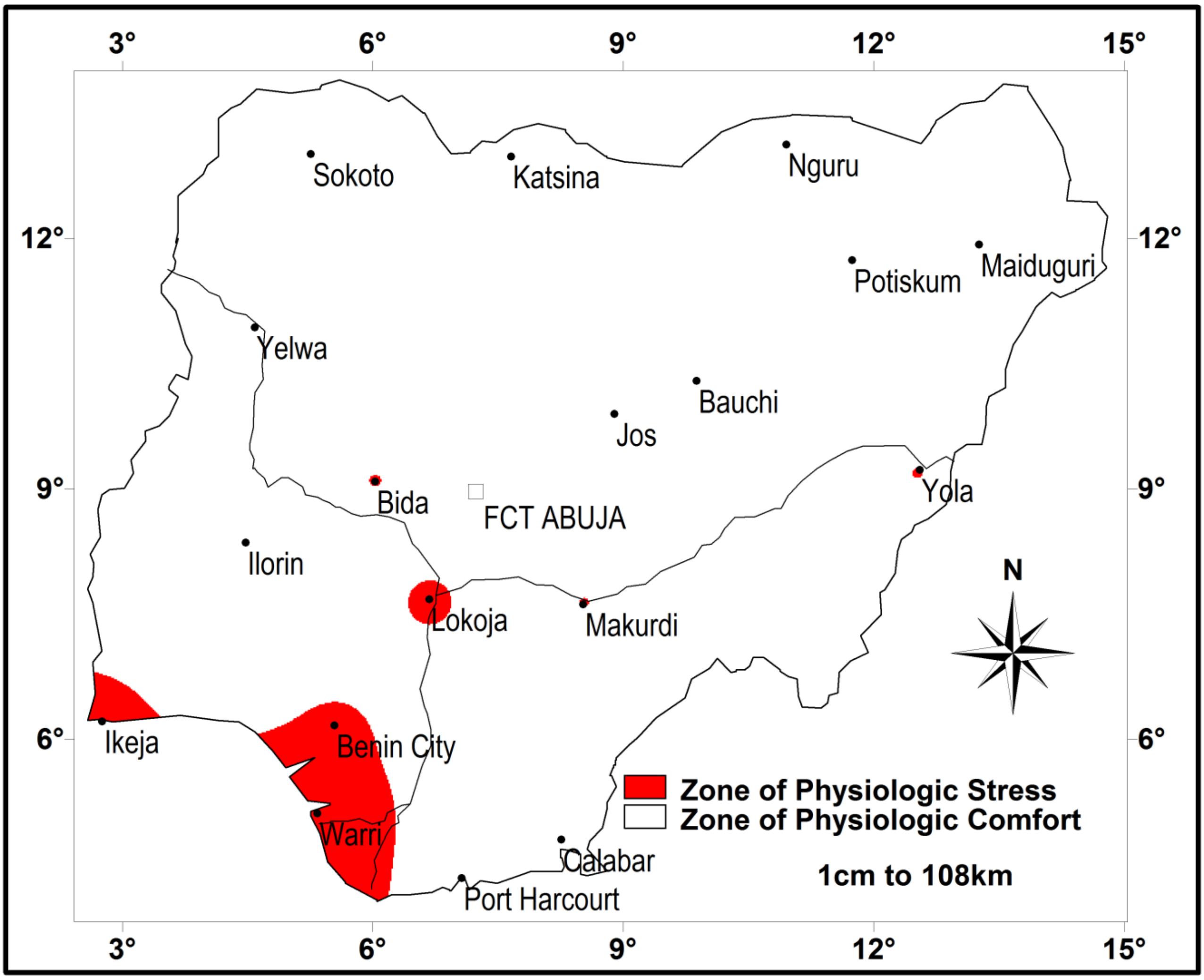


Figure 4.35: Annual Pattern of Physiologic Comfort derived from Relative Strain Index (1951-2009)

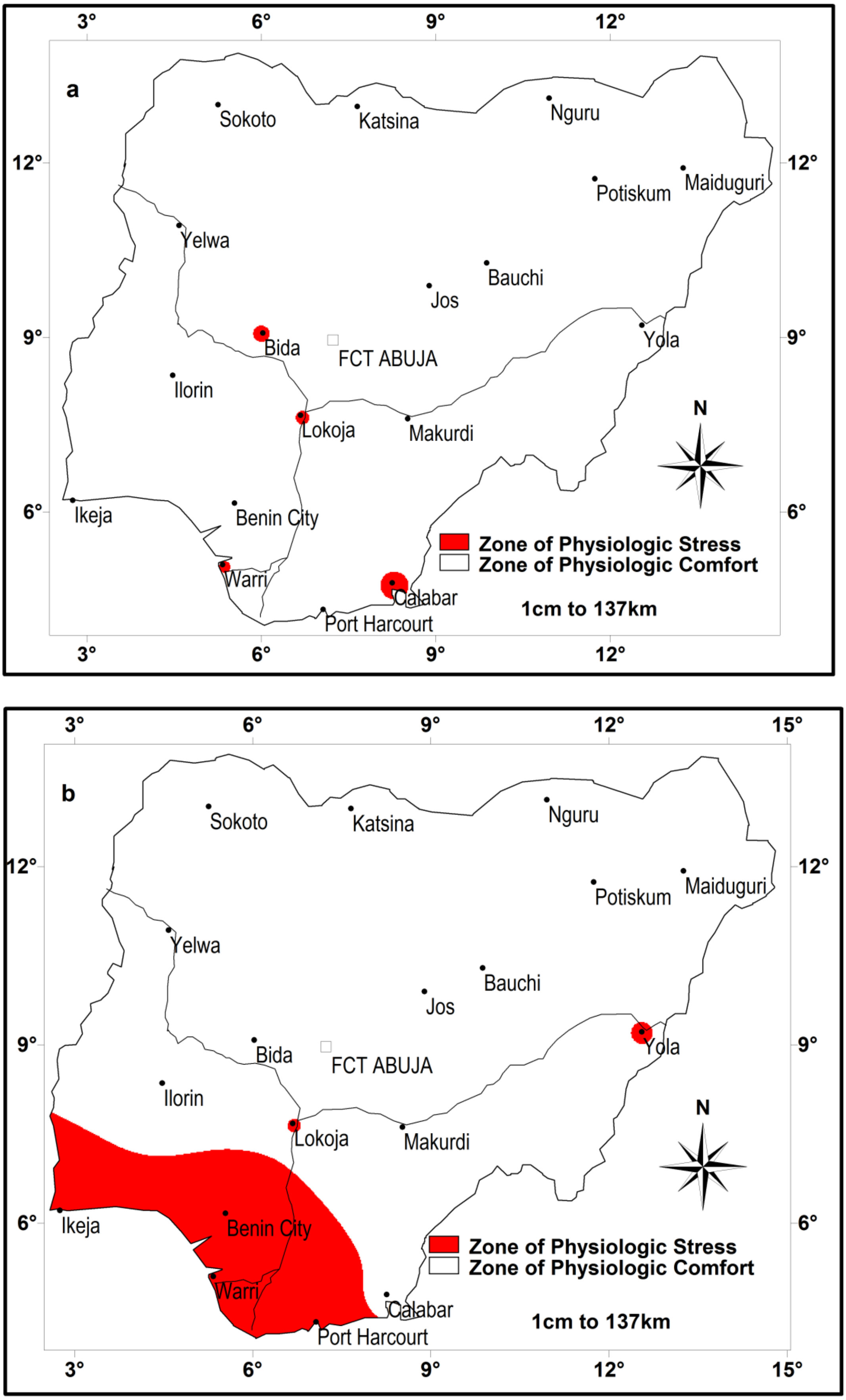


Figure 4.36a-b: Annual Physiologic Comfort Map of Nigeria in (a) 1951-1980 and (b) 1981-2009, as derived from Relative Strain Index

4.5.2. Decadal variation

Figure 4.38 showed that the decadal mean of RSI values has steadily increased over time since 1951. The linear regression model is given in equation 4.3.

$$y\ (ratio) = 0.01x + 0.15 \quad (R^2=0.90;\ p<0.05) \qquad 4.3$$

Based on the interpretation of the RSI (i.e. RSI less than 0.1 for cold stress; 0.1 to 0.2 ratio as a thermally comfortable period; RSI ratio greater than 0.2 as thermally heat stressed), the 2001-2010 decade is the most thermally stressed decade since 1951, and thermal stress is predicted to increase towards 2030 (Figure 4.37).

The patterns exhibited at the different locations as derived from the results of the interpolation of the known values for the different decades from 1951 to 2010 (1951-1960, 1961-1970, 1971-1980, 1981-1990, 1991-2000 and 2001-2010) as well as the predicted RSI patterns for subsequent decades (2011-2020 and 2021-2030) showed that the north-central region of Nigeria were vulnerable to cold stress between 1951 and 1970 (Figure 4.38). The cold period in the north-central however declined and was restricted to the area around the montane climate region (Jos) between 1971 and 1980. The magnitude of heat stress, on the other hand, gradually increased thereafter, from 1971-1980 decade to cover more than the southern half of Nigeria in the last (2001-2010) decade. The projected patterns for 2011-2020 and 2021-2030 show that the increasing vulnerability of the hitherto RSI classified comfortable region of the north-central Nigeria is expected.

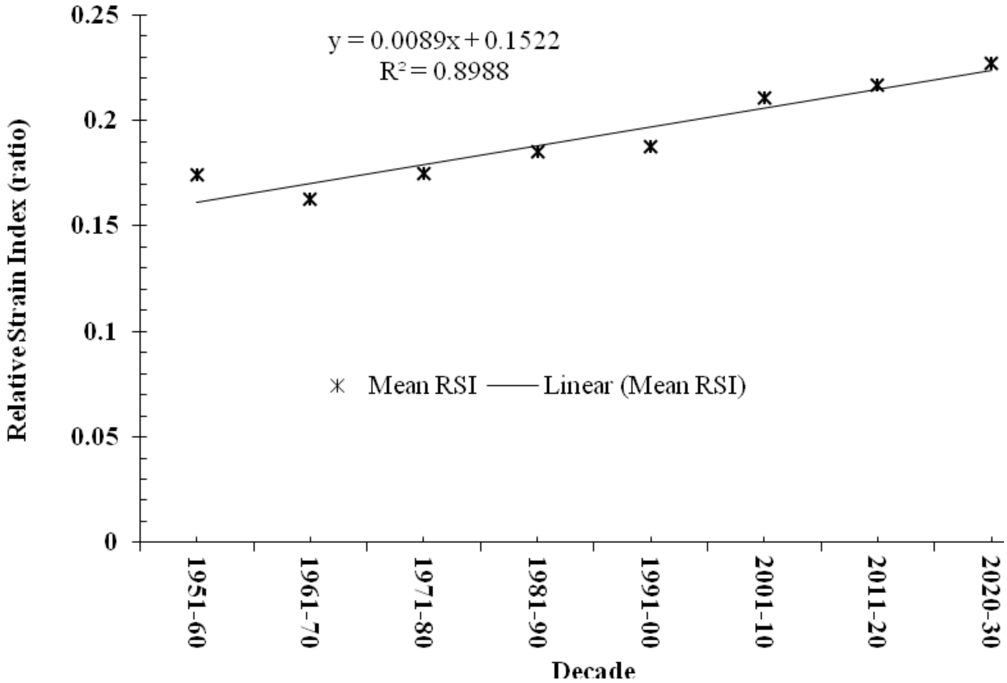


Figure 4.37: Trend of Decadal Mean in Relative Strain Index Ratio for Nigeria

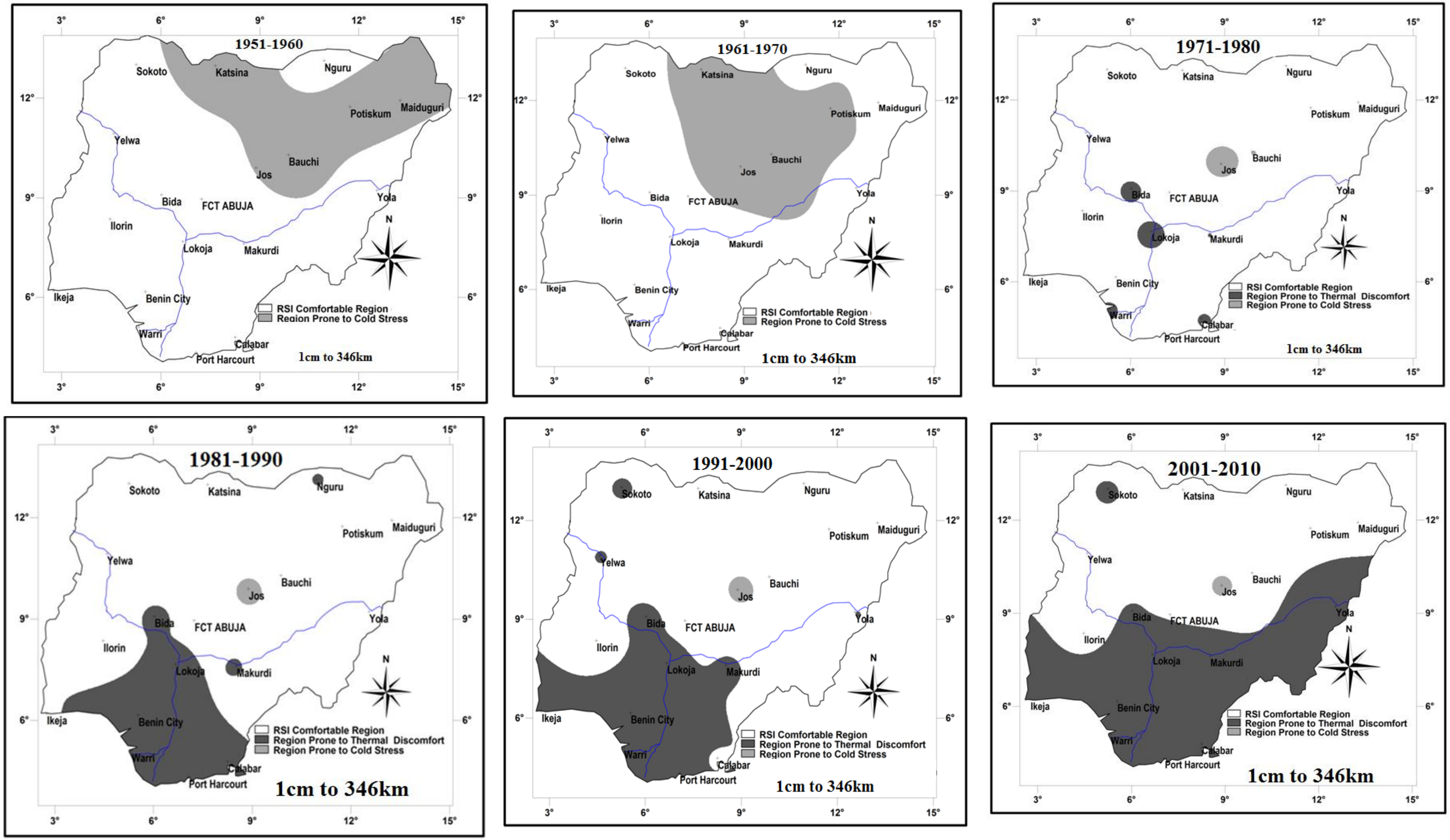


Figure 4.38a: Decadal Variations in the Distribution of Thermal Comfort and Discomfort Derived from Mean Relative Strain Index for Nigeria

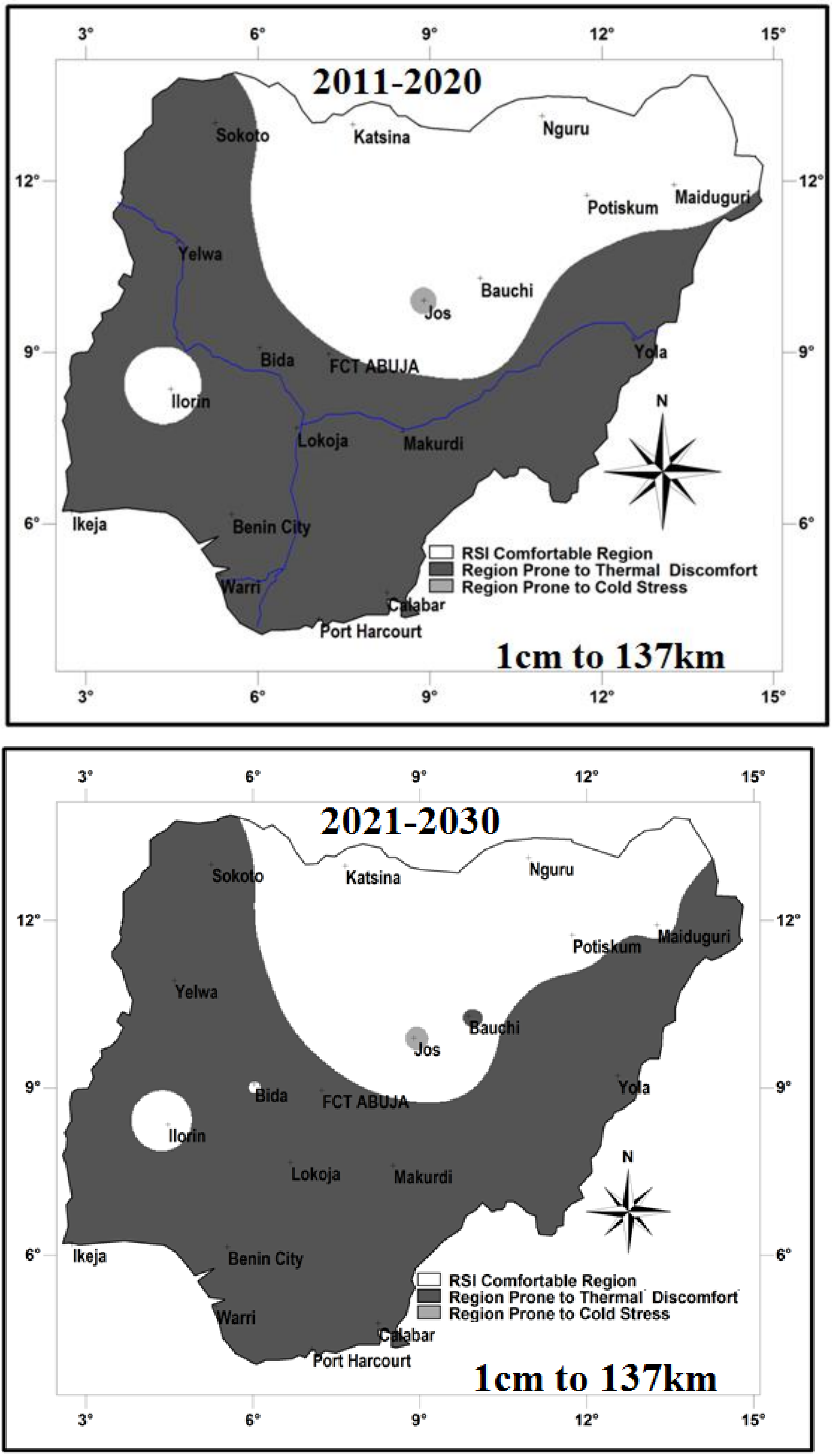


Figure 4.38b: Projected Pattern of Relative Strain Index over Nigeria for the Period of 2011-2030

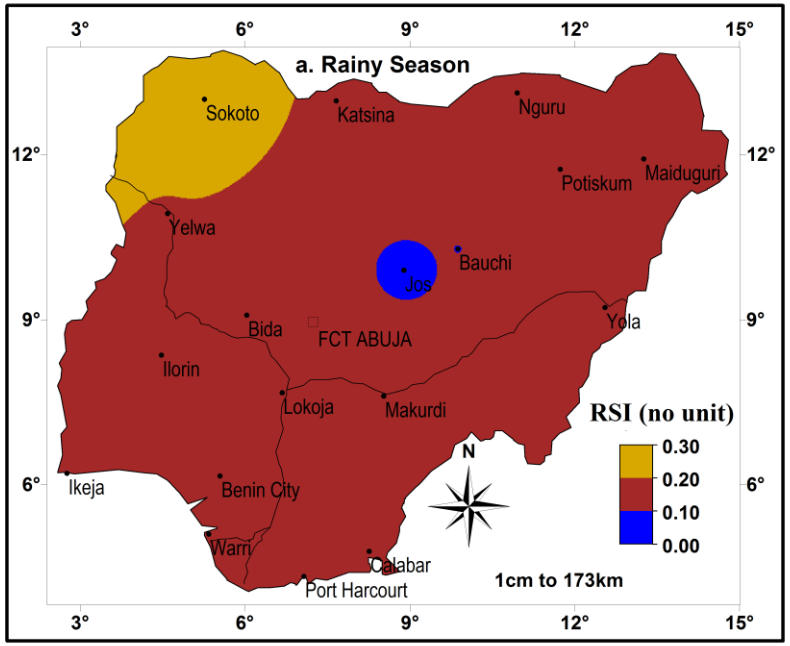
4.5.3. Seasonal variation

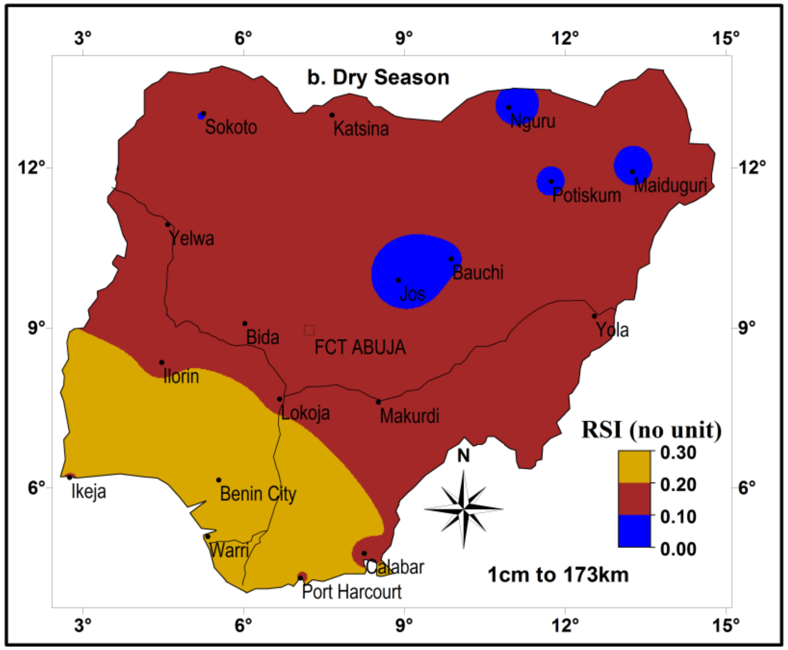
The seasonal distribution of RSI ratio for 1951-2009 at selected stations is summarised in Table 4.6. Similar to ETI and THI, RSI in the dry season and Harmattan were higher in the south than in the north while the rainy season's RSI was higher in the northwest than other parts of Nigeria (Figure 4.39a-c). Generally, RSI in the Harmattan (-0.1 to 0.2) was lower than either the dry or rainy season's (0.0-0.3). Figure 4.40a-c, which shows the results of the interpolated means reveal similar pattern of seasonal distribution of RSI with ETI and THI. RSI's pattern of distribution shows that the northwest is not physiologically comfortable in the rainy season while the southern region (consisting of the Niger-Delta and the southwest) is equally vulnerable to heat stress in the dry season. The Harmattan period is shown to be comfortable at all part of Nigeria. Miller (1952) has described the Harmattan as the 'redeeming' feature in the climate of Nigeria, being characterised by cool nights. Figure 4.40c nonetheless shows a dint of cold stress in the montane region.

Table 4.6: Seasonal Values of Relative Strain Index for Selected Stations in different Eco-Climatic Regions in Nigeria

Eco-Climatic Region	Stations	Rainy season (April-October) (1951-2009)		Dry season (Nov-March) (1951-2009)		Harmattan period (1951-2009) (Dec-Feb)	
		Mean (°C)	Range (°C) (min-max)	Mean (°C)	Range (°C) (min-max)	Mean (°C)	Range (°C) (min-max)
Tropical Savanna (Sahel)	Nguru	0.20	0.02-0.40	0.10	-0.10-0.20	0.10	-0.10-0.20
Tropical Savanna (Sudan)	Katsina	0.20	0.12-0.30	0.10	0.00-0.10	0.02	-0.10-0.10
	Sokoto	0.30	0.11-0.30	0.10	-0.10-0.20	0.10	-0.20-0.10
	Maiduguri	0.20	0.10-0.30	0.10	-0.10-0.20	0.03	-0.20-0.10
	Potiskum	0.20	0.02-0.30	0.10	-0.40-0.10	0.02	-0.40-0.10
	Yelwa	0.20	0.02-0.30	0.20	-0.10-0.20	0.10	-0.10-0.20
	Bauchi	0.10	0.01-0.20	0.10	-0.40-0.20	0.00	-0.40-0.10
	Yola	0.20	0.12-0.60	0.20	0.10-0.30	0.10	0.10-0.30
Montane	Jos	0.01	-0.70-0.04	0.02	0.00-0.10	-0.01	-0.10-0.04
Tropical Savanna (Guinea)	Bida	0.20	0.02-0.30	0.20	-0.20-0.50	0.20	-0.20-0.70
	Ilorin	0.20	0.10-0.20	0.20	0.10-0.20	0.10	0.1-0.20
	Lokoja	0.20	0.11-0.40	0.20	-0.20-0.30	0.20	-0.20-0.30
	Makurdi	0.20	0.10-0.10	0.20	-0.10-0.30	0.20	0.00-0.30
Tropical Wet and Dry	Ikeja	0.20	0.10-2.40	0.20	0.10-0.40	0.20	0.00-0.40
	Benin	0.20	0.01-0.20	0.30	0.20-0.40	0.20	0.20-0.30
	Calabar	0.20	0.00-0.20	0.20	-0.40-0.30	0.20	-0.40-0.30
Tropical Wet	Warri	0.20	0.10-0.20	0.30	0.10-0.30	0.20	0.00-0.30
	Port Harcourt	0.20	0.10-0.20	0.20	0.00-0.30	0.20	0.00-0.30

Seasonal relationship (r) is significant at p≤0.05 (*) and p≤0.01 (**)





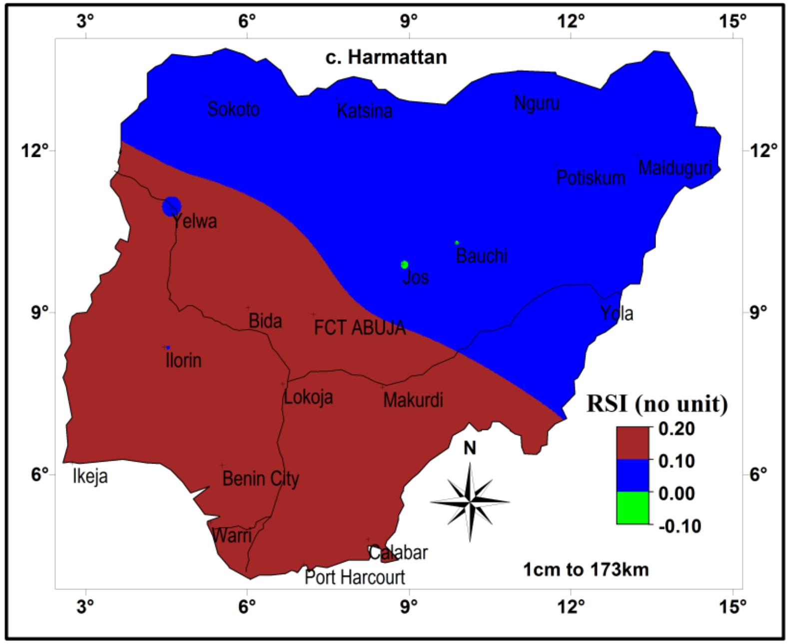
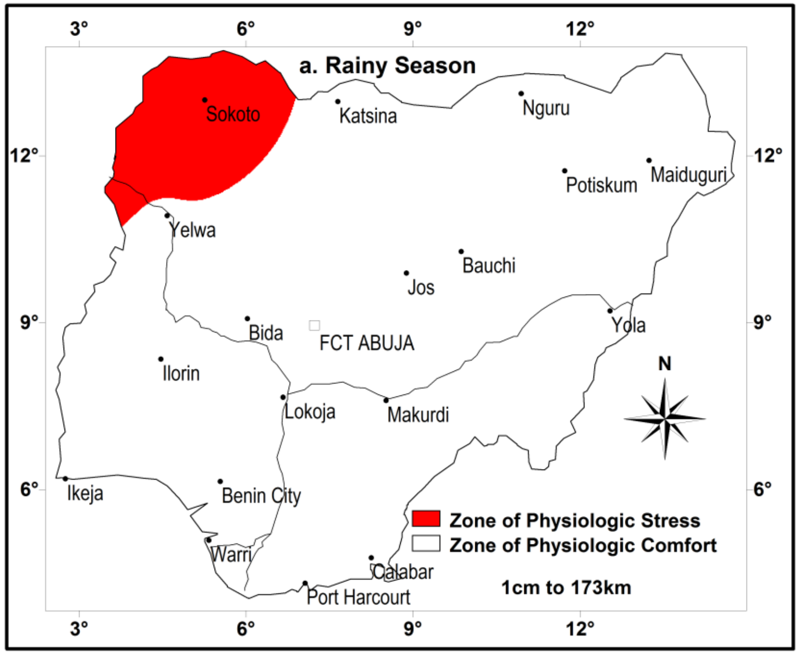
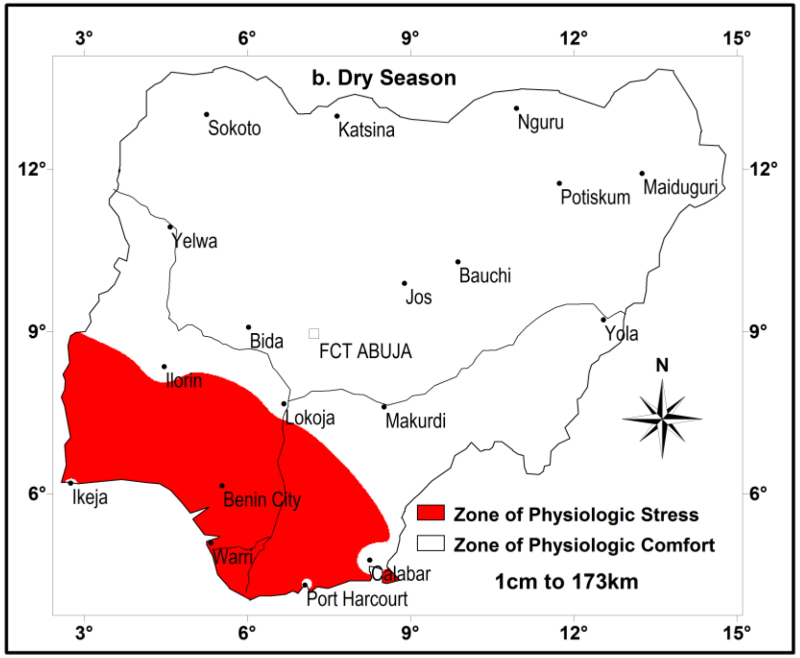


Figure 4.39: Seasonal Distribution of Relative Strain Index Ratio in Nigeria (1951-2009)





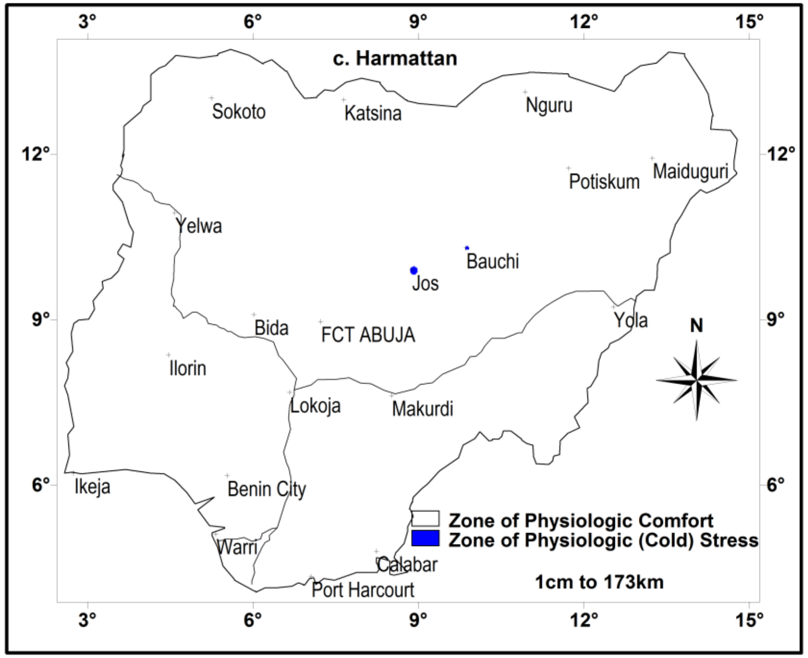


Figure 4.40: Zoning of Nigeria into Physiologic Comfort and Discomfort Zones, derived from Seasonal Relative Strain Index Ratio for 1951-2009

4.6. Comparison of the annual trends of ETI, THI and RSI

The values of trend analysis shows that except for Nguru, Bauchi and Potiskum in the north-eastern part of the sudano-sahelian region, all the stations that exhibited significant increasing trends with RSI also showed significant increase with ETI and THI. However, the three indices showed different results at Ilorin. While ETI has shown that the linear trend in the station's physiologic climate has insignificantly decreased with years ($p>0.05$), it was shown to have exhibited significant decrease ($r = -0.006$; $p<0.05$) with THI. Relatively Strain Index, on the other hand, showed that the station (Ilorin) exhibited significant increase between 1951 and 2009. In general, Table 4.7 which highlights the results of the trend analysis for ETI, THI and RSI for each of the 18 selected meteorological stations showed similar results for the three indices in 10 out of the 18 stations (about 55.5%). Effective temperature index and THI only were similar for 15 stations (83.3%), ETI and RSI only were similar for 9 (50%) and THI and RSI only produced similar results for 11 stations (61.1%). Table 4.7 further shows that contrasting results were more in the guinea savanna than other regions, hence strengthening the earlier argument that some physiologic indices are more suitable for some regions than for others. Further studies may however be required to conclude on this assertion.

Table 4.7: Comparison of the Results of Selected Indices derived from their Pattern of Trends between 1951 and 2009

		Physiologic climate indices		
Eco-Climatic region		**ETI**	**THI**	**RSI**
Tropical Savanna (Sahel)	Nguru	+*	+*	+
Tropical Savanna (Sudan)	Katsina	+	+	+
	Sokoto	+*	+*	+*
	Maiduguri	+	+	+*
	Potiskum	+*	+*	+
	Yelwa	-	-	-
	Bauchi	+*	+*	+
	Yola	+*	+*	+*
Montane	Jos	+	+	+
Tropical Savanna (Guinea)	Bida	-	+	+
	Ilorin	-	-*	+
	Lokoja	+	+	-
	Makurdi	-	+	+
Temperate Wet and Dry	Ikeja	+*	+*	+*
	Benin	+*	+*	+*
	Calabar	-	-	+
Temperate Wet	Warri	+*	+*	+*
	Port Harcourt	+*	+*	+*

Interpretations

+ = increasing trend
- = decreasing trend
* = significant at $p \leq 0.05$

4.7. Monthly variations in the effective temperature, temperature-humidity and relative strain indices

Figure 4.41a-e is a series of comparative line graphs to show the monthly patterns of the ETI, THI and RSI for 1951-2009. The monthly distribution showed similar patterns at most stations, especially within same climatic region. Double maxima occurred for the indices at most stations in the Tropical Rainforest (Tropical wet and dry, and Tropical wet) region in February and November, followed by a general decline from April until the minimum in August. Afterwards, there was a reduction in these regions. In the guinea savanna, single peak in March/April preceded a decline which reached a minimum in August, followed by a September/October rise before a drop. A peak in April/May characterised the sudan savanna while Nguru, in the sahel savanna, and the montane region peaked in May/June and April, respectively, with all the indices.

In addition, while the tropical rainforest region exhibited double maxima of ETI, THI and RSI values, a single maximum was obtained in other regions. The month within which the maximum occurred also appeared to shift by almost a month away from the preceding region from south, northwards. When examined with the thresholds for physiologic comfort (i.e. ETI = 18.9-25.6^{o}C; THI=15.0-24.0^{o}C; RSI=0.1-0.2), the monthly patterns suggested that the rainforest region is vulnerable to heat stress in February/March, guinea savanna in March/April, and April-June in the sudano-sahelian region. These months are characterised with the peak values of the physiologic indices (ETI, THI and RSI), and they are the months when the values obtained at different regions were greater than the upper threshold limits for the comfortable climate classification (Figure 4.41a-e). These identified months for high vulnerability to heat stress are observed to coincide with the periods of onset of rainfall in the respective climate region (Odekunle, 2008). Iloeje (2001) argued that March/April and April-June months coincide with the period when the sun travels through the south and northern regions of West Africa, and classified these months as the hottest months for places in the south and the northern regions, respectively. The patterns exhibited by the monthly variations in ETI, THI and RSI, especially the period of vulnerability to heat stress is within similar range to the period of high temperature and relatively low humidity in the respective parts of Nigeria as earlier described (Section 4.2).

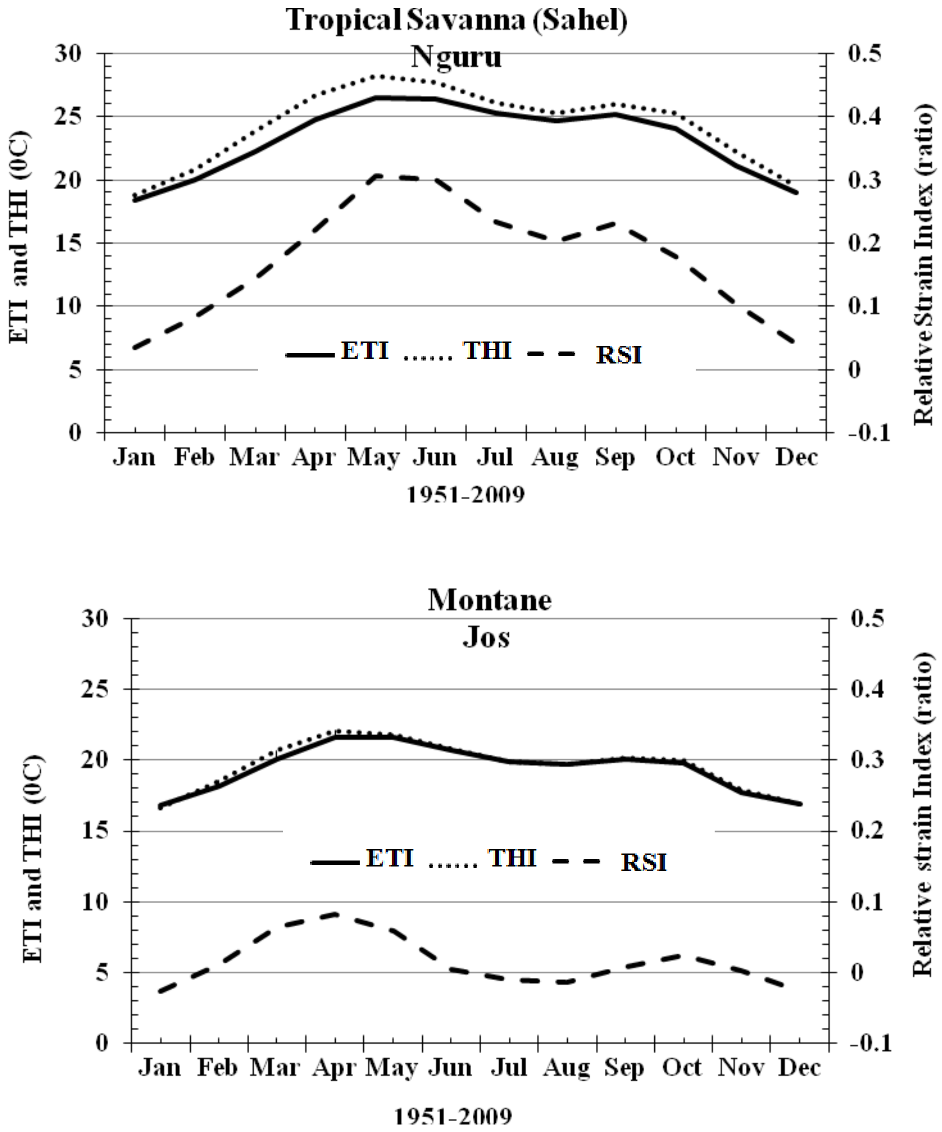


Figure 4.41a: Mean Monthly Variations in Effective Temperature Index (ETI), Temperature-Humidity Index (THI) and Relative Strain Index (RSI) in Selected Stations in the Tropical Savanna (Sahel) and Montane Regions (1951-2009)

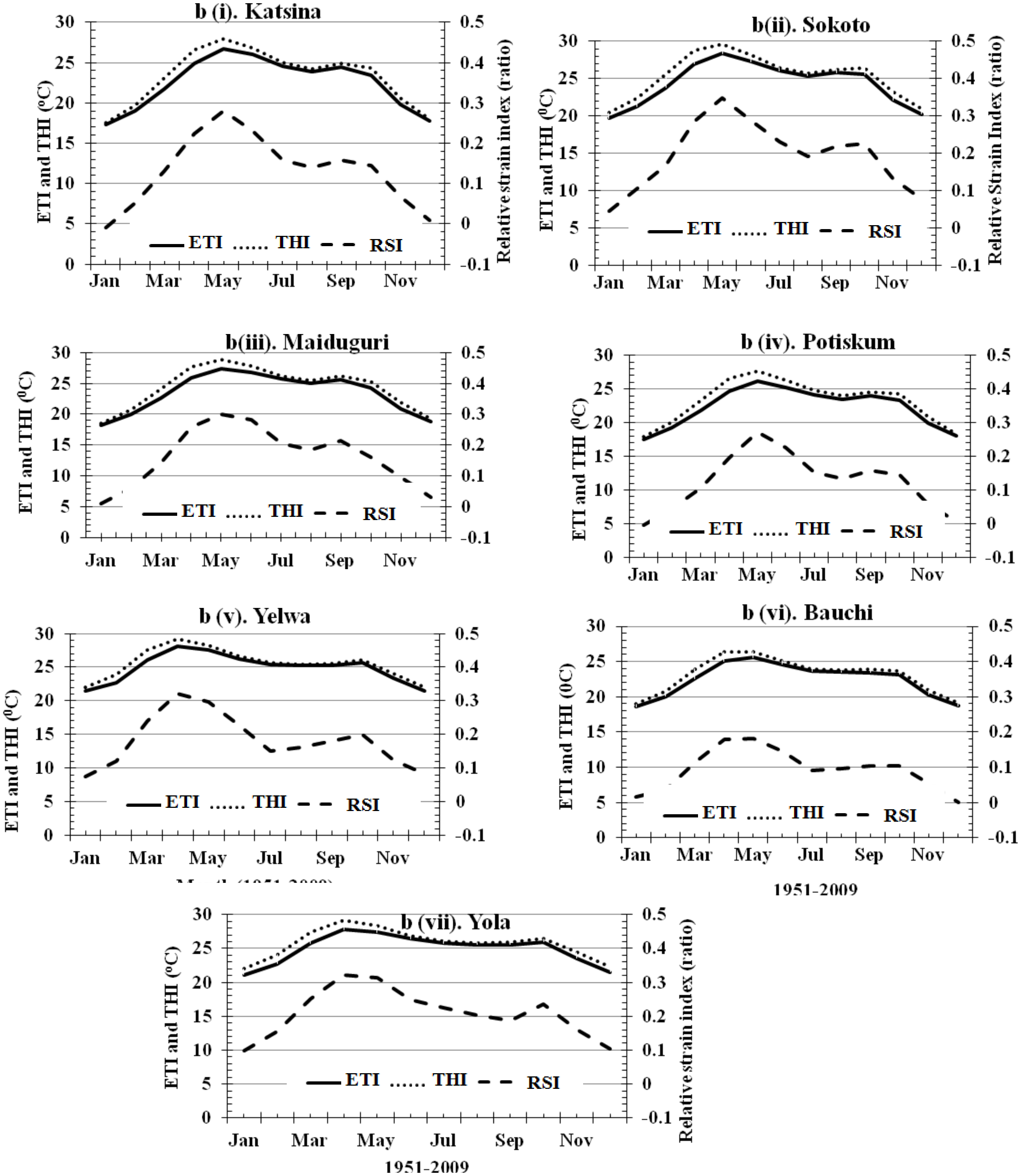


Figure 4.41b: Mean Monthly Variations in Effective Temperature Index (ETI), Temperature-Humidity Index (THI) and Relative Strain Index (RSI) in Selected Stations in the Tropical Savanna (Sudan) Region (1951-2009)

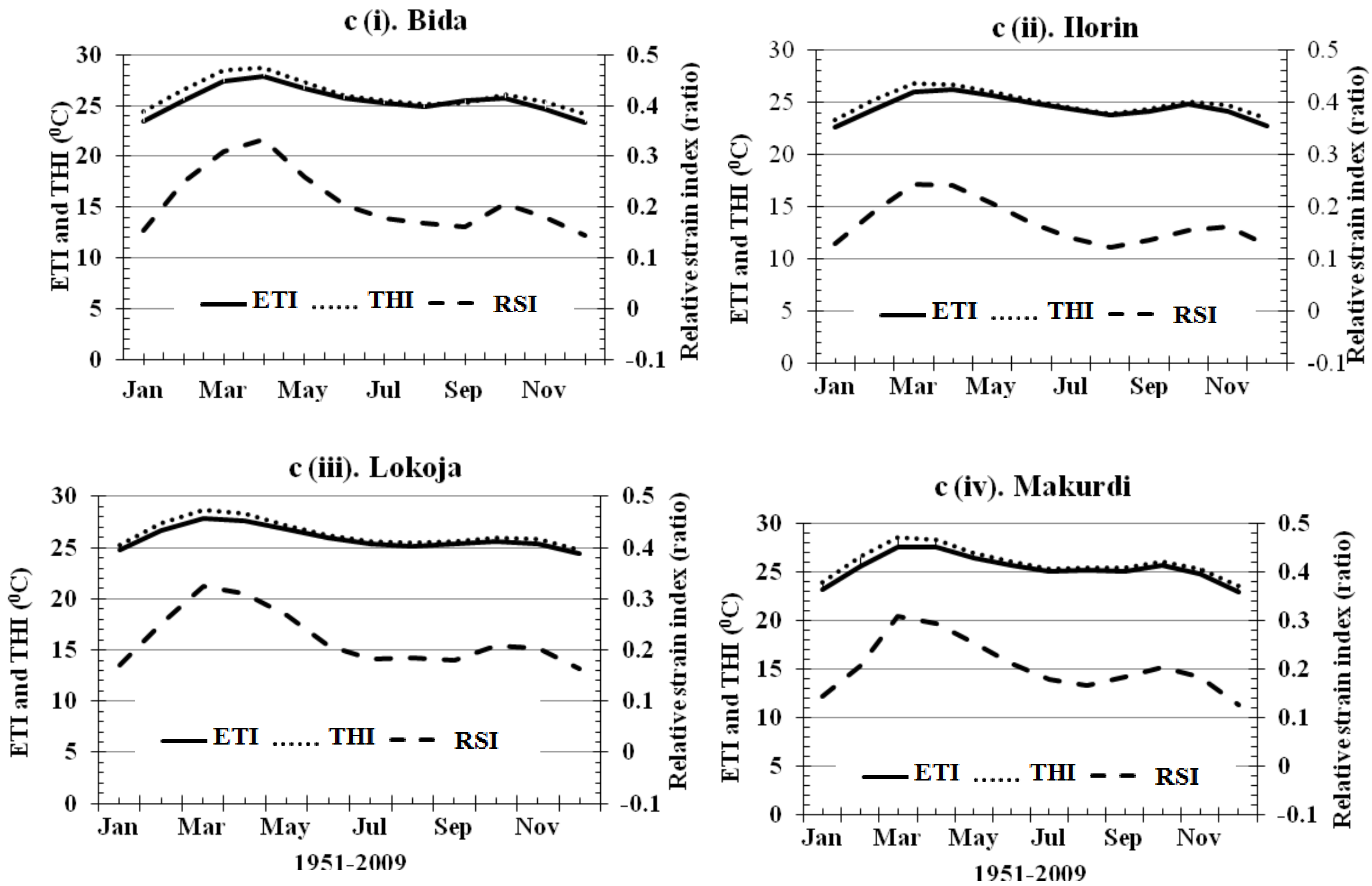


Figure 4.41c: Mean Monthly Variations in Effective Temperature Index (ETI), Temperature-Humidity Index (THI) and Relative Strain Index (RSI) in Selected Stations in the Tropical Savanna (Guinea) Region (1951-2009)

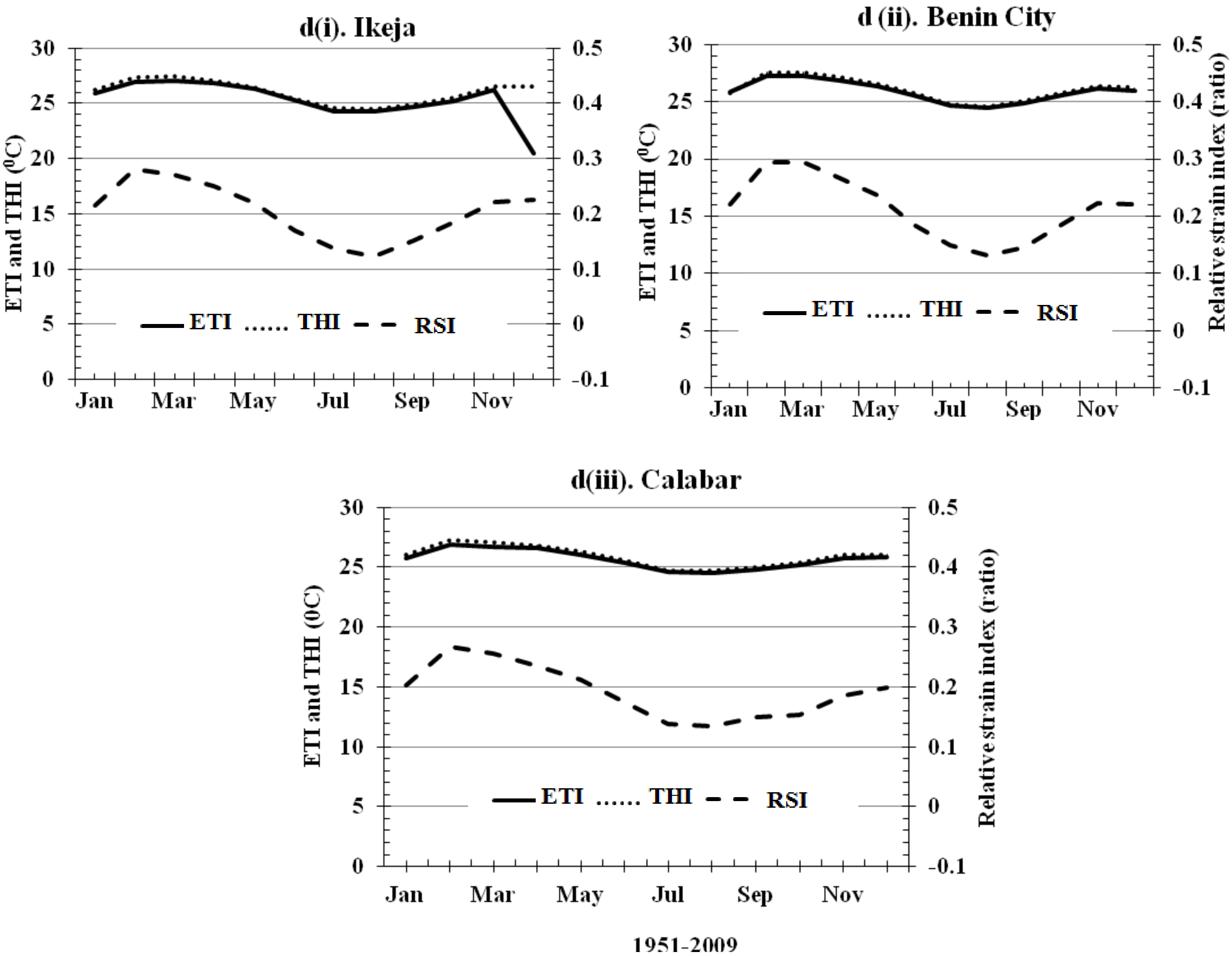


Figure 4.41d: Mean Monthly Variations in Effective Temperature Index (ETI), Temperature-Humidity Index (THI) and Relative Strain Index (RSI) in Selected Stations in the Tropical Wet and Dry Regions (1951-2009)

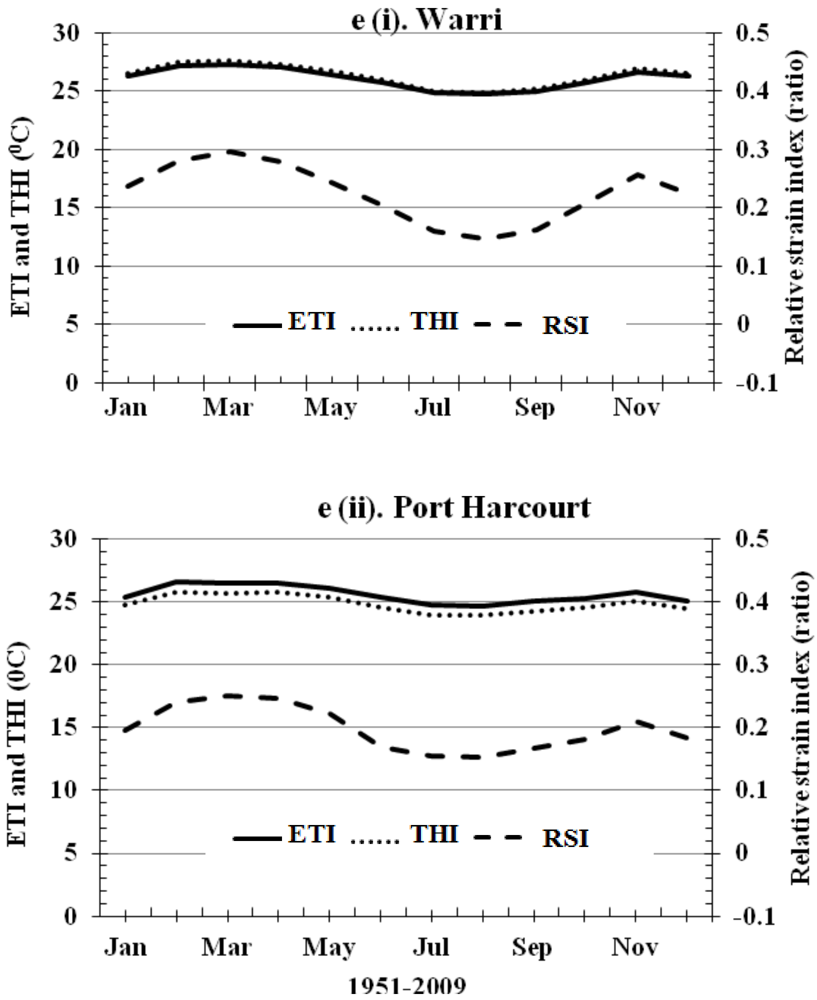


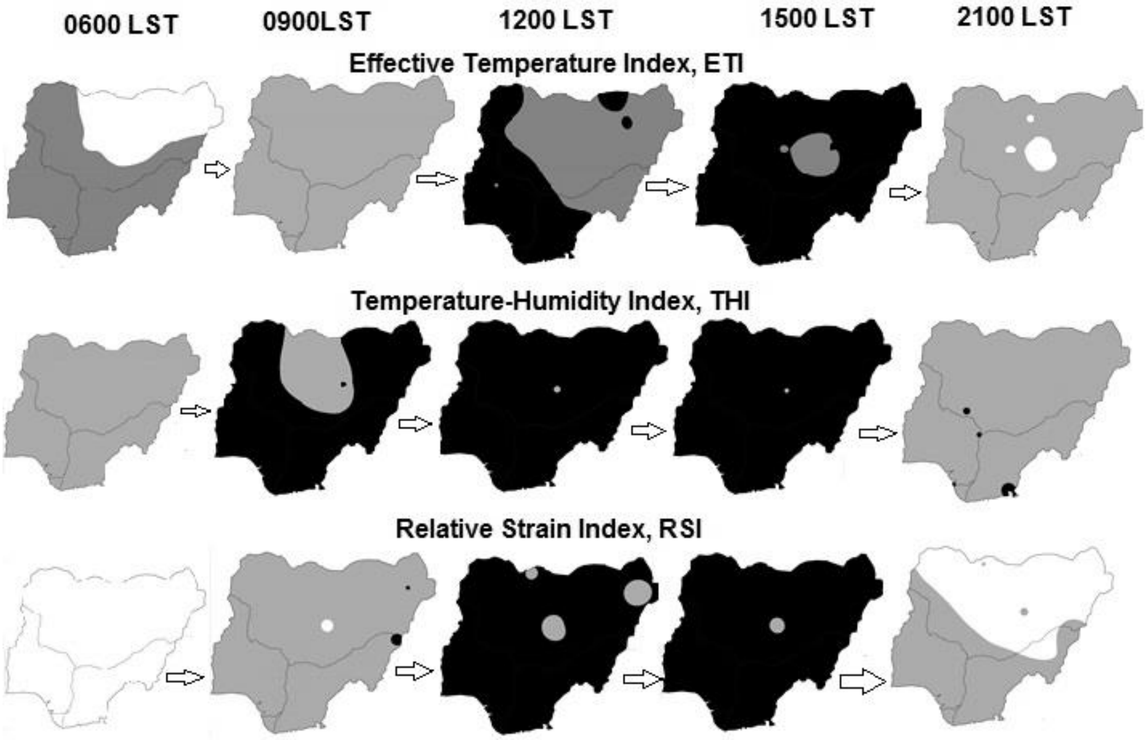
Figure 4.41e: Mean Monthly Variations in Effective Temperature Index (ETI), Temperature-Humidity Index (THI) and Relative Strain Index (RSI) in Selected Stations in the Tropical Wet Region (1951-2009)

4.8. Hourly variation

4.8.1. Mean physiologic comfort in 1971 and 2001

The mean hourly distributions of the mean THI, ETI and RSI for 1971 and 2001 showed that almost all parts of Nigeria (except the Jos area) exhibited heat stress condition at 1500 LST (Figure 4.42). Heat stress condition based on the THI results started earlier (0900 LST) in most part of Nigeria than either ETI or RSI. Figure 4.42 shows evidence of cold stress in the northern region at this time. The RSI results showed that Nigerian physiologic climate at 0600 LST was characterised by cold stress, while the ETI results showed that only the north central and north eastern region exhibited cold stress condition at 0600 LST.

Year 1971



Year 2001

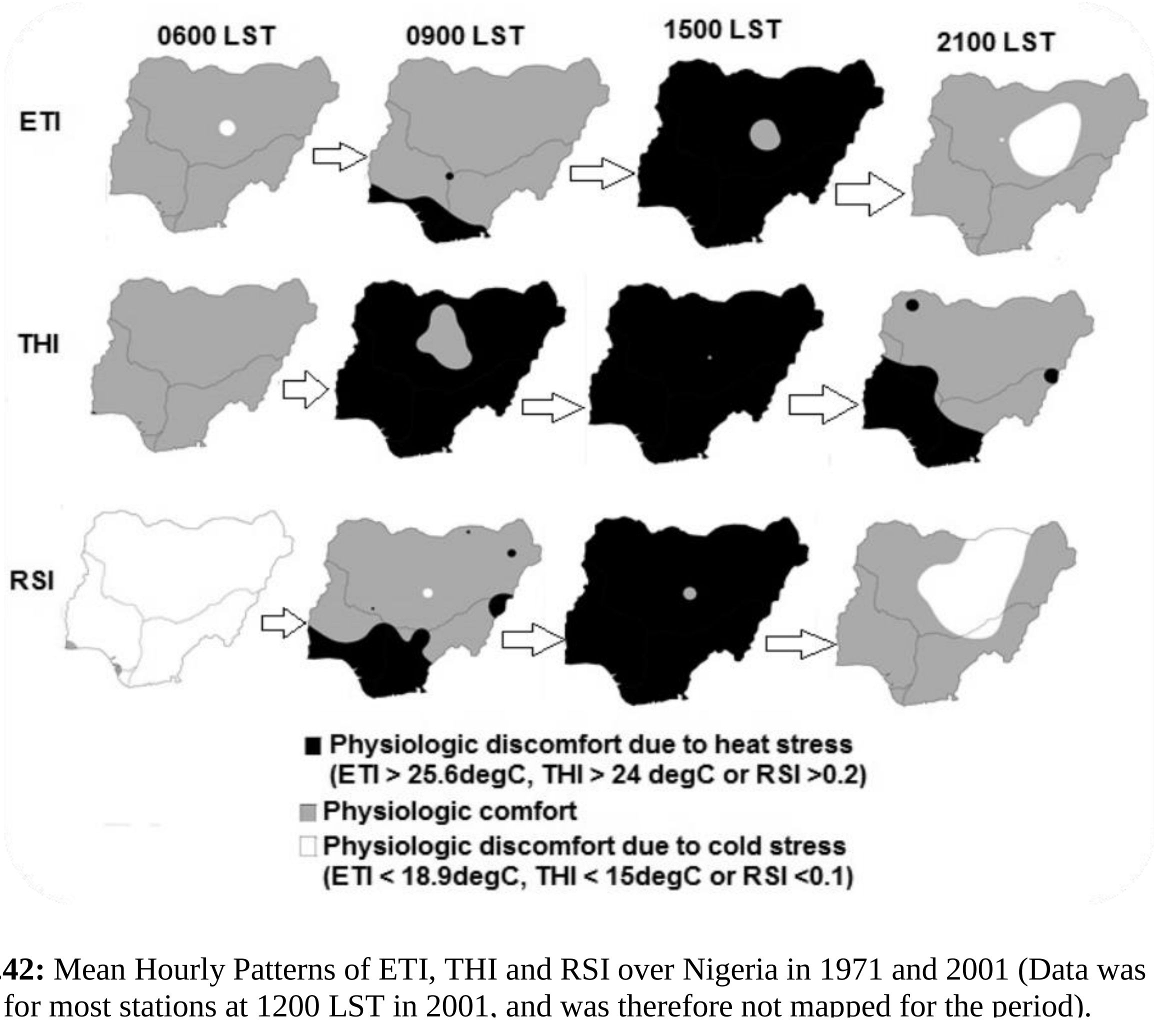


Figure 4.42: Mean Hourly Patterns of ETI, THI and RSI over Nigeria in 1971 and 2001 (Data was not available for most stations at 1200 LST in 2001, and was therefore not mapped for the period).

4.8.2. Case study analysis of selected days and variations across latitudes

When the physiologic climate patterns were compared across latitudes for selected days (March, July and December as representatives of the dry and rainy seasons, and Harmattan, respectively), variations also occurred in physiologic comfort, and it exhibits latitudinal and temporal variations (Figure 4.43). In March 1971, latitudes 4-7^{o}N showed more daytime physiologic comfort than the latitudes above 7^{o}N. Latitudes 10-12^{o}N exhibited conditions of thermal stress than the lower latitudes in this period based on the THI results. The ETI results in July exhibited contrasting results with those of THI and RSI. While the ETI showed 7-12^{o}N to exhibit cold stress for most of the day (0600-1200, 1400-1600 and 1900-2100), THI showed that the latitudes below 7^{o}N were subjected to heat stress for most hours between 0600 and 2100 LST with pockets of cold stress condition between 8 and 12^{o}N. The RSI on the other hand, showed that the region below 7^{o}N was subjected to a mix of cold and heat stresses while other region was under cold stress for most parts. In December, while the THI showed 1000-1600 LST to be under heat stress condition, the ETI showed region above 7^{o}N experienced cold stress in the morning time (0600-1000 LST) and night-time (1900-2100 LST). The December physiologic condition by RSI showed most daytime to be physiologically uncomfortable, and the condition was more severe at 9-11^{o}N. Comparison between 1971 and 2001 physiologic comfort conditions from the ETI, THI and RSI showed increased general increase in heat intensity and stress and decrease in cold stress in most part of the study area.

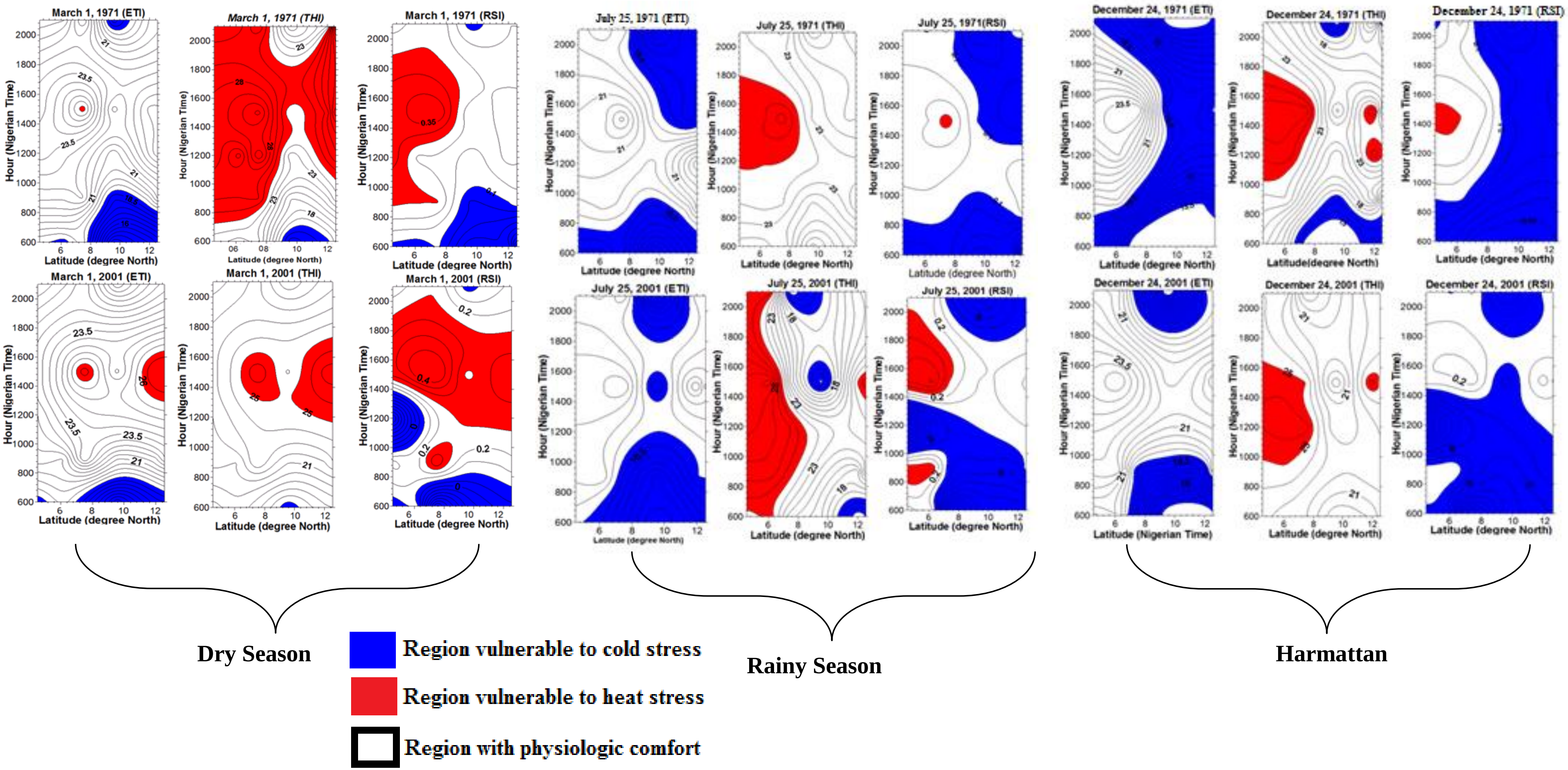


Figure 4.43: Patterns of the Daytime Hourly ETI, THI and RSI over Nigeria in March, July and December 1971 and 2001

4.8.3. Case study analysis of selected locations

The monthly variation of physiologic comfort at selected stations from the different zone showed that the pattern of physiologic comfort exhibited monthly and seasonal variations (Figure 4.44a-b). The results of ETI and RSI were similar, and therefore only ETI and THI are presented. In both ETI and THI, Lokoja (guinea savanna) showed most daytime hours of heat stress while Jos (montane) and Kano (tropical sudan savanna) exhibited a number of hours with cold stress. Both representatives of the rainforest region (Calabar and Benin) exhibited physiologic comfort in most part of the rainy season (June-October) except between 1200 and 1700 LST, while the dry season, Harmattan and the onset of the rainy season (November-April) heat stress is exhibited for about 8 hours (1000-1700 LST). The representative of the guinea savanna (Lokoja) showed at least 7 hours (1100-1700 LST) of heat stress, throughout the year, and night-time cold stress in December. The Harmattan period (November-January) was also characterised by morning and night-time cold stress, and February-October daytime (1000-1700 LST) heat stress in the sudan savanna. Jos, the representative of the montane climate, exhibited different physiologic climate from that of other climate in Nigeria. The THI results showed that Jos exhibits only about 4 hour-period of heat stress between February and April. Both the ETI and RSI results showed that Jos is also characterised by cold stress, in the daytime.

In general, the results of the daytime hourly physiologic comfort showed that the period between 1200 and 1500 LST was the most thermally stressful in Nigeria. This is typical of the tropical region where the sun is known to be directly overhead at noon before the heat accumulates and peaks shortly after. Similar to the results of this study, Samendra and Ayesha (1994) on a study of another tropical city, Dhaka, Bangladesh, also showed that temperatures and heat conditions usually peak at 1500 hour of the day, and more people usually feel uncomfortable around this hour than other hours of the day. Other studies (such as Runnals and Oke, 2004) also showed that maximum heat condition occurred in the afternoon, and that the morning-time and night-time were usually more comfortable than the daytime (just before and after noon). The night-time physiologic climate was not determined in this study because of data unavailability.

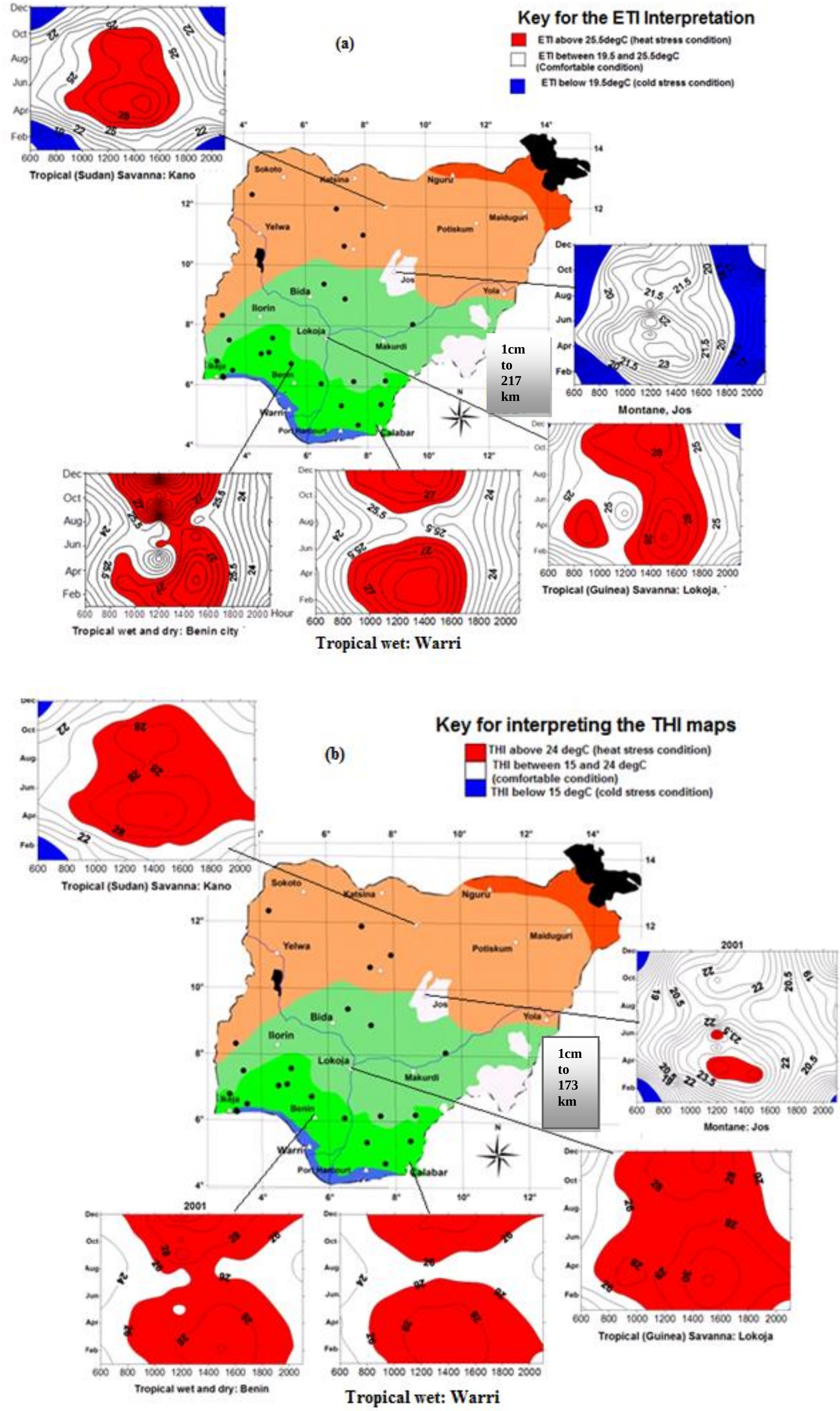


Figure 4.44: Representative ETI and THI at Selected Stations in different Eco-climatic Region in Nigeria

4.9. Relationship of selected physiologic comfort indices with latitudes, longitudes and altitude

Variations in the temperature, relative humidity, ETI, THI and RSI have motivated further examination into their relationships, and with latitude, longitude and altitude of corresponding locations (Table 4.8) A strong and positive correlation ($r=0.67$; $p=0.01$) was obtained between maximum and mean temperature, and between the minimum and mean temperature ($r=0.78$; $p=0.01$). Relative humidity also exhibited positively strong correlation with the minimum temperature ($r=0.67$; $p=0.01$) but exhibited an inverse correlation with maximum temperature ($r=-0.57$; $p=0.05$). In addition, altitude (elevation) on which the meteorological station is located was inversely but strongly correlated with the minimum ($r = -0.94$; $p = 0.01$), mean temperature ($r = -0.76$; $p = 0.01$), relative humidity ($r = -0.66$; $p = 0.01$), ETI, THI and RSI ($r \geq -0.97$; $p = 0.01$). Latitude, on the other hand, exhibited strong and inverse relationship with minimum temperature ($r = -0.55$; $p = 0.05$), relative humidity ($r = -0.95$; $p = 0.01$) and ETI ($r = -0.61$; $p = 0.01$) but direct relationship with maximum temperature ($r = 0.61$; $p = 0.01$). Latitude, however, exhibited weak inverse relationship with mean temperature, THI and RSI. With longitude, only a fairly strong but inverse correlation existed with relative humidity ($r=-0.58$; $p=0.05$) while its relationship with other parameters were not significant.

Table 4.8: Correlation Coefficients (R) Matrix of the Physiologic Indices, Temperature, Relative Humidity, Altitude, Latitudes and Longitudes in Nigeria

	Latitude	Longitude	Altitude	Temperature			Relative Humidity	Physiologic indices		
				Minimum	Maximum	Mean		ETI	THI	RSI
Latitude	-	0.35	0.55*	-0.55*	0.64**	-0.04	-0.95**	-0.61**	-0.44	-0.43
Longitude	0.35	-	0.37	-0.44	0.35	-0.03	-0.58*	-0.43	-0.38	-0.33
Altitude	0.55*	0.37	-	-0.94**	-0.20	-0.76**	-0.66**	-0.97**	-0.95**	-0.94**
MinT	-0.55*	-0.44	-0.94**	-	0.17	0.78**	0.67**	0.97**	0.97**	0.97**
MaxT	0.64**	0.35	-0.20	0.17	-	0.67**	-0.57*	0.13	0.31	0.33
MeanT	-0.04	-0.03	-0.76**	0.78**	0.67**	-	0.14	0.74**	0.84**	0.83**
RH	-0.95**	-0.58*	-0.66**	0.67**	-0.57*	0.14	-	0.73**	0.58*	0.56*
ETI	-0.61**	-0.43	-0.97**	0.97**	0.13	0.74**	0.73**	-	0.97**	0.96**
THI	-0.44	-0.38	-0.95**	0.97**	0.31	0.84**	0.58*	0.97**	-	0.97**
RSI	-0.43	-0.33	-0.94**	0.97**	0.33	0.83**	0.56*	0.96**	0.97**	-

**correlation is significant at p=0.01

*correlation is significant at p=0.05

The relationship of temperature, relative humidity, ETI, THI and RSI were further determined using their linear graphical patterns and linear regression analysis. Figure 4.45, which present the relationships among these parameters, on the one hand, and latitude, longitude and altitude, on the other, show that temperature (minimum, maximum and mean) steadily increased with latitude until it dropped around Jos, after which it continued to rise. Temperature, before 8.5^{o}E also fluctuated slowly and steadily increased, thereafter. The pattern exhibited by temperature with latitude and longitude suggest that temperature would have continued to slowly increase but for location at Jos (9.5^{o}N; 8.5^{o}E). The relationship of temperature with altitude nevertheless showed that temperature appreciably declined from altitude above 600m. The station located at 9.5^{o}N; 8.5^{o}E, which is Jos in the montane region, and characterised by altitude around 1285 m above the mean sea level, strengthens the importance of altitude in climate study. Furthermore, Tables 4.8 and 4.9 suggest that temperature (except maximum temperature), relative humidity, ETI, THI and RSI significantly decreased with increasing altitude ($r \geq -0.66$; $p=0.01$). These parameters (temperature, relative humidity, ETI, THI and RSI) are also predicted to decrease with increasing altitude (Table 4.9).

Table 4.9 shows the results of the linear regression of ETI, THI and RSI across latitude, longitudes and altitudes. The results show that the minimum and mean temperatures, ETI, THI and RSI and relative humidity exhibited significant relationships with at least one of latitude, longitudes and altitudes. The results implied that the physiologic variables decreased as one goes upward (altitude), northward (latitude) and eastwards (longitude). The maximum temperature on the other hand exhibits a positive regression pattern with both longitude and latitude, and this implies that the maximum temperature in Nigeria increases towards the north, on the one hand, and towards the east on the other hand. The overall implication of this result is that the daytime heat stress is more significant in the northern Nigeria, and can be severe in the northeast.

The relationships of temperature, relative humidity, ETI, THI and RSI with longitude, latitude and altitude therefore suggest that, given the current natural and anthropogenic systems, temperature (except maximum), relative humidity, ETI, THI and RSI decrease with increase in latitude, longitude or altitude. Maximum temperature however increases only with increase in latitude and longitude.

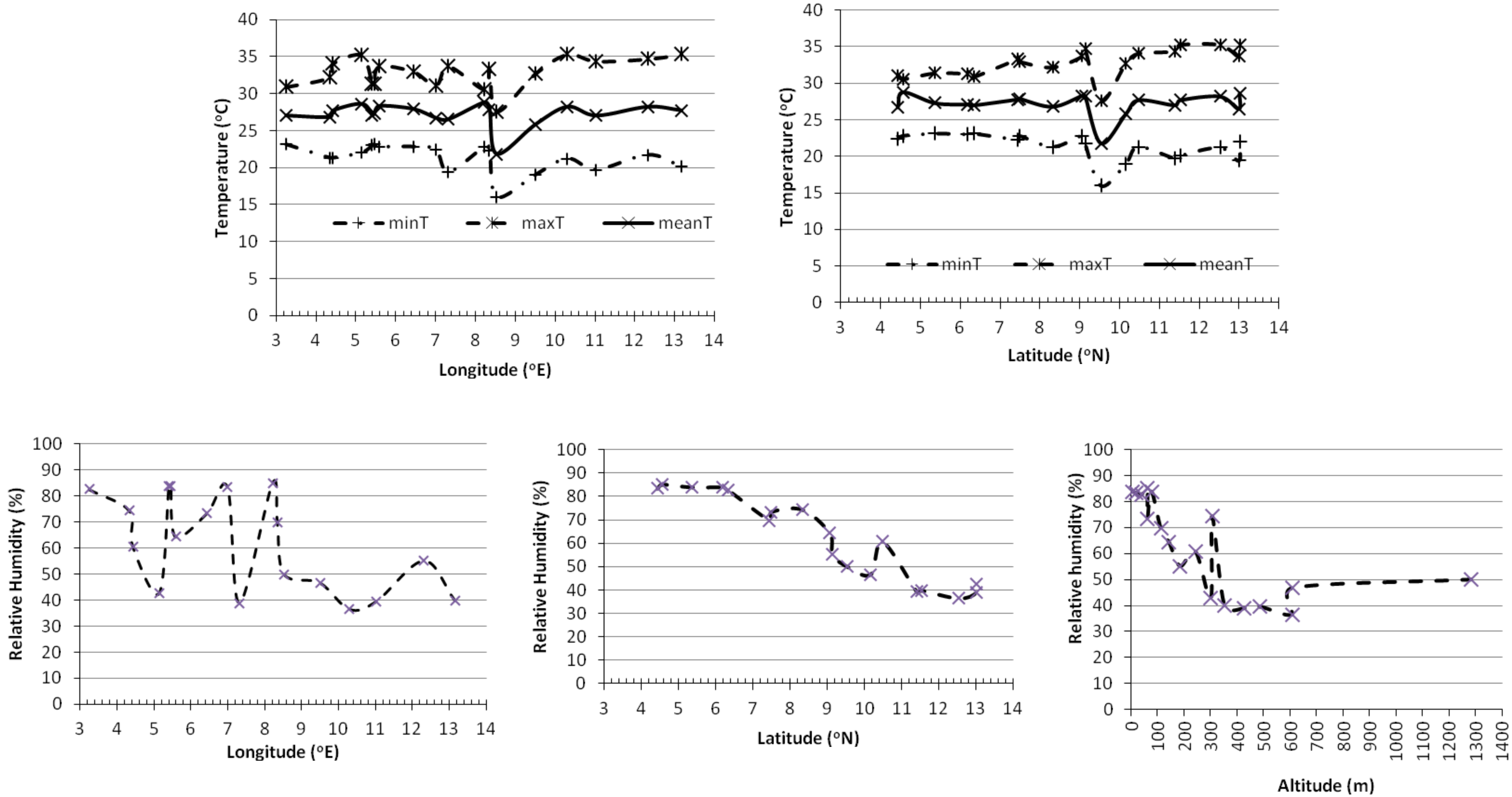


Figure 4.45: Relationship in the Pattern of Variation in Temperature, Relative Humidity, Effective Temperature Index (ETI), Temperature-Humidity Index (THI) and Relative Strain Index (RSI) with Latitude, Longitude and Altitude in Nigeria

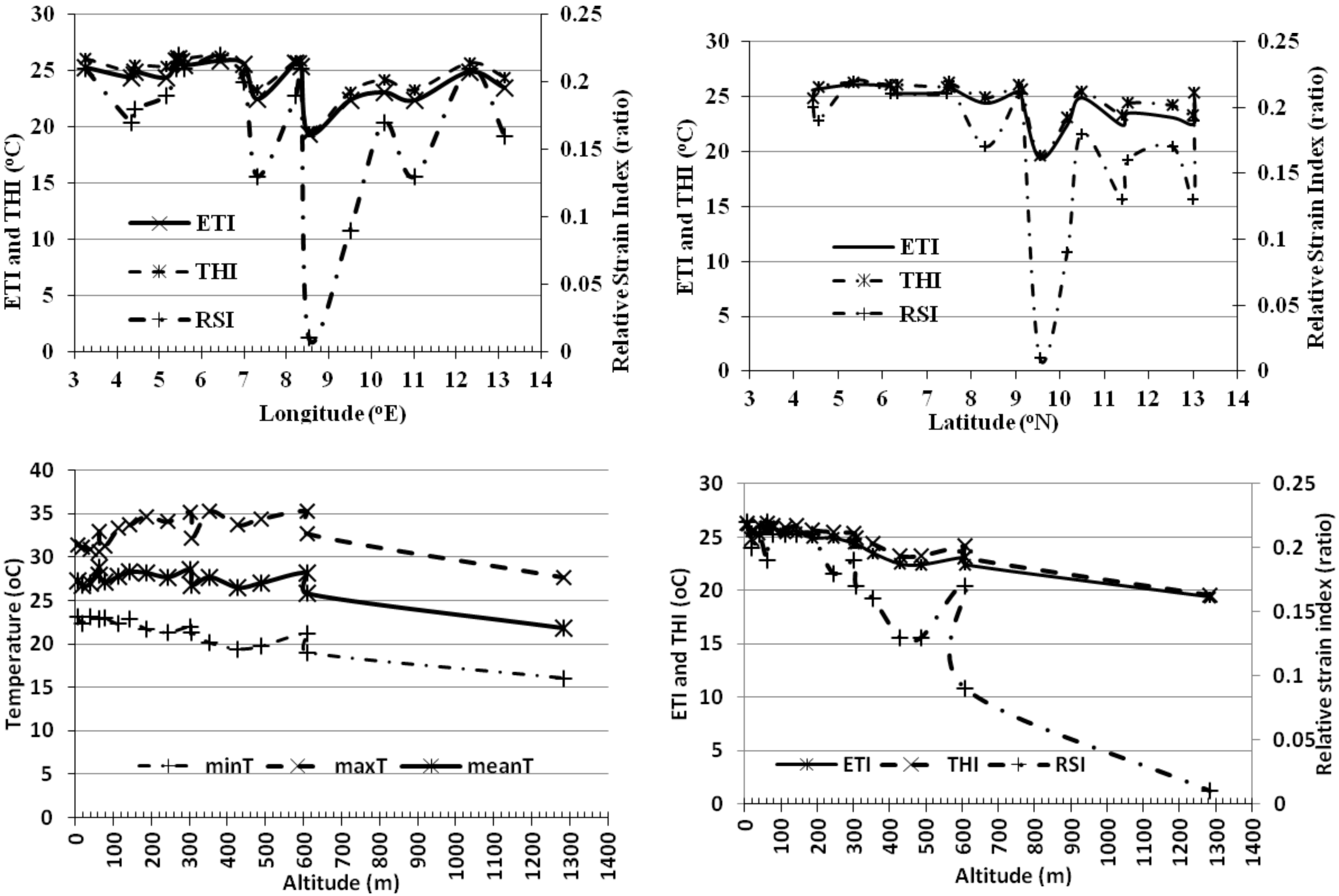


Figure 4.45 (contd): Relationship in the Pattern of Variation in Temperature, Relative Humidity, Effective Temperature Index (ETI), Temperature-Humidity Index (THI) and Relative Strain Index (RSI) with Latitude, Longitude and Altitude in Nigeria

Table 4.9: Linear Predictive Models for Temperature, Relative Humidity and Selected Physiologic Indices with Latitude, Longitude and Altitude in Nigeria

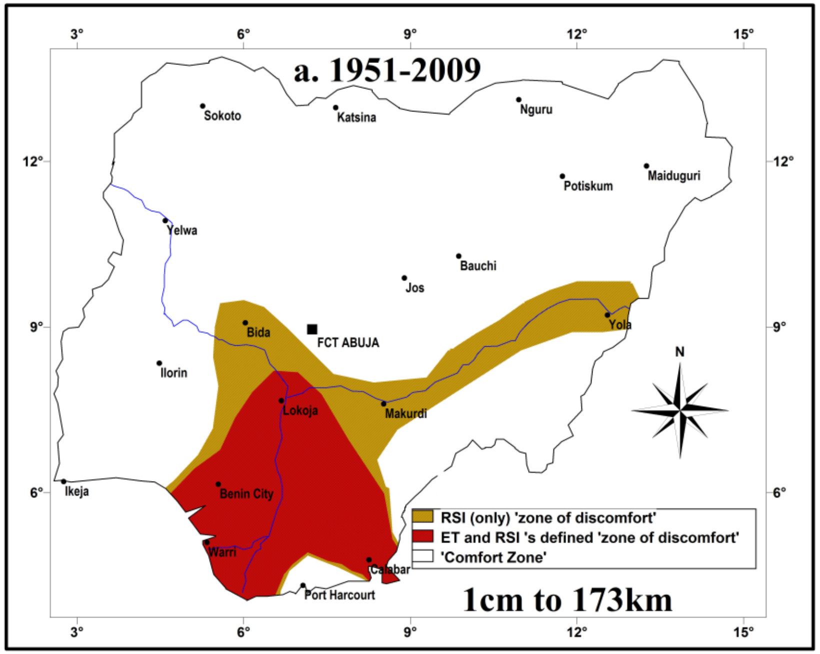
	Latitude	Longitude	Altitude
Minimum temperature	y = -0.36x + 24.57	y = -0.29x + 23.52	y = -0.01x + 22.99
Maximum temperature	y = 0.47x + 28.65	y = 0.25x + 30.94	y = -0.001x + 33.19
Mean temperature	y = -0.02x + 27.35	y=-0.02x + 27.29	y = -0.004x + 28.29
Relative humidity	y = -6.19x + 116.72	y = -3.75x + 90.02	y = -0.04x + 73.08
Effective temperature index	y = -0.38x + 27.70	y = -0.26x + 26.29	y = -0.01x + 25.90
Temperature-humidity index	y = -0.26x + 27.16	y = -0.22x + 26.51	y = -0.01x + 26.33
Relative strain index	y = -0.01x + 0.25	y = -0.01x + 0.22	y = -0.0002x + 0.22

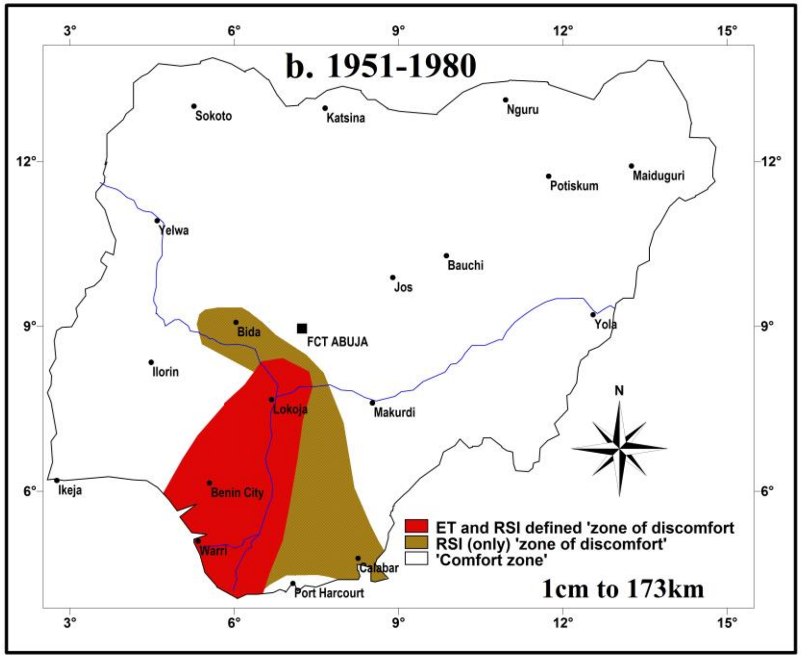
Uncertainties with the results on relationship and prediction, however, are with scaling and data aggregation. For example, previous results (on monthly and seasonal variations) have shown that different climate regions exhibit different patterns of distribution of temperature and thermal indices (ETI, THI and RSI), suggesting that use of annual means may over-generalise. There may therefore be a need for further study to establish this relationship, and confirm the predicted trends. This will however be possible with focus on each climate region, using data from denser (than used in this study) network of meteorological stations.

4.10. Delineation of Regional Physiologic Climate in Nigeria from ETI, THI and RSI

Individual results of temperature, relative humidity, ETI, THI and RSI have shown some overlapping areas in their classification of the Nigerian climate into physiologic climate regions, and some contrasting areas too. The results are assembled in this section to draw out a regional map of physiologic comfort for Nigeria. Classification by ETI, THI and RSI for 1951-2009 annual averages (Figure 4.46a) shows the Niger-Delta region and the River Benue trough, extending west to Bida around River Niger trough as physically uncomfortable. Earlier studies (e.g. Ayoade, 1978; Komolafe and Agwal, 1987; Ogunsote and Ogunsote, 2002) have also shown the Rivers Niger and Benue trough as physiologically uncomfortable in Nigeria. Many towns in the Niger-Delta region has equally been shown to be thermally stressed due to increased level of carbon emission in the area by oil exploratory activities and gas flaring (Isiche and Sanford, 1976; Odum, 1977; Ogundare and Sidiq, 2010). Similarly, Figures 4.46b and 4.46c, which show the 1951-1980 and 1981-2009 period, reveal that the southwest and the north-western Nigeria are classified as physiologically uncomfortable in the 1981-2009 period. This is probably as a result of increased urbanisation in these regions, especially in 1981-2009 over 1951-1980 period.

Given the observed trend in the results of the parameters analysed in this study, and the argument by Munot and Kothawale (2000) that aggregation of data for annual means often overshadow the influence of some important factors of climate, especially air masses, Figure 4.47a-c shows the seasonal pattern of physiologic comfort regionalisation obtained from the seasonal means of ETI, THI and RSI. The region along the troughs of Rivers Niger and Benue, extending towards the northeast and northwest is classified as the most uncomfortable climate region in the rainy season (Figure 4.47a). During the rainy season, the tropical maritime air mass (mT) dominates the southern region (Agboola and Hodder, 1979; Iloeje, 2001).





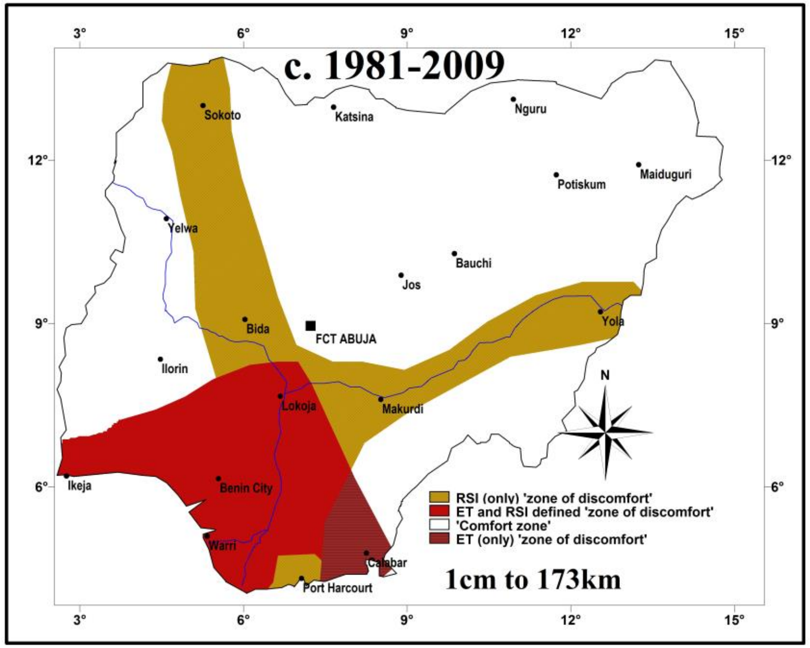
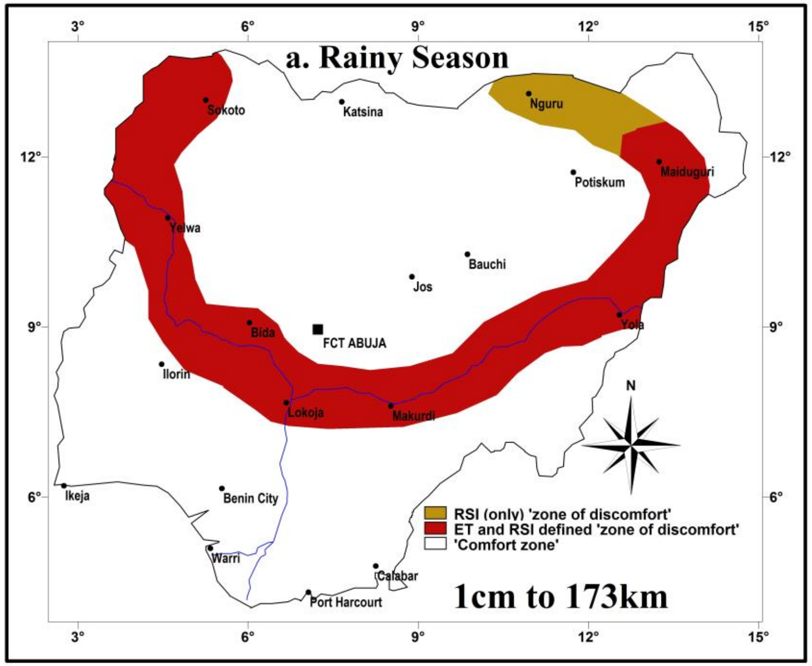
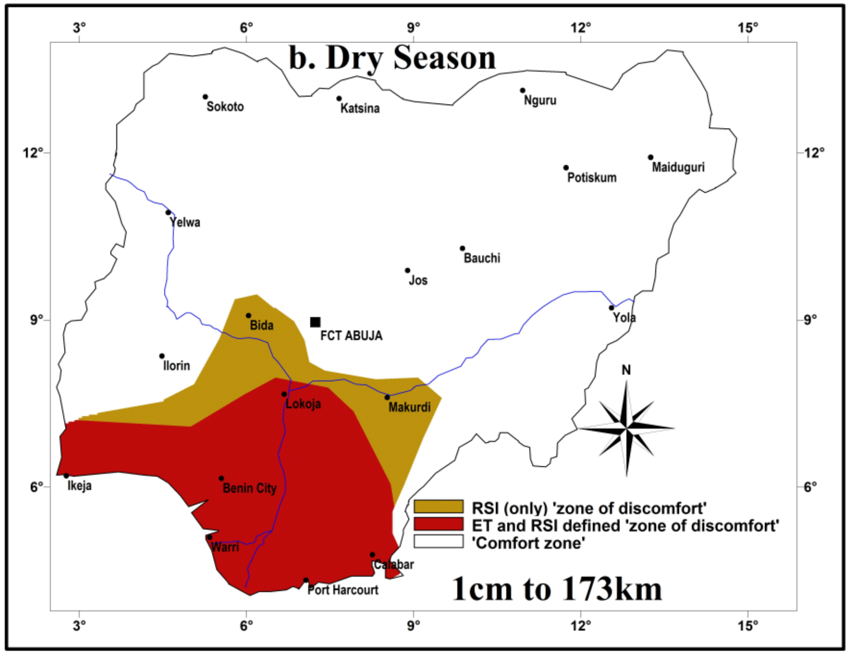


Figure 4.46: Physiologic Comfort Climates derived from the Annual Means of the Effective Temperature, Temperature-Humidity and Relative Strain Indices.





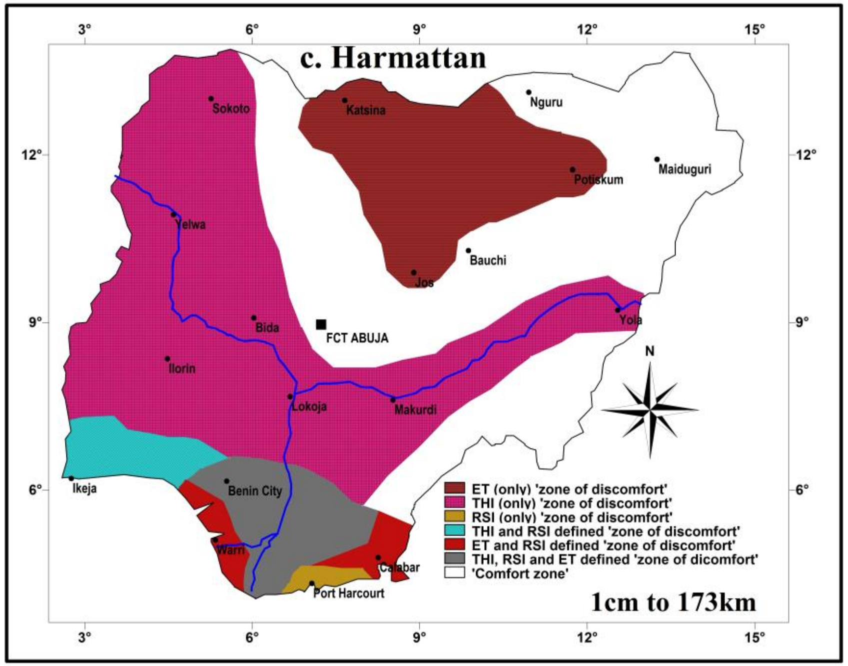


Figure 4.47: Physiologic Comfort Climates derived from Seasonal Averages of Effective Temperature, Temperature-Humidity and Relative Strain Indices (1951-2009)

The moisture-laden mT is able to soothe the temperature in the southern region during this season, to make it physiologically comfortable (Miller, 1952). Similarly, the north-central region that is also classified as comfortable may have been influenced by the high altitude in the region. This region is characterised by the north-central highlands which rises between 1200 and 1500m (Iloeje, 2001). The results of the correlation between altitude and the physiologic indices (Section 4.9) have earlier suggested a significant and inverse relationship, suggesting that ETI, THI and RSI were influenced in this region by the altitude.

The dry season pattern, nevertheless, shows that the southern region was physiologically uncomfortable (Figure 4.47b). With the explanation for the rainy season pattern, it may be suggestive that the thermal stress in the southern region in the dry season was influenced by the retreat of the mT in the dry season. The daytime condition as measured by the results of maximum temperature that was discussed in Section 4.1.1.2 suggests that the daytime condition in the northern region is thermally stressed. The results have shown that maximum temperature is high (35-37^{o}C) in the north, particularly in the north east and north west, and the variability is just about 10% (Section 4.2). The variability of minimum temperature is however high (about 20-25%, in the north east) (Section 4.1), suggesting a relatively high night-time variability and high temperature range; a situation that may negate the mapped comfort, especially in the northeast (Turkes et al., 1995). The map for the Harmattan (Figure 4.47c) suggest that the north-central region is vulnerable to cold stress in the Harmattan, while most parts of Nigeria, including the south and the northwest would experience heat stress.

Given the results of this study on physiologic climate, Figure 4.48 is hypothesised based on the distribution of ETI, THI and RSI at the investigated stations by K-mean cluster analysis described in Chapter three (Section 3.8). The map (Figure 4.48) categorises Nigeria into the following physiologic climate zones. The basis of the grouping is also explained below:

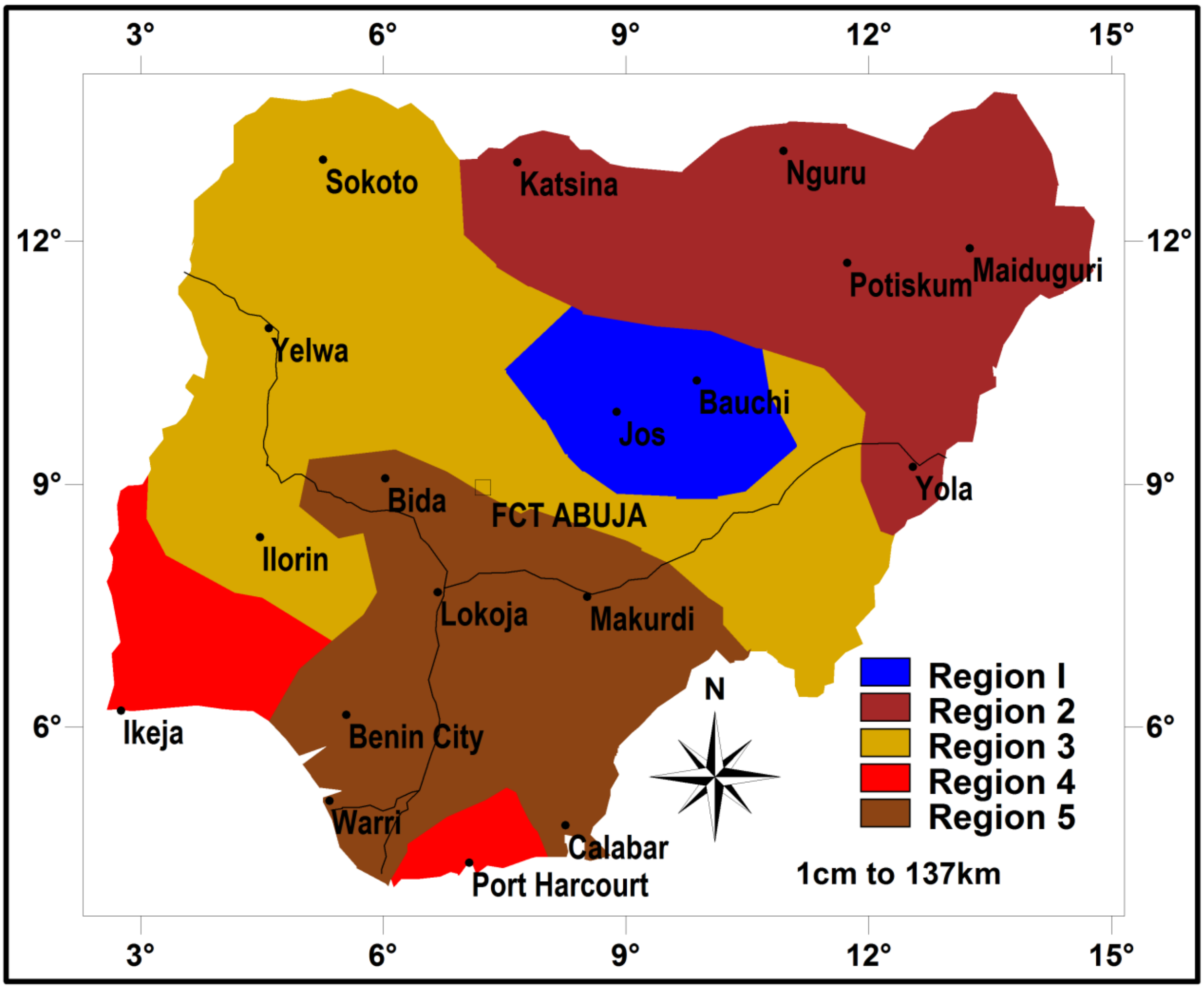


Figure 4.48: Delineation of Nigeria into Physiologic Climate Zones using Effective Temperature, Temperature-Humidity and Relative Strain Indices from 1951 to 2009

a. **Region 1:** This comprises area around the montane eco-climatic region. It apparently offers the most conducive physiologic climate in Nigeria. Both minimum and maximum temperatures are generally low in this region (17.2-20.0 and 22.3-33.3^{o}C) and relative humidity is also moderate (about 50% in average). The seasonal differences in the thermal condition in this region is also low (r <0.60; p=0.05), although the region is vulnerable to cold stress in the Harmattan. The altitude in this region is between 1200 and 1500 m. In this study, Bauchi is also classified within the region. This result may have been informed by the influence of the montane region on the station's climate at most period of the year.
b. **Region 2**: This comprises part of the western Nigeria, and some part of the eastern Nigeria, comprising locations in guinea, sudan and sahel savanna. This region's classification could have been significantly affected by seasonal influences. Parts of this region may exhibit physiological stress in the rainy season and Harmattan.
c. **Region 3:** This comprises the highly urbanised and industrialised regions, which have shown increased level of physiologic climate indices (ETI, THI and RSI) in 1981-2009, over the 1951-1980 period. Meteorological stations within this region also exhibit similar seasonal and monthly patterns in temperature and relative humidity.
d. **Region 4:** This region includes, primarily the Niger delta region, which was shown to be physiologically uncomfortable in the dry season and the Harmattan, and the northeastern Nigeria. Existing studies showed that the condition in the Niger delta region may have been significantly altered by the magnitude of crude oil exploitation and gas flaring activities in this region. The classification of the north-eastern region into this region is probably based on its high (35-37^{o}C) maximum temperature, as well as its relatively high (20-25%) minimum temperature. This is nonetheless, contrary to the classification of the region (northeast) as comfortable by the integrative indices in the dry season and Harmattan period. Both temperature (earlier classified in this study as a unitary index) and the integrative indices (ETI, THI and RSI) need to be considered for effective conclusion on physiologic comfort (Lee, 1953; Terjung, 1967).
e. **Region 5:** This is classified as the most uncomfortable zone in Nigeria by this study. It consists of the part of the Niger-Benue trough and the north-eastern Nigeria. In

addition, the River Niger-Benue trough has been grouped in this region based on the classification of the region as uncomfortable in almost all the periods considered (e.g. 1981-2009, 1951-2009, Dry, Harmattan and rainy season in 1951-2009).

4.11. Evaluation of Perception and Adaptive Strategies to Physiologic Stress in Nigeria

4.11.1. Characteristics of Sampled Respondents

Table 4.10 shows the demographic and economic characteristics of the respondents. The questionnaire was administered only to Nigerians. About 60 % of the respondents worked indoor while 40 % worked outdoor. Most of the respondents were adults between the ages of 18 and 60 years, who worked either on full or part time basis at the sample locations. This age group (18-60 years) makes up the most productive set of the population. More than 70% of the respondents had lived in the sample location for at least 5 years and this gives the group an advantage of fair understanding of the climate of the sample location. More than 99% of the respondents had attained at least primary education status, suggesting that they would easily understand the content of the questionnaire and its purpose and not less than 40 % of the workers claimed to make a minimum of five hundred thousand (500,000 Naira) per annum; an equivalent of about 9 United States dollars per day.

Table 4.10: Demographic and Socio-Economic Characteristics of Respondents

Variables	Options*	Frequency	Percentage
Age (years)	<18	79	2.2
	18-30	1588	44.1
	31-60	1498	41.6
	>60	155	4.3
	No response	280	7.8
Height	<1.5 m	695	19.3
	1.5-1.79m	2286	63.5
	≥1.8m	349	9.7
	No response	270	7.5
Weight (kg)	<40	144	4
	40-60	1300	36.1
	61-80	1573	43.7
	>80	302	8.4
	No response	281	7.8
Sex	Male	2146	59.6
	Female	1375	38.2
	No response	79	2.2
Region of origin	Tropical wet	900	25
	Tropical wet and dry	900	25
	Guinea savanna	900	25
	Sudano-sahelian savanna	900	25
Length of Residence (years)	<5	933	26.9
	5-10	864	24
	11-15	569	15.8
	16-20	479	13.3
	>20	504	14
	No response	251	6
Educational Qualification	None	15	0.8
	Primary School	328	9.1
	Secondary & Technical	796	22.2
	Tertiary	2430	67.5
	No response	31	0.4
Occupation	Self-Employed	1246	34.6
	Civil Servant	1008	28
	Private Organisation	731	20.3
	NGO	122	3.4
	Others	436	12.1
	No response	57	1.6
Annual Income (in million ₦)	<0.5	1872	54
	0.5-1.5	1105	34.7
	>1.5	400	11.3
	No response	223	6.2
Total sample		3600	100

*'options' refers to the alternatives provided for respondents to select from

Source: Fieldwork, 2010

4.11.2. Perceptions on prevailing weather

Figure 4.49a describes the perceptions of the sampled population on physiologic climate at different seasons of the year, and the indoor microclimate. The dry season was mostly (33%) described as ‘hot’, rainy season as either ‘cool’ (34.6%) or ‘cold’ (31.7%), and Harmattan was generally (44.2%) considered to be ‘cold’. When asked for the preferred weather, a dominant percentage of the respondents would prefer the air condition during Harmattan; dry and rainy seasons to be either ‘cool’ or slightly cool (Figure 4.49b). A ‘cool weather’ is described as the atmospheric condition when the dry bulb temperature is less than 18.9^{o}C (Terjung, 1966; Jauregui, 1991). Slightly cool, warm and hot weather periods are described as the period when the atmospheric temperature is 19.0-24.9, 25.0-27.0 and above 27^{o}C, respectively (Jauregui, 1991). Olaniran (1982), however suggested that a combination of the ‘cool weather’ (10-21^{o}C) with relative humidity above 50% is required to produce a comfortable climate.

Variation in relative humidity across the different region in Nigeria, shown in the earlier results (Section 4.2) is a possible explanation for the seasonal differences in Figure 4.49. Figure 4.50 shows that perception of respondents varied in all the seasons. Variation in perception of individual to physiologic stress is known to depend on the ability of the individual to adjust to variations in weather and climate or adapt physiologically to wide range of weather and climate (Sewel et al., 1968). Factors that would help an individual’s physical, mental and physiologically preparedness include fitness-helping infrastructure, such as properly maintained or designed air conditioning system (Liu et al, 2008), adequate and responsive building structure (Ajibola, 2001; Ogbona and Harris, 2008) and responsive clothing and other body wears (Ogbona and Harris, 2008). Similar to what was obtained for general pattern shown in Figure 4.50, most respondents (more than 60% in each latitudinal group) described the dry season as either ‘hot’, ‘warm’ or ‘slightly warm’ while the rainy season was either ‘cold’, ‘cool’ or ‘slightly cool’ by most respondents (> 70%). The Harmattan period was also described as ‘cold’, ‘cool’ or ‘slightly cool’ (Figure 4.51). The pattern exhibited by the frequencies of responses in each latitudinal grouping suggests more agreement in the lower latitude (4-10^{o}N) than the higher altitude (10-14^{o}N). The level of ‘agreement’ is defined as the condition in which more respondents agree to similar ‘suggested’ option or alternative. There were more diverse opinions concerning the dry season at 8-14^{o}N than both rainy season and Harmattan period.

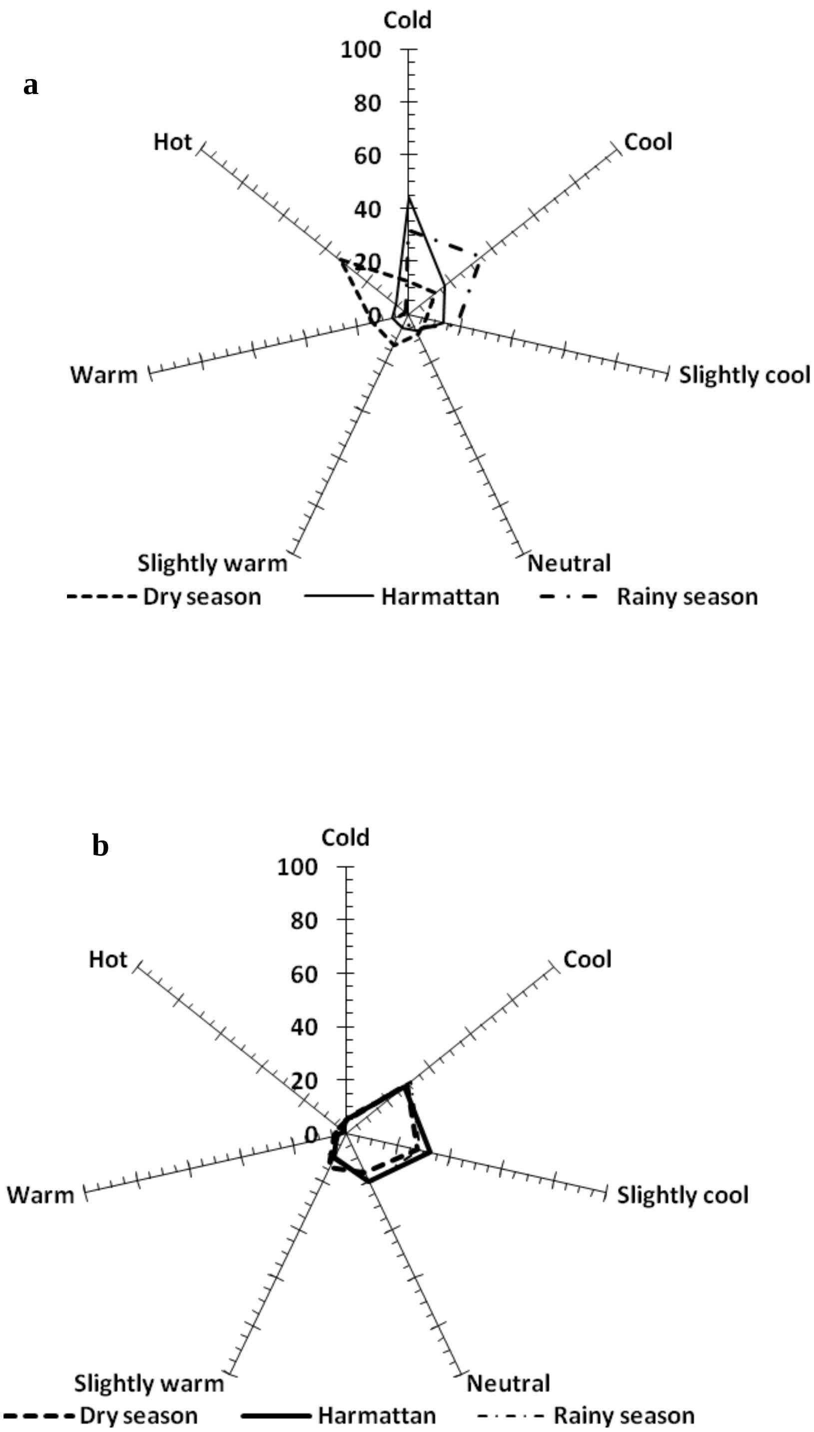
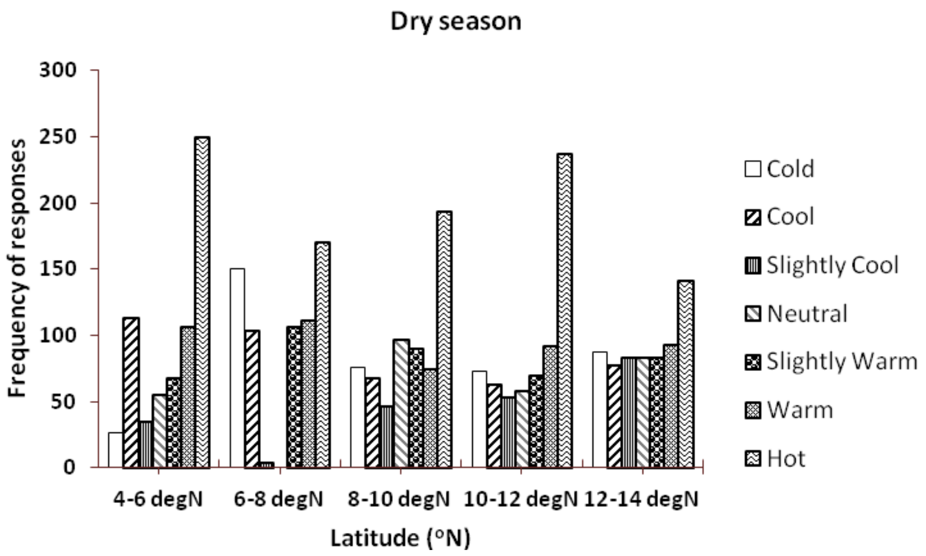
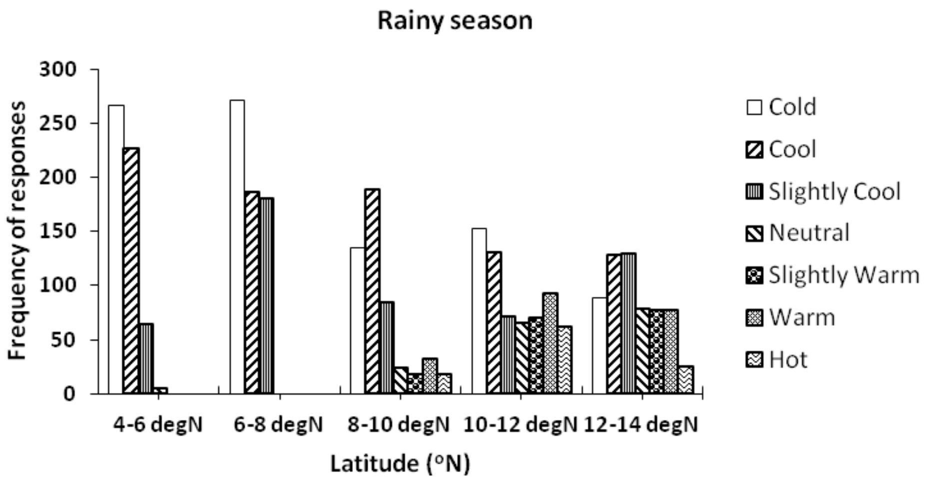


Figure 4.49: (a) Perception on Prevailing and (b) Preferred Weather


Dry season
300
250
200
150
100
50
0
Frequency of responses
4-6 degN
6-8 degN
8-10 degN
10-12 degN
12-14 degN
Latitude (°N)
Cold
Cool
Slightly Cool
Neutral
Slightly Warm
Warm
Hot


Rainy season
300
250
200
150
100
50
0
Frequency of responses
4-6 degN
6-8 degN
8-10 degN
10-12 degN
12-14 degN
Latitude (°N)
Cold
Cool
Slightly Cool
Neutral
Slightly Warm
Warm
Hot

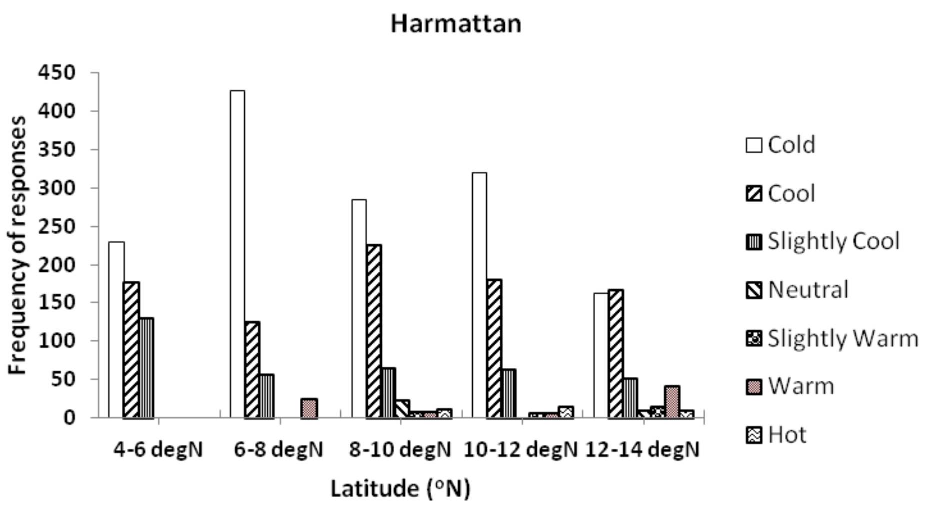

Harmattan
450
400
350
300
250
200
150
100
50
0
Frequency of responses
4-6 degN
6-8 degN
8-10 degN
10-12 degN
12-14 degN
Latitude (°N)
Cold
Cool
Slightly Cool
Neutral
Slightly Warm
Warm
Hot

Figure 4.50: Perception on Seasonal Average Weather Condition

4.11.3. Perception on reaction to stressful weather

Figure 4.51 describes the perception on the seasonal dimension of some dominant weather-related physiologic sicknesses. It is instructive to note that only perceivable (not requiring significant medical diagnosis) sicknesses or diseases were considered in this study. Out of the sicknesses investigated, heat rash, headaches (dry season), severe cold, headache and cough (rainy season), dry skin, dry throat and dry eyes (Harmattan), were dominant. The sicknesses that received most votes from the respondents in the dry season and Harmattan period, in this study, are heat-related. Miller (1952) and Adefolalu (1985) argued that sicknesses in the dry season and Harmattan period in Nigeria are both heat and dust related; there are also complaints of cold and dryness. In the rainy season, vulnerability to cold may increase. Existing studies (e.g. Koopman et al., 1991; Reiter, 2001; Altizer et al., 2006; Patz and Balbus, 1996) also showed that various vector borne diseases, cardiovascular problems exhibit seasonal variations.

4.11.4. Perception on Adaptation Strategies to Uncomfortable Weather

The effect of cold and heat stresses during the ‘cold’ and ‘hot’ weather were ameliorated through clothing or dressing mode and air conditioning or fanning systems. Figure 4.52 shows the perception on the seasonal choice of clothing. Preference for light dresses dominated the dry season, and thick dresses was preferred during Harmattan, irrespective of the ecological region. Most respondents alternated light and thick dresses during the day and night times. There was a general agreement over the choice of these approaches (≥70%). Figure 4.53 shows the perception on the preferred office and house’s microclimate of the respondents. Most respondents would prefer to work indoors, and in offices with functional air conditioners, and live in houses fitted with fans or air conditioning systems to change the house microclimate (which was mostly described to be hot, except in Jos).

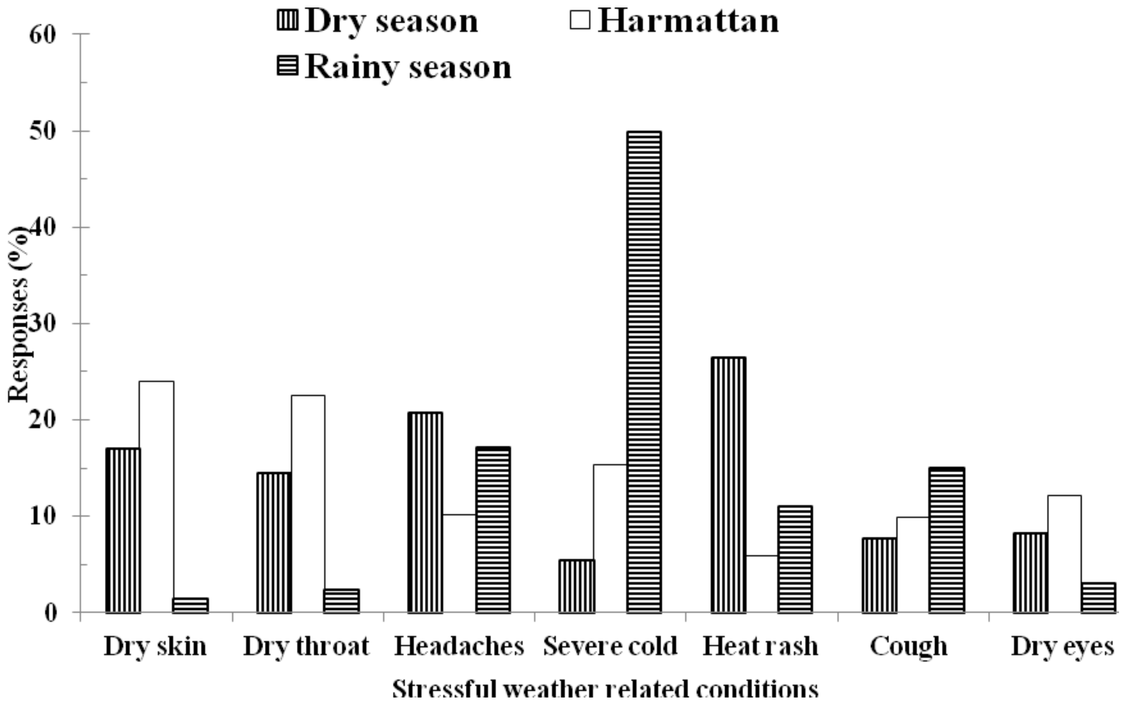


Figure 4.51: Perception on Seasonal Distribution of Weather Related Sicknesses (Multiple responses were allowed)

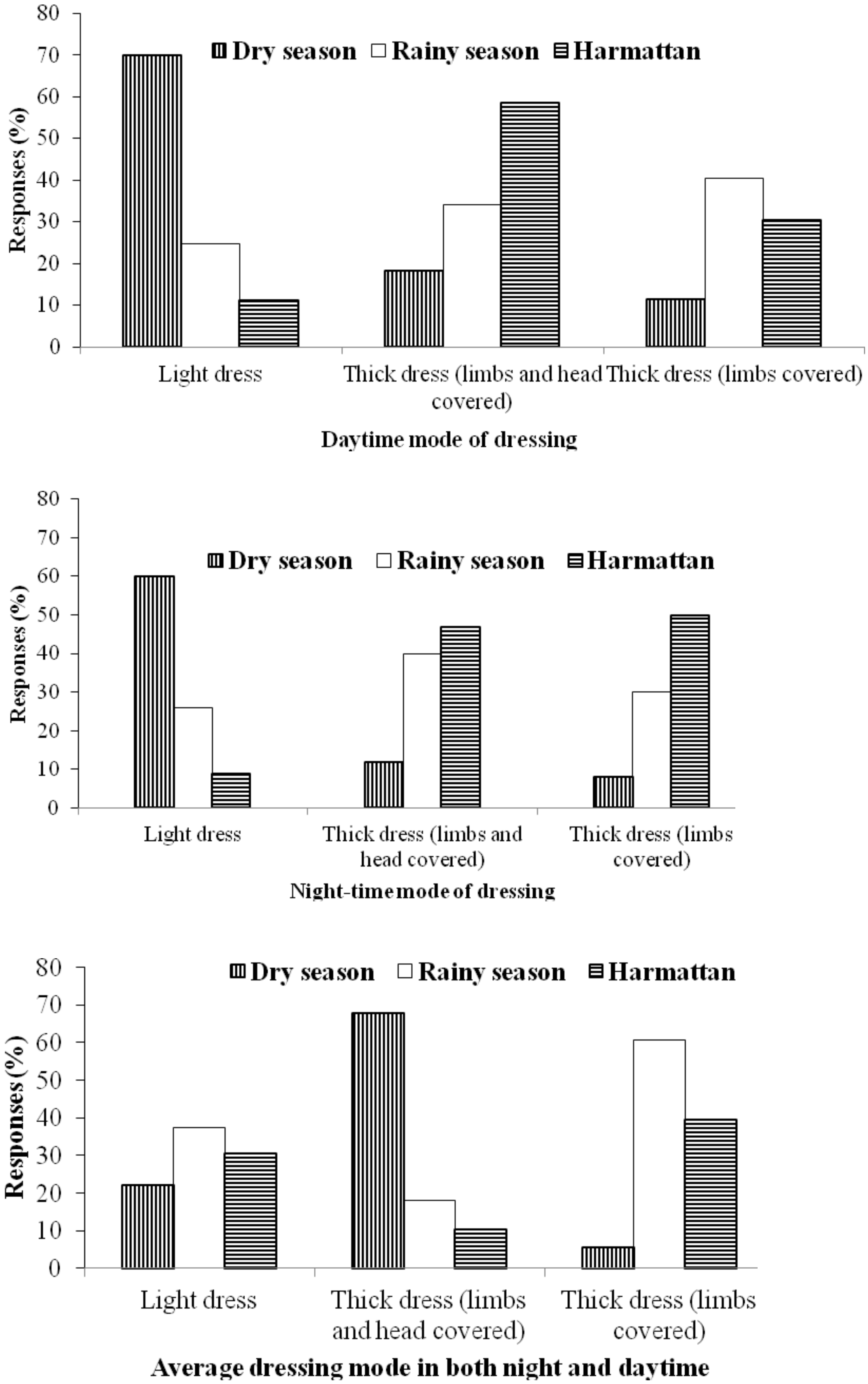
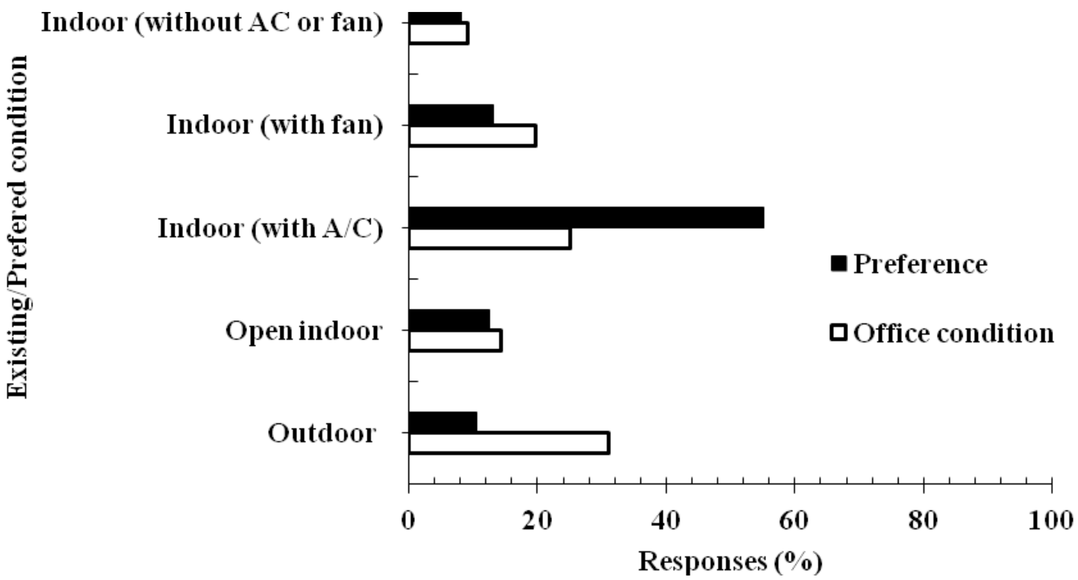


Figure 4.52: Percentage Responses on Dressing Mode as Adaptive Strategy to Seasonal Changes in Weather

Source: Fieldwork, 2010



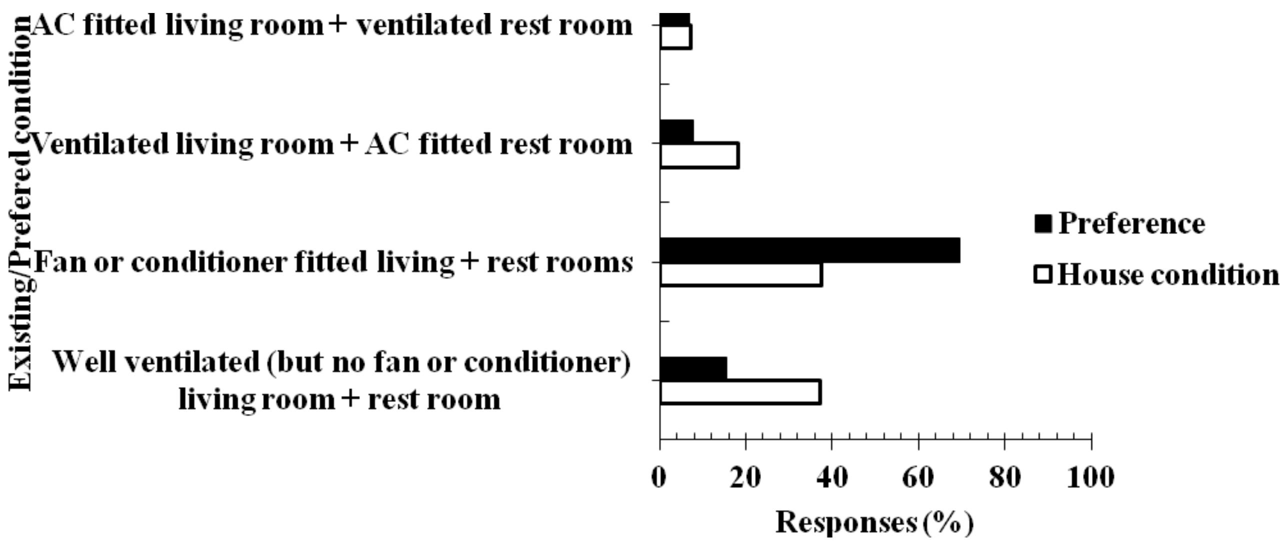


Figure 4.53: Office and Residential Conditions and Perceptions on Preferred Condition

Source: Fieldwork, 2010

4.12. Implication of the Research Results on Projected Hypotheses

The result of this study has shown that the first hypothesis which states that, physiologic climate, in terms of thermal discomfort, in Nigeria exhibits significantly increasing trend from 1951 to 2009 is true for most regions. Minimum, maximum and mean temperatures were shown to have increased at most stations in the rainforest and savanna regions ($b \leq 0.05$; $p \leq 0.05$), except at few stations (Ilorin and Yelwa). Relative humidity has decreased at most stations in the rainforest and guinea savanna ($b \geq 0.13$; $p \leq 0.05$) but the variations at the stations in the sudano-sahelian savanna were not significant. The effective temperature (ETI), temperature-humidity-index (THI) and relative strain (RSI) indices were also shown to exhibit significant increase, especially at stations in the rainforest and sudano-sahelian region. Relative strain index (RSI) at Ilorin, in the guinea savanna, however exhibited significant decrease ($b=-0.006$; $p<0.05$). The RSI, THI and ETI at the montane region exhibited non-significant variations throughout the period. Therefore, it is appropriate to submit here that significant increases have been generally observed in both the unitary (temperature) and integrative (ETI, THI and RSI) indices in most parts of Nigeria. Decrease in relative humidity is also an indication of increased thermal stress (Brager and de Dear, 1998), hence the hypothesis is accepted, and this study concludes, in this regard, that thermal discomfort in Nigeria has significantly increased (worsened) in the recent decades (1981-2009) than previous period (1951-1981).

Secondly, the hypothesis that suggests that temperatures, relative humidity, ETI, THI and RSI are significantly correlated is supported by the results of the Pearson correlation coefficients of the indices. Minimum temperature, effective temperature index, temperature-humidity index and relative strain index exhibited positive, strong and significant correlations ($r \geq 0.97$; $p = 0.01$), but less strong with mean temperature ($r =0.74-0.84$; $p=0.01$) and relative humidity ($r = 0.56-0.74$; $p \leq 0.01$). Only relative humidity however exhibited significant but inverse relationship with maximum temperature ($r = -0.54$; $p < 0.05$). Although this result of the Pearson correlation suggests that the hypothesis can be accepted, caution is however taken based on results from the seasonal and diurnal variations which suggest significant influence of seasons and period of the day on the relationships. Nevertheless, the hypothesis is accepted for this study.

In addition, the hypothesis that suggested that physiologic climate (thermal discomfort) exhibits direct relationship with increasing distances away from the Atlantic Ocean is rejected in this study. The rejection of this hypothesis is based on the observation of the pattern of relationship between latitude and the physiologic indices evaluated in the study (Table 4.8).

Maximum temperature exhibited direct relationship with increasing latitude ($r = 0.64$; $p=0.01$) while THI ($r = - 0.44$; $p> 0.05$) and RSI ($r= -0.43$; $p > 0.05$) exhibited inverse correlation which were not significant. Minimum temperature, relative humidity and ETI however exhibited inverse but significant correlations with latitude ($r \geq 0.55$; $p \leq 0.05$). The results of the study also showed the alternating influence of the moisture laden mT and dust laden Harmattan, as well as local altitude and anthropogenic factors.

Furthermore, the hypothesis that suggested that direct relationship exists between altitude and physiologic climate (thermal discomfort) is also rejected based on the results in this study. Comparison of the montane region with other regions suggested that the montane climate was stable and comfortable than other region in most period of the study, except in the morning (about 0600 LST) and in the Harmattan period. In addition, the result of the Pearson correlation showed that temperature, relative humidity, ETI, THI and RSI exhibited inverse and strong relationship ($r \geq -0.66$; $p \leq 0.05$) with altitude.

Adequacy of the adaptive measures of the sampled population in Nigeria to physiologic stress was measured in this study by assessing the preference of the population in line with their existing strategies to stay comfortable. This study has shown that the people considered clothing or wear type, and availability of air conditioning system as adaptive measures. Based on the results of this study, more respondents would prefer to work in an air-conditioned office (69%) than the percentage working in that condition at the time of the study (22%). About 68% would also prefer to live in fan or air conditioner fitted living and rest rooms than the 36% that lived there during the administration of the questionnaire. These differences (47% and 32%, for work and living condition) suggest that more people desire to work and live in better conditions than they live now, for comfort. The study therefore rejects the hypothesis that stated that adaptive approaches to physiologic stress are adequate for protection against prevailing physiologic climate in most regions in Nigeria.

CHAPTER FIVE

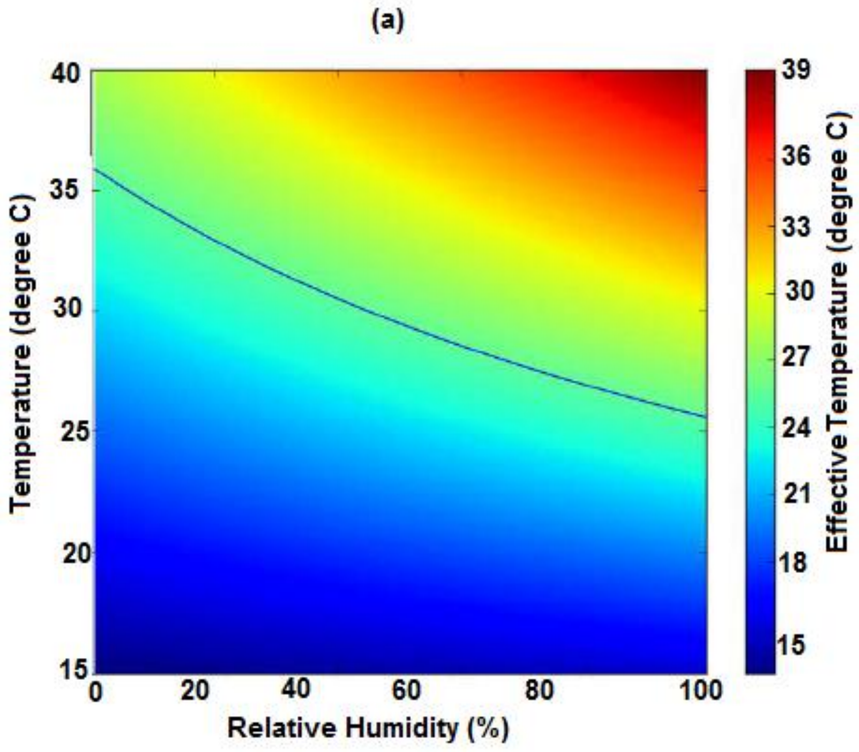
SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

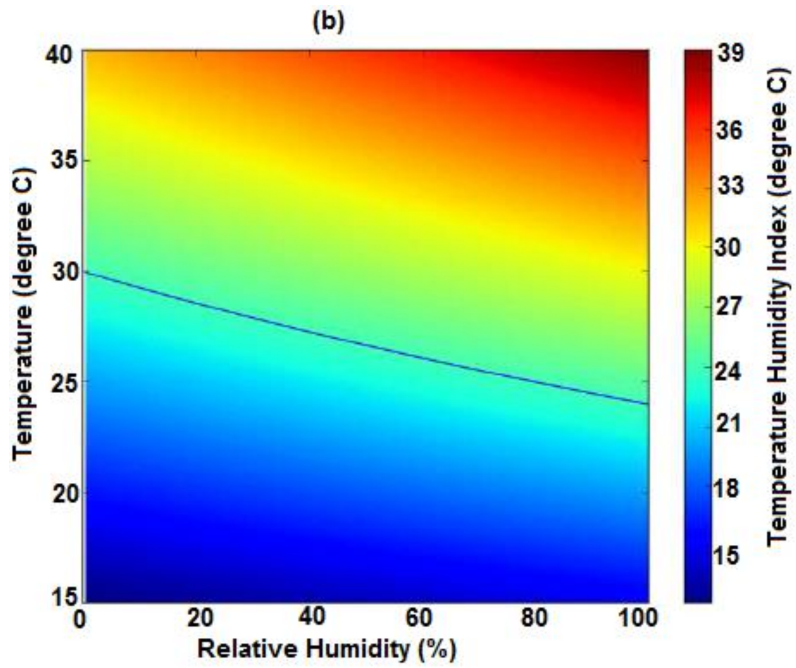
5.1. Summary

This study examined the spatial and temporal variations in the physiologic climates in Nigeria, using both unitary (temperature and relative humidity) and integrative indices (ETI, THI and RSI). Indices of physiologic climate that were investigated were selected after a careful review of previous studies and consideration of available climate data in the Nigerian Meteorological Agency. The integrative indices were computed using adopted ETI and RSI formulae by Nigerian authors (Ayoade, 1978; Olaniran, 1982), while the formula used for the computation of the RSI (which has rarely been used on the Nigerian climate) was adopted, from a study in the South America (Alessandro and de Garin, 2003). Selected meteorological stations represented 2^o by 2^o grid networks, and a total of 18 meteorological stations were investigated. The choice of selected stations was informed by data availability from 1951 to 2009, and fair representativeness of the entire climate regions in Nigeria. Data were analysed for temporal (hour, month, season, annual, decadal, and periodic; 1951-2009, 1951-1980 and 1981-2009) and spatial variations using geostatistics and geographical information techniques.

Results showed that mean annual minimum, maximum and mean temperatures (standard deviation in parenthesis) for 1951-2009 were 21.4 (3.45), 32.8 (3.37) and 27.1 (2.73)^{o}C, respectively, while the mean relative humidity (standard deviation in parenthesis) for 1951-2009 was 61.98(24.8)%. The mean (standard deviation in parenthesis) ETI, THI and RSI were 24.3(0.85)^{o}C, 24.8(1.83)^{o}C and 0.2(0.18), respectively. While the results of the linear regression of the unitary indices, especially the maximum temperature, showed that daytime heat stress was prominent in the upper end of the latitude (9-14^{o}N) and the southwestern region, the integrative indices (ETI, THI and RSI), which combines at least two of the unitary indices showed that regions, which exhibited high mean temperature (>33^{o}C) and high relative humidity (>80%) at any time of the day will exhibit significant physiological stress than other areas. Figures 5.1a-c shows the relationships between the unitary (temperature and relative humidity) and the integrative indices (ETI, THI and RSI). The relationships between the indices showed that there is difference between the integrative indices giving same temperature and relative humidity data, and this explains why there was a disparity in the results of the integrative indices. The larger blue region' in the RSI result (Figure 5.1c) suggests that it is capable of showing more cold stress vulnerable region than both ETI and THI. The THI and ETI, on the other hand, suggest that heat stress is more likely in region with high relative humidity and high mean temperature because the ‘red region’ is large towards the position. Blue region and red region are used to depict the transition from cold stress period to the heat stress period in Figure 5.1a-c.

The result of the integrative indices does not however interprete fully the observations showed by the unitary indices. The maximum temperature is an important measure of the daytime (1200-1500 hour) radiation when the daily temperature is often considered to be highest (Voogt, 2002). The results of the investigation into the maximum temperature in this study showed that the northern part of Nigeria (especially the northeastern region) is characterised by more condition of heat stress during the daytime than the southern region. This result is acceptable because the cloud cover is generally thin in the northern region in daytime due to generally low atmospheric moisture, and radiation is generally high. The night-time or minimum temperature is however generally low as the heat is often released back to the atmosphere by terrestrial or infra-red radiation (McGregor and Nieuwolt, 1998). It is therefore necessary to highlight the assumption that the northern Nigeria is physiologically uncomfortable due to heat stress since the region is often characterised by high maximum temperature is not entirely correct because maximum temperature is known to define the daytime temperature rather than the night-time temperature which is often defined in terms of the minimum temperature (Voogt, 2002). On the other hand, it may be preferred to link the high maximum temperature in the northern region to the daytime physiologic heat stress condition, but this cannot be stated for the night-time physiologic condition. The dissimilar relationship between the mean temperature, relative humidity and either ETI, THI and RSI probable explains the differences in the three indices (Figure 5.1a-c).





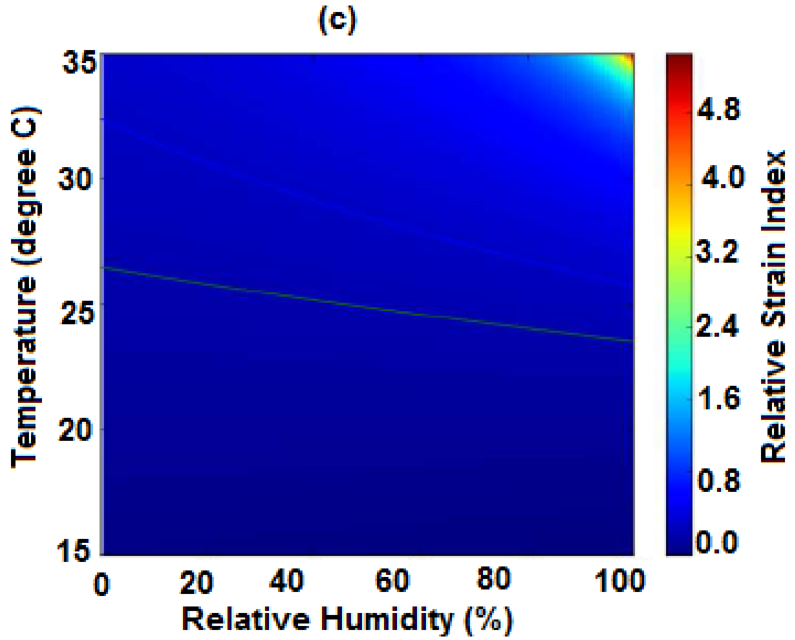


Figure 5.1a-c: (a) Effective Temperature, (b) Temperature–Humidity and (c) Relative Strain Indices over Different Ranges of Temperature and Relative Humidity in Nigeria.

Furthermore, the influence of relief on the climate of Nigeria is shown to be significant by the physiologic comfort classification of Jos, the montane station as the 'most' thermally comfortable region in Nigeria. On the other hand, regions classified as thermally uncomfortable, the valleys of the Niger and Benue rivers, Niger–Delta region, southwest and northeastern Nigeria exhibit some contrasting features. Previous study (Ayoade, 1978) has similarly classified the Niger–Benue valley as the most uncomfortable climate region in Nigeria. The reason for this is not yet fully understood, however. Nonetheless, the location of the Niger–Benue valley places it at the front of the Inter Tropical Discontinuity (ITD) for more days of the year than any other part of Nigeria. Further study will be required to understand the effect of its position on the thermal condition there. Studies on the Niger–Delta region (e.g. Ogundare and Sidiq, 2010) have implicated gas flaring activities as a result of oil exploration as the main cause of rise in ETI. The southwestern Nigeria has rapidly urbanized since colonial times. Commerce and industry have grown and with them administration and the human population, and these have had their impacts on local climate with 'heat islands' in many of the towns (e.g. Omogbai, 1985; Aina, 1989; Adebayo, 1991; Efe, 2004; Adelekan, 2005; Akinbode et al., 2008).

In addition, the comparison of the periods 1951–1980 and 1981–2009 and decadal means of the three thermal indices (ETI, THI and RSI), showed significant increase in the area that experiences thermal distress with increasing time. The projected figures suggest that heat stress will spread to almost everywhere except the north central region within the next two decades. The monthly patterns showed that thermal stress is first experienced in the rainforest region before the northern region, in a trend that is similar to the movement of the ITD. The seasonal distribution of the thermal condition showed that more areas experienced thermal stress in the north in the rainy season while during the dry season, more areas experience thermal stress in the south. More areas in the north were more comfortable in the Harmattan. Of the three seasons, Harmattan was observed to be most comfortable in the north of Nigeria, although the Harmattan period is characterized by dust which is a more serious hazard than heat at this time.

The study on the perception of comfort climate in Nigeria showed that the people considered 'cool' or 'slightly cool' as comfortable. Cool weather is described by Terjung (1966) to be around 21.1 °C of dry bulb temperature or when the physiologic equivalent temperature is between 8 and 18 °C (Matzarakis and Mayer 1996). As universal as this estimate appears, its relativeness as it is actually related to the local people is not well understood. Nevertheless, the comfortable climate in Nigeria is perceived by most respondents to occur in the rainy season, while perception of the dry season vary significantly with geographical region, condition of place of work and residence of the respondents. The dry season was described as generally 'hot' and Harmattan as ‘cold’. The approach of coping with the uncomfortable weather is also largely influenced by the socio- economic status of the people, and strategies; including dressing mode, clothing materials and use of air conditioners and fan. One major issue that this study has not covered is the extent to which the coping strategies have been effective. This would perhaps require information about respondents’ health and hospital records of weather related health cases and not only the people’s perception as used in this study. However, both the people and hospitals could not provide this. While most respondents considered their health records as personal or the health facilities as ‘not very useful’ for them, most of the health carers could not provide such, claiming that the sick rarely report such cases. Nevertheless, the survey of the perception of the people suggested that the coping strategies are inadequate, and that the people’s ability to cope with a prevailing weather condition is limited by their socio-economic status.

5.2: Conclusions

The results of the analysis of selected unitary (temperature and relative humidity), integrative indices (ET, THI and RSI) and perception of sampled population on physiologic climate of Nigeria have been evaluated in this study. The study showed that the indices exhibited complementary strengths and limitations in elucidating the different phases of the physiologic climate in the study area. While it is probably difficult to regard an index as best suitable for Nigeria, the choice of multiple indices as used in this study is advocated for study in any large country. The study also showed that the preferred comfort climate in Nigeria was largely described as ‘cool’ or ‘slightly cool’ (i.e. when the dry bulb temperature is around 21.1 °C); the prevailing weather varies with seasons, subjecting the people to different levels of stress at different times of the year. Subsequently, based on the findings of this research, the study accepted the hypothesis that physiologic stress has increased in Nigeria between 1951 and 2009 but reject the hypothesis that physiologic comfort in Nigeria is directly related to proximity to either the influence of the Atlantic Ocean or Sahara. It also showed that the physiologic climate of Nigeria could not be explained on the basis of the existing vegetation or rainfall-based climate classification systems but by a complex interaction of the influence of altitude, latitude and urbanisation.

In general, the comfort indices are differently suitable in the pattern of thermal comfort based on the different degree at which they relate with temperature and relative humidity as earlier shown in this study. The ETI, THI and RSI as found in this study may not produce exact outcomes but they are closely related in their interpretations of thermal conditions as all the indices showed that temperature has increased from 1971 to 2001 because lesser regions experienced cold stress, and many region that showed comfortable thermal climate in 1971 exhibited heat stress as at 2001. The change in the March condition may however be linked to the change in the onset of stress condition as the monthly investigation has shown. Although, it will require further study to understand the anomaly in the July variation in latitude 4–6^{o}N, studies of the effect of the sea surface temperature (e.g Odekunle and Eludoyin, 2008) suggest that the anomaly can be attributed to the influence of the trade winds.

5.3: Recommendations

The study recommends on the need to distinguish between the role of urbanisation and the movement of the ITD in the emergence or prevalence of physiologic stress in Nigeria. It is also recommended that dynamics and effect of physiologic stress on specific illness can be focused by more researches such that early warning system can be developed for vulnerable regions. The present approach for green urban environment by some States in Nigeria should also be encouraged and intensified. Greening of the urban areas can help reduce CO_2 atmospheric escape, and reduce vulnerability to physiologic stress in these areas.

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APPENDIX 1
DEPARTMENT OF GEOGRAPHY
UNIVERSITY OF IBADAN, NIGERIA

<u>Questionnaire Requesting Responses on the Physiologic Climate of Nigeria</u>

Dear Sir/Ma,
Please, the questionnaire below is set to request for your responses on the Physiologic Climate on Nigeria. It will be appreciated if you will just take some time off your busy schedule to respond to the questions. It is for research only.

<u>Instruction: Please, insert X or tick (√) in the box in front of the alternative of your choice as appropriate</u>

1. Can you please describe your age? <18 ☐ 18 – 30 ☐ 31 – 60 ☐ >60 years ☐

2 Describe your height: <5 ft(153cm) ☐ 5-5.9ft (153-182cm) ☐ ≥ 6 ft (1.83cm) ☐

3. Weight: < 40Kg ☐ 40 – 60Kg ☐ 61 – 80Kg ☐ 81-100Kg ☐ > 80Kg ☐

4. Sex: Male ☐ Female ☐

5. Marital Status: Single ☐ Married ☐ Separated ☐ Widowed ☐

6. Tribe: Yoruba ☐ Hausa ☐ Fulani ☐ Igbo ☐ Ibibio/Ijaw ☐
English ☐ Asian ☐ Dutch ☐ Others________________

7. Highest Education Achievement: Primary School ☐ Secondary/Technical ☐
ND/NCE ☐ HND/First degree ☐ Masters degree/Professional Qualification/PhD ☐

8. Occupation type: Self Employed ☐ Civil Servant ☐ Private Organisation ☐ NGO ☐
Others ☐ (please write) ________________________________

9. How will you rate your employment status?
Low income earning (< 500, 000 /year) ☐
Medium (500,000 – 1.5m/year) ☐
High (>1.5m/year) ☐

10a. In which of the regions in Nigeria are you residing?
South-South ☐ North - East ☐ North-West ☐ North -Central ☐
South-West ☐ South-East ☐

10b. If this is different from your place of work, in which of them is your place of work?
South-South ☐ North - East ☐ North-West ☐ North -Central ☐
South-West ☐ South-East ☐

11a. If not, which State?______________________________

11b. If you answer 10b, please indicate the Local Government Area________

11c. On what environment will you then base your assessment? (Please choose only one option)
Work ☐ Residence ☐

12a. How many years have you been here?
<5 years ☐ 5 – 10 years ☐ 11 – 15years ☐ 15–20years ☐ >20 years ☐

13. How will you describe the weather condition of this place in the dry season?
Cold ☐ Cool ☐ Slightly Cool ☐ Neutral ☐ Slightly Warm ☐ Warm ☐ Hot ☐

14. If given a chance to alter the weather, how will you prefer it in the dry season?
Cold ☐ Cool ☐ Slightly Cool ☐ Neutral ☐ Slightly Warm ☐ Warm ☐ Hot ☐

15. How will you describe it in the harmattan period?
Cold ☐ Cool ☐ Slightly Cool ☐ Neutral ☐ Slightly Warm ☐ Warm ☐ Hot ☐

16. How will you prefer it this time?
Cold ☐ Cool ☐ Slightly Cool ☐ Neutral ☐ Slightly Warm ☐ Warm ☐ Hot ☐

17. How do you feel during the wet season?
Cold ☐ Cool ☐ Slightly Cool ☐ Neutral ☐ Slightly Warm ☐ Warm ☐ Hot ☐

18. But how will you prefer it?
Cold ☐ Cool ☐ Slightly Cool ☐ Neutral ☐ Slightly Warm ☐ Warm ☐ Hot ☐

19. Which of these best describe your place of work?
Outdoor ☐ Open Indoor (under a shade) ☐ Indoor (with A/C) ☐
Indoor (with fan) ☐ Indoor (without AC or Fan) ☐

20. How will you prefer it?
Outdoor ☐ Open Indoor (under a shade) ☐ Indoor (with A/C) ☐
Indoor (with fan) ☐ Indoor (without AC or Fan) ☐

21. Which of these best describe your residence?
Well ventilated sitting room + ventilated rest room (No AC/fan) ☐
AC / fan fitted sitting room + AC/fan fitted rest room ☐
Ventilated sitting room (No AC/fan) +AC /fan fitted rest room ☐
AC/fan fitted sitting room +ventilated restroom (No AC/fan) ☐

22. How will you prefer it?
Well ventilated sitting room + ventilated rest room (No AC/fan) ☐
AC / fan fitted sitting room + AC/fan fitted rest room ☐
Ventilated sitting room (No AC/fan) +AC /fan fitted rest room ☐
AC/fan fitted sitting room +ventilated restroom (No AC/fan) ☐

23. Can you give any reason for your preference in 22?...

24. How will you describe your clothing in the dry season?
☐

Light (arms uncovered)
Thick (arms and head covered)
Thick (only arms covered)

25. How will you describe it in the harmattan period?
Light (arms uncovered)
Thick (arms and head covered)
Thick (only arms covered)

26. How is the clothing in wet season?
Light (arms uncovered)
Thick (arms and head covered)
Thick (only arms covered)

27. Is your response in 24-26 above for both day and night? Yes ☐ No ☐

28. If your answer to 27 is No, Please tick your choice for each season from the alternatives below

Dry Season
Light dress during the day and thick at night
Thick dress in the day and light at night
Light dress throughout the day
Thick dress throughout the day

Harmattan period
Light dress during the day and thick at night
Thick dress in the day and light at night
Light dress throughout the day
Thick dress throughout the day

Wet Season
Light dress during the day and thick at night
Thick dress in the day and light at night
Light dress throughout the day
Thick dress throughout the day

29. Do you prefer to sleep outside your room, i.e. in the backyard or courtyard in the dry season? Yes ☐ No ☐

30. When do you often suffer from any of the following?

Dry skin:	Dry Season ☐	Harmattan ☐	Wet Season ☐
Dry throat:	Dry Season ☐	Harmattan ☐	Wet Season ☐
Headaches:	Dry Season ☐	Harmattan ☐	Wet Season ☐
Severe cold:	Dry Season ☐	Harmattan ☐	Wet Season ☐
Heat rash:	Dry Season ☐	Harmattan ☐	Wet Season ☐
Cough:	Dry Season ☐	Harmattan ☐	Wet Season ☐
Dry eyes	Dry Season ☐	Harmattan ☐	Wet Season ☐

APPENDIX 2A

Alpha (Cronbach). This model is a model of internal consistency, based on the average inter-item correlation.

```
job 'Cronbach'
open 'ques.txt'; ch=2; width=300
text [nval=2] title
read [ch=2] title
print title
read [ch=2]  y[1...38]
calc miss=-1
calc miss=mvinsert(miss;miss.lt.0)
calc rn=y[10]

for reg=1...6
subset [cond=rn.eq.reg] y[1...38]; y1[1...38]
"
for i=31...38
  calc y[i]=miss
endfor
"
calc nq=38
calc q=nval(y1[1])
vari [nval=q] sums
vari [nval=nq] vars
calc dif=1-q
calc nw=38
pointer [nval=q] ab
variate [nval=nw] ab[]
equate [oldformat=!((1,#dif)#nw,-1)] y1; ab

for i=1...q
  calc sums$[i]=sum(ab[i])
endfor
for j=1...nq
  calc vars$[j]=var(y[j])*(q-1)/q
endfor
calc k=nq
calc sumsum=sum(sums)
calc vartot=var(sums)*(q-1)/q
"
print sums
print vars

"
calc sumvars=sum(vars)
calc alpha=(k/(k-1))*(1-(sumvars/vartot))
calc region=reg
print region,alpha

endfor
stop
```

APPENDIX 2B: Algorithm for Trend Analysis

```
open 'sokotostationnow.txt'; channel=2; width=5000
text [nvalues=2] ET
read [channel=2] ET
print ET
variate [nval=59] annualt
variate [nval=59] yy; values=!(1951...2009)
read [channel=2] station,month,year,max,min,rh,meant
"
boxplot [method=sche] meant
"
calc k=0
for y=1951...2009
  subset [condition=year.eq.y] meant; t
  calc k=k+1
  calc annualt$[k]=mean(t)
endfor
frame window=1,2; yupper=1,0.55; ylower=0.45,0; xupper=0.9,0.9; xlower=0.1,0.1
calculate black=rgb(0;0;0)
calc red =rgb(250;0;0)
calc blue=rgb(0;0;250)
calc green=rgb(0;150;0)
pen 19; size=1; colour=black
pen 1; colour=red; linestyle=0; symbol=-9; method=point; size=1; thickness=1.5
pen 2; colour=blue; linestyle=0; symbol=-9; method=point; size=1; thickness=1.5
pen 3; colour=green; linestyle=1; symbol=0; method=line; thickness=1.5
axes win=1; xlower=1951; xupper=2008; ylower=25; yupper=32; \
  ytitle='Annual mean temperature/ ~^{o}C'; xtitle="
dgraph [window=1; keywindow=0] y=annualt; x=yy; pen=1
calc y1=year-1951
calc y0=yy-1951

"
Compute trend from monthly mean temperatures.
"
model meant
fit [fprob=y] y1

"
Compute trend from annual mean temperatures.
"
model annualt
fit [fprobability=yes] y0

rkeep estimates=b
print b; decimals=4
calc pred=b$[1]+b$[2]*y0
calc r=annualt-pred
print yy, annualt,r; decimals=4
calc rbot=min(r)*1.2
calc rtop=max(r)*1.2
axes win=2; xlower=1951; xupper=2008; ylower=rbot; yupper=rtop; \
  ytitle='Residual temperature/ ~^{o}C'; xtitle='Year'
```

```
dgraph [window=2; keywindow=0;scr=k] y=r; x=yy; pen=2
dgraph [window=1; keywindow=0;scr=k] y=pred; x=yy; pen=3
correlate [max=5; print=a,p] r
describe [select=mean,median,min,max,var,skew] annualt
calc maxt=max(annualt)
calc mint=min(annualt)
calc bart=mean(annualt)
calc vart=var(annualt)
calc skewt=skew(annualt)
print bart,mint,maxt,vart,skewt; decimals=3
stop
```

APPENDIX 2C: Algorithm for testing independency of residuals

GenStat Release 13.1 (PC/Windows XP) 11 August 2011 13:18:29


```
open 'sokotostationnow.txt'; channel=2; width=5000
text [nvalues=2] ET
read [channel=2] ET
print ET
variate [nval=58] annualt
variate [nval=58] yy; values=!(1951...2009)
read [channel=2] station,month,year,max,min,rh,meant
"
boxplot [method=sche] meant
"
calc k=0
for y=1951...2008
   subset [condition=year.eq.y] meant; t
   calc k=k+1
   calc annualt$[k]=mean(t)
endfor
frame window=1,2; yupper=1,0.55; ylower=0.45,0; xupper=0.9,0.9; xlower=0.1,0.1
calculate black=rgb(0;0;0)
calc red =rgb(250;0;0)
calc blue=rgb(0;0;250)
calc green=rgb(0;150;0)
pen 19; size=1; colour=black
pen 1; colour=red; linestyle=0; symbol=-9; method=point; size=1; thickness=1.5
pen 2; colour=blue; linestyle=0; symbol=-9; method=point; size=1; thickness=1.5
pen 3; colour=green; linestyle=1; symbol=0; method=line; thickness=1.5
axes win=1; xlower=1951; xupper=2008; ylower=25; yupper=32; \
   ytitle='Annual mean temperature/ ~^{o}C'; xtitle=''
dgraph [window=1; keywindow=0] y=annualt; x=yy; pen=1
calc y1=year-1951
calc y0=yy-1951

"
Compute trend from monthly mean temperatures.
"
model meant
fit [fprob=y] y1

"
Compute trend from annual mean temperatures.
"
model annualt
fit [fprobability=yes] y0

rkeep estimates=b
```

```
print b; decimals=4
calc pred=b$[1]+b$[2]*y0
calc r=annualt-pred
print yy, annualt,r; decimals=4
calc rbot=min(r)*1.2
calc rtop=max(r)*1.2
axes win=2; xlower=1951; xupper=2008; ylower=rbot; yupper=rtop; \
   ytitle='Residual temperature/ ~^{o}C'; xtitle='Year'

dgraph [window=2; keywindow=0;scr=k] y=r; x=yy; pen=2
dgraph [window=1; keywindow=0;scr=k] y=pred; x=yy; pen=3
correlate [max=5; print=a,p] r
describe [select=mean,median,min,max,var,skew] annualt
calc maxt=max(annualt)
calc mint=min(annualt)
calc bart=mean(annualt)
calc vart=var(annualt)
calc skewt=skew(annualt)
print bart,mint,maxt,vart,skewt; decimals=3
stop
```

APPENDIX 3

Percentages (of discomfort in 59 (1951-2009)) used for classification of Physiologic Climate

	RSI		THI		ETI
KATSINA	0	JO	0	KA	0
POTISKUM	0	BA	9.1	PO	0
JOS	0	KA	11.3	JO	0
ILORIN	2.2	PO	32.7	IL	0
MAIDUGURI	2.3	NG	63.6	MA	0
BAUCHI	5.5	LO	76.4	BA	0
NGURU	7.3	IK	81.8	SO	2.2
IKEJA	54.6	YO	84.9	NG	3.6
YOLA	54.7	YE	85.5	YE	5.5
SOKOTO	55.6	MA	86.1	YO	18.9
YELWA	56.4	PH	91.1	IK	29.1
PORT-**H**ARCOURT	57.8	IL	95.6	BI	38.2
BENIN	72.7	MAK	97.8	MAK	48.9
LOKOJA	74.6	BI	98.2	PH	53.3
CALABAR	82.2	BE	98.2	CA	60
BIDA	89.1	WA	100	LO	63.6
WARRI	92.7	SO	100	BE	69.1
MAKURDI	100	CA	100	WA	87.3

Appendix 4.1: Descriptive Statistics and Trend in Minimum Temperature (°C) between 1951 and 2009 over Nigeria

Climate Region	**Station**	**Summary of Minimum temperature (1951-2009)**				Trend			
		Mean	St. Dev	CV	Range (min-max)	Constant (a)	Year (b)	F-stat	P-value
Tropical Savanna (Sahel)	Nguru	21.2	4.4	20.8	19.3-31.0	20.0	0.04	7.5	0.01*
Tropical Savanna (Sudan)	Katsina	19.4	4.3	22.2	18.3-27.7	18.8	0.02	3.4	0.07
	Sokoto	22.0	3.6	16.1	12.8-29.0	20.4	0.01	35.0	0.00*
	Maiduguri	20.1	4.6	23.0	18.9-28.1	19.3	0.02	2.0	0.16
	Potiskum	19.7	4.5	22.7	17.5-27.1	18.5	0.04	6.0	0.01*
	Yelwa	21.3	3.6	16.9	11.1-28.2	21.0	0.01	1.5	0.22
	Bauchi	19.0	3.5	18.5	19.2-25.1	17.8	0.04	22.9	0.00*
	Yola	21.7	3.2	14.8	10.7-29.0	20.8	0.04	12.5	0.00*
Montane	Jos	16.0	2.3	14.3	17.2-20.0	17.2	-0.03	19.9	0.00*
Tropical Savanna (Guinea)	Bida	22.8	1.8	8.0	17.8-28.2	22.3	0.02	20.2	0.00*
	Ilorin	21.3	1.7	7.8	11.3-25.0	20.4	0.03	26.2	0.00*
	Lokoja	22.8	2.0	8.7	14.1-27.7	22.5	0.01	5.9	0.02*
	Makurdi	22.3	2.5	11.1	11.5-27.2	21.2	0.03	15.1	0.00*
Tropical Wet and Dry	Ikeja	23.1	1.3	5.8	19.9-29.0	21.7	0.05	37.9	0.00*
	Calabar	23.0	0.8	3.4	20.1-25.9	22.6	0.01	16.6	0.00*
	Benin	22.8	1.0	4.6	18.4-26.3	21.8	0.04	260.9	0.00*
Tropical Wet	Warri	23.1	0.9	4.0	19.3-25.9	22.4	0.03	158.6	0.00*
	Port Harcourt	22.4	1.2	5.5	15.1-24.7	21.8	0.02	19.3	0.00*
Overall (monthly data) average		21.4	3.4	12.6	10.7-31.0	20.8	0.02	80.2	0.00*

Linear trend of the asterisked (*) probability (P) value is significant at the corresponding station within 95% confidence level (p≤0.05)

Appendix 4.2: Descriptive Statistics and Trend in Maximum Temperature (ºC) between 1951 and 2009 over Nigeria

Climate region	Station	Summary of Maximum Temperature (1951-2009)				Trend			
		Mean	St. Dev.	CV	Range (min-max)	Const. (a)	Year (b)	F-Stat	P value
Tropical Savanna (Sahel)	Nguru	35.3	3.6	10.2	24.6-42.7	34.67	0.02	2.7	0.10
Tropical Savanna (Sudan)	Katsina	33.7	3.4	10.0	24.0-40.8	33.1	0.02	4.5	0.03*
	Sokoto	35.2	3.2	9.0	28.4-42.2	34.6	0.02	6.3	0.01*
	Maiduguri	35.3	3.6	9.6	25.5-42.7	35.1	0.01	0.5	0.50
	Potiskum	34.4	3.3	9.6	25.0-41.9	33.4	0.03	6.8	0.01*
	Yelwa	34.1	3.0	8.8	28.5-41.1	34.8	-0.03	11.3	0.00*
	Bauchi	32.7	2.8	8.6	24.9-40.1	32.2	0.02	7.3	0.01*
	Yola	34.7	3.1	8.8	29.3-41.9	34.4	0.01	1.9	0.17
Montane	Jos	27.6	2.3	8.2	22.3-33.3	27.1	0.02	5.4	0.02*
Tropical Savanna (Guinea)	Bida	33.7	2.8	8.3	20.9-39.8	33.1	0.02	12.1	0.00*
	Ilorin	32.2	2.6	8.1	27.5-37.9	32.7	-0.02	3.4	0.07
	Lokoja	33.0	2.4	7.2	28.0-39.1	32.6	0.02	6.4	0.01*
	Makurdi	33.3	2.6	7.9	28.7-41.9	32.5	0.02	6.6	0.01*
Tropical Wet and Dry	Ikeja	30.9	1.9	6.3	26.7-35.3	30.3	0.02	21.8	0.00*
	Benin	31.3	2.0	6.5	26.9-37.0	30.7	0.02	19.5	0.00*
	Calabar	30.6	1.8	6.0	26.2-35.2	30.0	0.02	10.3	0.00*
Tropical Wet	Warri	31.4	1.8	5.8	27.1-35.1	31.2	0.01	6.2	0.01*
	Port Harcourt	31.1	1.8	5.9	27.0-35.9	30.2	0.03	17.7	0.00*
Overall (monthly data) average		32.8	3.4	8.0	42.7-20.9	32.5	0.01	28.6	0.00*

Linear trend of the asterisked (*) probability (P) value is significant at the corresponding station within 95% confidence level (p≤0.05)

Appendix 4.3: Descriptive Statistics and Trend in Mean Temperature (°C) between 1951 and 2009 over Nigeria

Climate zone	Station	Summary of Mean Temperature (1951-2009)				Trend			
		Mean	St. Dev.	CV (%)	Range (min-max)	Const (a)	Year (b)	F-value	P value
Tropical Savanna (Sahel)	Nguru	28.2	3.5	12.5	18.2-36.2	27.3	0.03	6.4	0.01*
Tropical Savanna (Sudan)	Katsina	26.5	3.5	13.3	17.7-33.6	26.0	0.02	4.6	0.03*
	Sokoto	28.6	3.0	10.4	21.2-35.2	28.5	0.03	23.7	0.00*
	Maiduguri	27.7	3.6	12.8	18.1-35.7	26.9	0.03	20.2	0.00*
	Potiskum	27.0	3.4	12.5	18.0-34.0	26.0	0.03	8.4	0.00*
	Yelwa	27.7	2.3	8.2	13.6-39.4	26.9	-0.01	1.5	0.22
	Bauchi	25.8	2.6	10.2	18.2-32.0	25.0	0.03	21.8	0.00*
	Yola	28.2	2.4	8.5	21.6-35.0	27.6	0.02	10.5	0.00*
Montane	Jos	21.8	1.7	7.7	14.1-26.3	21.9	-0.01	3.0	0.59
Tropical Savanna (Guinea)	Bida	28.3	1.9	6.8	19.0-37.4	22.7	0.02	21.7	0.00*
	Ilorin	26.8	1.6	6.0	21.7-30.7	26.6	0.01	1.2	0.28
	Lokoja	27.9	1.7	6.1	23.9-32.9	27.5	0.01	10.3	0.00*
	Makurdi	27.8	1.8	6.6	22.5-32.8	27.2	0.02	1.5	0.22
Tropical Wet and Dry	Ikeja	27.0	1.4	5.3	21.6-31.3	26.0	0.04	124.4	0.00*
	Benin	27.1	1.4	5.0	23.9-31.7	26.3	0.03	81.5	0.00*
	Calabar	26.8	1.2	4.4	24.1-30.4	26.3	0.02	15.2	0.00*
Tropical Wet	Warri	27.3	1.2	4.3	24.6-30.4	26.8	0.02	43.0	0.00*
	Port Harcourt	26.7	1.1	4.2	18.4-32.7	26.0	0.02	35.1	0.00*
Overall (monthly data) average		27.0	2.8	8.0	13.6-39.4	26.6	0.02	79.0	0.00*

Linear trend of the asterisked (*) probability (P) value is significant at the corresponding station within 95% confidence level (p≤0.05)

Appendix 4.4: Descriptive Statistics and Trend in Relative Humidity (%) between 1951 and 2009 over Nigeria

Climate Region	Stations	Summary of Relative Humidity (1951-2009)				Trend			
		Mean	St. Dev	CV (%)	Range (min-max)	Const. (a)	Year (b)	F-value	P-value
Tropical Savanna (Sahel)	Nguru	36.5	21.1	57.8	18.0-90.0	36.8	-0.01	0.01	0.92
Tropical Savanna (Sudan)	Katsina	38.9	23.5	60.4	16.0-84.0	41.7	-0.10	2.4	0.13
	Sokoto	42.7	23.6	55.3	18.0-85.0	40.8	0.06	0.6	0.45
	Maiduguri	39.9	20.7	51.9	14.0-79.0	42.8	-0.09	1.5	0.22
	Potiskum	39.5	23.9	60.5	15.0-88.0	40.8	-0.04	0.21	0.65
	Yelwa	60.7	19.1	31.5	14.0-88.0	60.0	0.03	0.3	0.60
	Bauchi	46.7	23.1	49.5	17.0-86.0	42.0	0.17	8.5	0.01*
	Yola	55.2	23.5	42.6	18.0-90.0	54.0	0.04	0.7	0.55
Montane	Jos	50.0	25.9	51.8	15.0-88.0	44.7	0.16	3.3	0.07
Tropical Savanna (Guinea)	Bida	64.4	18.1	28.1	16.0-88.0	66.8	-0.09	3.9	0.05*
	Ilorin	74.4	11.6	15.6	23.0-98.0	76.0	-0.05	1.6	0.21
	Lokoja	73.4	8.2	11.2	40.0-87.0	72.4	-0.07	13.0	0.00*
	Makurdi	69.8	14.2	20.3	22.0-86.0	71.6	-0.05	1.2	0.28
Tropical Wet and Dry	Ikeja	82.6	5.8	7.1	35.0-97.0	86.3	-0.13	86.9	0.00*
	Benin	83.9	5.7	6.8	34.0-94.0	84.9	-0.03	5.8	0.02*
	Calabar	85.1	5.0	5.8	50.0-94.0	86.6	-0.04	6.4	0.01*
Tropical Wet	Warri	83.9	4.8	5.7	29.8-94.0	84.9	-0.03	7.7	0.01*
	Port Harcourt	83.4	5.5	6.6	40.0-92.0	84.6	-0.03	3.0	0.09
Overall (monthly data) mean		62.0	24.8	31.6	14.0-97.0	63.6	-0.05	10.61	0.00*

Linear trend of the asterisked (*) probability (P) value is significant at the corresponding station within 95% confidence level (p≤0.05)

Appendix 4.5: Descriptive Statistics and Trend in Effective Temperature Index (°C) between 1951 and 2009 over Nigeria

Climate Region	Stations	Summary of Effectiive Temperature Index (1951-2009)				Trend			
		Mean	St. Dev.	CV (%)	Range (min-max)	Const (a)	Year (b)	F-value	P-value
Tropical Savanna (Sahel)	Nguru	23.1	1.5	6.5	20.0-27.2	21.46	0.06	36.4	0.00*
Tropical Savanna (Sudan)	Katsina	22.5	0.6	2.5	20.3-23.3	22.45	0.00	0.0	0.89
	Sokoto	24.4	0.6	2.3	22.9-25.7	23.44	0.03	37.3	0.00*
	Maiduguri	23.5	0.6	2.4	22.2-25.6	23.49	0.00	0.0	0.96
	Potiskum	22.4	1.3	5.8	19.6-23.7	20.70	0.06	57.1	0.00*
	Yelwa	24.9	0.5	2.1	23.4-26.1	24.90	-0.01	0.0	0.99
	Bauchi	22.4	0.7	2.9	20.9-24.0	21.61	0.03	54.0	0.00*
	Yola	24.9	0.9	3.4	23.5-28.1	24.07	0.03	18.3	0.00*
Montane	Jos	19.4	0.3	1.7	18.4-20.1	19.31	0.00	0.9	0.36
Tropical Savanna (Guinea)	Bida	25.5	0.8	3.2	21.7-27.8	25.64	-0.01	0.9	0.35
	Ilorin	24.4	0.5	2.1	22.6-25.4	24.77	-0.01	3.1	0.09
	Lokoja	25.9	0.7	2.5	22.3-27.6	25.90	0.001	0.0	0.98
	Makurdi	25.4	0.9	3.5	20.9-26.7	25.59	-0.01	0.4	0.56
Tropical Wet and Dry	Ikeja	25.3	0.6	2.3	24.5-27.9	24.59	0.03	44.6	0.00*
	Benin	25.9	0.6	2.2	23.9-27.0	25.14	0.03	64.9	0.00*
	Calabar	25.7	0.9	3.5	20.1-26.4	25.89	-0.01	0.4	0.52
Tropical Wet	Warri	26.1	0.4	1.4	25.4-26.8	25.62	0.02	68.9	0.00*
	Port Harcourt	25.6	0.4	1.6	24.3-26.3	24.89	0.02	29.5	0.00*
Overall (monthly data) mean		24.1	0.85	2.8	18.4-28.1	23.02	0.01	56.2	0.03*

Linear trend of the asterisked (*) probability (P) value is significant at the corresponding station within 95% confidence level ($p \leq 0.05$)

Appendix 4.6: Descriptive Statistics and Trend in Temperature-Humidity Index (^oC) between 1951 and 2009 over Nigeria

Climate Region	Stations	Summary of Temperature-Humidity Index (1951-2009)				Trend			
		Mean	St. Dev.	CV (%)	Range (min-max)	Const (a)	Year (b)	F-Stat	P-value
Tropical Savanna (Sahel)	Nguru	24.2	1.5	6.1	21.4-28.9	22.64	0.05	31.02	0.00*
Tropical Savanna (Sudan)	Katsina	23.3	0.6	2.5	21.4-24.2	25.1	0.01	0.9	0.35
	Sokoto	25.4	0.6	2.5	23.7-26.9	24.3	0.03	42.4	0.00*
	Maiduguri	24.4	0.6	2.4	23.2-26.6	24.2	0.00	0.2	0.63
	Potiskum	23.3	1.2	5.0	20.7-24.6	21.7	0.05	76.9	0.00*
	Yelwa	25.5	0.7	2.7	22.5-26.5	25.7	-0.01	1.4	0.24
	Bauchi	23.1	0.7	3.1	21.3-24.6	22.2	0.03	54.1	0.00*
	Yola	25.7	0.9	3.6	24.5-29.2	24.7	0.03	23.4	0.00*
Montane	Jos	19.6	0.4	2.0	18.2-20.5	19.4	0.01	1.8	0.19
Tropical Savanna (Guinea)	Bida	26.1	0.6	2.1	23.6-27.1	26.0	0.00	0.5	0.47
	Ilorin	24.9	0.5	2.0	22.9-25.7	25.1	-0.01	1.1	0.00*
	Lokoja	26.3	0.6	2.4	23.3-28.2	26.3	0.00	0.3	0.61
	Makurdi	25.9	0.7	2.9	22.6-27.4	25.9	0.00	0.1	0.89
Tropical Wet and Dry	Ikeja	26.1	0.6	2.4	25.1-28.8	25.3	0.03	59.1	0.00*
	Benin	26.1	0.6	2.5	24.0-27.2	25.3	0.03	59.7	0.00*
	Calabar	25.9	0.8	2.9	21.4-26.6	25.9	-0.01	0.1	0.78
Tropical Wet	Warri	26.3	0.9	1.4	25.7-27.0	25.8	0.02	81.9	0.00*
	Port Harcourt	24.8	2.1	8.3	20.5-26.6	22.1	0.10	74.7	0.00*
Overall (monthly data) mean		24.8	1.8	7.3	18.2-29.2	24.1	0.02	67.2	0.01*

Linear trend of the asterisked (*) probability (P) value is significant at the corresponding station within 95% confidence level ($p \leq 0.05$)

Appendix 4.7: Descriptive Statistics and Trend in Relative Strain Index between 1951 and 2009 over Nigeria

Climate Region	Stations	Summary of Relative Strain Index (1951-2009)				Trend (regression of monthly data for 1951-2009)			
		Mean	St. Dev.	CV (%)	Min	Const (a)	Year (b)	F-stat	P-value
Tropical Savanna (Sahel)	Nguru	0.17	0.05	29.4	-0.03-0.32	0.17	0.00	0.23	0.64
Tropical Savanna (Sudan)	Katsina	0.13	0.02	15.4	0.02-0.17	0.13	-0.01	0.02	0.88
	Sokoto	0.19	0.03	15.8	0.09-0.24	0.15	0.01	21.49	0.00*
	Maiduguri	0.16	0.02	12.5	0.10-0.23	0.14	0.01	6.54	0.01*
	Potiskum	0.13	0.10	76.9	-0.38-0.19	0.04	0.03	6.84	0.12
	Yelwa	0.18	0.06	33.3	-0.06-0.24	0.21	0.00	4.54	0.04
	Bauchi	0.09	0.10	98.0	-0.38-0.17	0.07	0.01	1.00	0.32
	Yola	0.21	0.05	23.8	0.11-0.41	0.15	0.00	21.39	0.00*
Montane	Jos	0.01	0.01	96.0	-0.05-0.04	0.01	0.00	0.59	0.45
Tropical Savanna (Guinea)	Bida	0.21	0.06	28.6	-0.2-0.33	0.22	0.00	0.12	0.74
	Ilorin	0.17	0.02	11.8	0.10-0.21	0.17	0.00	0.84	0.37
	Lokoja	0.22	0.04	18.2	-0.03-0.33	0.22	-0.01	0.01	0.93
	Makurdi	0.21	0.04	19.0	0.01-0.27	0.21	0.00	0.17	0.69
Tropical Wet and Dry	Ikeja	0.21	0.04	19.0	0.12-0.38	0.16	0.01	32.14	0.00*
	Benin	0.21	0.04	19.0	0.08-0.29	0.17	0.01	46.74	0.00*
	Calabar	0.19	0.09	47.4	-0.40-0.24	0.21	0.00	0.15	0.70
Tropical Wet	Warri	0.22	0.02	9.09	0.15-0.27	0.20	0.00	35.76	0.00*
	Port Harcourt	0.20	0.03	15.0	0.10-0.24	0.15	0.00	32.52	0.00*
Overall (monthly data) mean		0.20	0.18	90.0	-0.05-0.41	0.12	0.01	24.6	0.01*

Linear trend of the asterisked (*) probability (P) value is significant at the corresponding station within 95% confidence level ($p \leq 0.05$)

APPENDIX 5

Decadal Variations Summary

Mean Temperature

Decade	Nguru	Katsina	Sokoto	Maiduguri	Potiskum	Yelwa	Bauchi	Yola	Jos	Bida	Ilorin	Lokoja	Makurdi	Ikeja	Calabar	Benin	Warri	PH
1951-60	27.18	25.9	27.6	27.02	26.3	27.61	25.5	27.81	21.7	27.83	26.51	27.6	27.07	26.165	26.22	26.38	27.07	26
1961-70	27.38	26.5	27.9	27.57	26.4	27.73	25.4	27.87	21.9	27.97	26.64	27.65	27.23	26.568	26.59	26.72	27.22	26.43
1971-80	27.87	26.8	28.3	27.62	26.8	27.804	25.4	27.95	22.03	28.19	26.9	27.91	27.82	27.005	26.72	26.97	27.36	26.52
1981-90	29.58	26.5	28.9	27.77	27.1	28.097	26.2	28.56	21.48	28.38	26.87	28.07	27.83	27.265	26.92	27.36	27.51	26.91
1991-00	28.18	26.8	29	27.79	27.4	27.863	26.3	29.07	21.74	27.76	26.57	28.24	28.06	27.662	26.85	27.5	27.73	26.92
2001-10	28.26	27.1	29.4	28.2	27.9	26.195	26.6	30.43	22.12	30.03	27.06	27.34	28.29	29.216	27.25	27.85	27.66	27.21
2011-20	28.6	27.1	29.7	28.13	28.2	26.516	27	30.7	21.94	29.73	26.91	27.63	28.46	29.413	27.23	28.11	27.86	27.37
2020-30	28.67	27.3	30	28.22	28.5	26.15	27.3	31.36	21.98	30.18	26.94	27.54	28.66	30.05	27.34	28.39	27.98	27.56

Effective Temperature Index

Decade	Yola	Potiskum	Yelwa	Bauchi	Katsina	Maiduguri	Sokoto	Benin	Calabar	Ikeja	Bida	Ilorin	Lokoja	Makurdi	Jos	Nguru	Warri	PH
1951-60	24.66	20	24.9	21.97	22.5			25.23		24.8	25.44		25.82			20.5	25.74	
1961-70	24.48	22.7	25	21.93	22.2	23.687	23.9	25.64	25.63	25.09	25.56	24.93	25.85	25.279	19.37	23.21	25.87	24.86
1971-80	24.58	22.8	24.9	22.03	22.5	23.312	24.1	25.75	25.74	25.01	25.5	24.32	25.96	25.612	19.49	23.35	25.96	25.42
1981-90	24.85	22.4	24.9	22.68	22.8	23.352	24.6	26.08	25.83	25.27	25.67	24.37	26.05	25.608	19.22	24.57	26.27	25.77
1991-00	24.87	23.3	25.2	23.2	22.1	23.567	24.7	26.3	25.76	25.49	25.64	24.1	26.22	25.752	19.52	23.75	26.43	25.81
2001-10	27.38	23.6	23.8	22.9	22.7	23.631	25.1	26.7	26.4	26.76	26.04	24.87	24.68	25.045	19.86	23.58	26.53	25.95
2011-20	27.44	23.8	24	23.5	22.5	23.652	25.4	26.95	26.38	26.92	25.96	24.73	24.9	25.223	19.83	23.83	26.77	26.2
2020-30	28.23	24	23.7	23.81	22.5	23.712	25.8	27.24	26.55	27.42	26.04	24.85	24.58	25.119	19.96	23.84	26.97	26.39

Temperature-Humidity Index

Decade	Bida	Ilorin	Lokoja	Makurdi	Ikeja	Benin	Calabar	Jos	Katsina	Sokoto	Maiduguri	Potiskum	Yelwa	Bauchi	Yola	Nguru	Warri	PH
1951-60	25.98		26.2		25.4	25.431			23.19			21.2	25.45	22.627	25.39	21.88	25.96	20.8
1961-70	25.94	25.2	26.2	25.71	25.8	25.831	25.8	19.42	22.78	24.74	24.46	23.42	25.57	22.512	25.2	24.07	26.09	24.71
1971-80	26.03	24.9	26.4	26.2	25.9	25.754	25.9	19.71	23.23	25.04	24.23	23.54	25.55	22.593	25.35	24.29	26.21	25.63
1981-90	26.3	24.9	26.5	26.1	26.1	26.348	26.1	19.52	23.7	25.57	24.29	23.52	25.72	23.323	25.68	25.78	26.51	26
1991-00	26.25	24.6	26.7	26.28	26.3	26.563	26	19.68	22.94	25.74	24.47	24.09	25.82	23.8	25.76	24.72	26.71	26.06
2001-10	25.99	25.4	25.2	25.78	26.9	26.788	26.7	19.91	23.82	26.14	24.57	24.51	23.33	23.803	28.38	24.63	26.85	26.35
2011-20	26.08	25.3	25.5	25.94	27	27.177	26.6	19.86	23.69	26.46	24.58	24.71	23.59	24.385	28.47	24.9	27.11	26.62
2020-30	26.05	25.4	25.2	25.89	27.3	27.496	26.8	19.92	23.79	26.8	24.64	25.02	23	24.783	29.33	24.92	27.34	26.87

Relative Strain Index

Decade	Bida	Ilorin	Lokoja	Makurdi	Ikeja	Benin	Calabar	Jos	Katsina	Sokoto	Maiduguri	Potiskum	Yelwa	Bauchi	Yola	Nguru	Warri	PH
1951-60	0.211		0.22		0.18	0.1816			0.129			0.14	0.197	0.1064	0.183	0.156	0.208	
1961-70	0.204	0.18	0.21	0.201	0.17	0.1872	0.19	0.02	0.123	0.164	0.153	0.138	0.179	0.1078	0.188	0.152	0.209	0.151
1971-80	0.227	0.17	0.23	0.213	0.2	0.1987	0.21	0.02	0.137	0.19	0.156	0.133	0.204	0.1043	0.191	0.169	0.213	0.192
1981-90	0.23	0.17	0.24	0.221	0.2	0.2279	0.21	0.015	0.151	0.186	0.164	0.149	0.168	0.1303	0.203	0.217	0.237	0.21
1991-00	0.228	0.16	0.24	0.229	0.22	0.2401	0.2	0.019	0.11	0.215	0.175	0.159	0.212	0.1319	0.21	0.18	0.244	0.212
2001-10	0.206	0.17	0.23	0.29	0.25	0.2545	0.24	0.027	0.15	0.223	0.174	0.17	0.237	0.182	0.371	0.148	0.255	0.215
2011-20	0.207	0.16	0.24	0.298	0.26	0.2712	0.23	0.026	0.135	0.235	0.187	0.178	0.239	0.1946	0.372	0.158	0.27	0.228
2020-30	0.202	0.16	0.24	0.322	0.28	0.2873	0.24	0.028	0.134	0.247	0.196	0.188	0.252	0.2171	0.423	0.151	0.283	0.236

	Minimum Temperature																	
	Nguru	Katsina	Sokoto	Maiduguri	Potiskum	Yelwa	Bauchi	Yola	Bida	Ilorin	Lokoja	Makurdi	Ikeja	Calabar	Benin	Warri	Port Harcourt	Jos
1951-1960	19.5	18.8	20.6	19.22	18.7	20.755	18.3	21.31	22.34	20.79	22.78	21.68	22.02	22.477	21.87	22.55	21.85	16.27
1961-1970	20	18.8	20.8	19.8	18.9	21.175	18.2	21.29	22.52	20.57	22.6	21.6	22.44	22.701	22.41	22.71	21.99	16.67
1971-1980	20.59	19.9	21.6	19.83	19.5	21.533	18.7	21.24	22.84	21.3	22.61	22.22	22.73	23.049	22.86	23.03	22.23	16.42
1981-1990	23.31	19.9	22.9	20.23	20.1	21.633	19.5	22.25	23.07	21.63	22.55	22.35	23.42	23.131	23.03	23.41	22.53	15.44
1991-2000	21.21	19.2	22.6	20.28	20.1	20.916	19.3	22.66	22.86	21.47	23.03	22.62	23.72	22.867	23.31	23.68	22.61	15.61
2001-2010	20.96	20.2	22.9	20.95	20.5	22.218	21.2	23.73	23.62	22.08	23.8	22.82	25.51	23.412	23.35	23.45	23.03	16.33
2011-2020	21.61	20	23.4	20.99	20.8	22.011	21.6	24.26	23.62	22.36	23.95	23.1	25.93	23.326	23.61	23.85	23.32	15.77
2021-2030	21.68	20.1	23.8	21.22	21.2	22.189	22.4	24.95	23.83	22.67	24.32	23.35	26.75	23.411	23.8	24.04	23.6	15.68

Maximum Temperature																		
	Nguru	Katsina	Sokoto	Maiduguri	Potiskum	Yelwa	Bauchi	Yola	Bida	Ilorin	Lokoja	Makurdi	Ikeja	Calabar	Benin	Warri	PH	Jos
1951-1960	34.75	33.3	34.6	34.82	33.8	34.465	32.5	34.71	33.32	32.41	32.42	32.47	30.28	29.953	30.81	31.06	30.16	27.38
1961-1970	34.76	33.8	35	35.2	34	34.285	32.4	34.31	33.42	32.37	32.7	32.86	30.73	30.474	31.03	31.17	30.78	27.13
1971-1980	35.14	33.4	35.1	35.4	34	34.075	32.1	34.7	33.54	32.49	33.2	33.43	31.01	30.398	31.07	31.15	30.77	27.64
1981-1990	35.85	33.7	35	35.31	34.2	34.582	32.8	34.94	33.69	32.11	33.6	33.32	30.99	30.717	31.68	31.36	31.23	27.53
1991-2000	35.15	33.9	35.3	35.29	34.6	34.811	33.3	34.9	33.84	31.68	33.46	33.5	31.38	30.831	31.69	31.8	31.38	27.86
2001-2010	35.45	34.2	36	35.39	35.3	29.252	33.4	41.04	34.99	32.14	30.66	33.81	31.68	30.777	31.75	31.61	31.4	28.14
2011-2020	35.48	34.3	36	35.21	35.5	30.143	33.8	40.66	35.04	31.74	31.09	33.87	31.83	30.838	32.05	31.89	31.6	28.33
2021-2030	35.53	34.5	36.3	35.15	35.8	28.985	34.2	42.31	35.44	31.6	30.48	34.02	32.05	30.889	32.26	32.05	31.76	28.55

Relative Humidity

	Sokoto	Katsina	Nguru	Yelwa	Jos	Bauchi	Yola	Ilorin	Lokoja	Bida	Ikeja	Warri	PH	Calabar	Benin	Potiskum	Makurdi	Maiduguri
1951-1960		42.4	38.6	60.98		44.725	54.2		75.03	66.47	86.29	84.32			84.6			
1961-1970	42.64	39.6	35.6	59.37	47.3	44.033	53.8	76.58	74.67	64.62	86.32	84.62	83.97	85.875	84.78	41.26	71.06	43.77
1971-1980	41.36	38.4	34.8	59.83	47.8	45.304	55.7	74.9	73.2	64.37	81.28	84.75	84.12	86.248	84.27	39.11	70.05	38.98
1981-1990	41.5	36.4	37.6	59.24	50.3	46.175	54.5	73.28	72.37	64.73	79.29	83.78	83.31	84.133	82.6	36.57	68.94	37.49
1991-2000	44.14	36.3	37.3	63.13	52.8	52.254	56.6	72.43	72.63	64.02	79.92	83.24	82.54	84.692	83.14	40.11	68.39	39.95
2001-2010	45.11	38.3	38.3	60.13	53.2	54.032	1341	73.78	71.02	62.13	81.68	83.14	82.84	84.158	83.55	40.03	68.68	38.37
2011-2020	46.44	37.1	39.1	62.3	55.1	57.413	1131	71.9	70.69	62.51	79.5	82.38	82.09	83.471	82.89	40.33	67.87	37.64
2021-2030	47.8	37.1	40	62.96	56.7	60.51	1421	71.15	70.02	62.03	78.91	81.83	81.64	82.933	82.65	40.84	67.39	37.05

APPENDIX 6.

Diurnal data (1971) used for the study

	Mean Temperature							Relative Humidity			
	0600LST	0900LST	1200LST	1500LST	2100LST	0600LST	0900LST	1200LST	1500LST	2100LST	0600LST
STATION											
Bauchi	20.00	27.62	30.99	31.84	24.65	67.62	42.96	34.99	33.88	57.10	18.83
Benin	22.76	26.31	30.73	30.42	24.35	96.78	84.26	69.70	68.20	92.65	22.60
Bida	23.17	27.16	30.78	32.54	27.25	77.41	62.98	52.13	46.72	64.54	22.02
Calabar	24.03	26.22	28.95	28.80	25.48	97.06	85.17	72.19	72.35	92.57	23.87
Ikeja	22.75	25.91	29.31	29.42	24.08	96.81	82.71	70.70	70.20	93.70	22.59
Ilorin	21.51	25.74	31.27	31.84	24.53	91.42	74.04	31.68	50.09	75.98	21.16
Jos	17.41	22.91	25.60	25.79	20.02	65.37	44.87	35.50	37.66	58.09	16.47
Kaduna	18.79	25.17	29.37	30.46	22.82	74.43	55.60	43.95	40.35	60.90	18.08
Kano	19.56	26.43	32.68	34.06	24.33	61.83	43.24	19.68	29.93	50.15	18.29
Katsina	20.40	27.33	30.09	32.68	25.71	53.44	35.99	27.95	25.12	42.98	18.67
Lokoja	22.98	27.20	30.91	32.40	26.48	87.97	73.15	42.19	52.16	73.77	22.36
Maiduguri	20.25	29.25	28.59	34.43	24.63	60.81	39.24	20.19	26.99	46.83	18.78
Makurdi	22.28	27.42	32.30	32.39	25.14	85.01	68.35	23.13	50.04	73.76	21.60
Nguru	18.15	28.38	33.82	32.86	22.69	36.54	34.58	29.50			16.15
Port-Harcourt	22.31	26.46	29.08	29.03	24.56	96.40	82.98	71.18	69.67	91.17	22.13
Potiskum	20.13	28.07	32.83	33.46	24.75	32.88	38.89	30.59	27.09	47.90	18.06
Sokoto	22.24	28.40	33.27	34.73		49.94	37.70	29.34	25.70		19.97
Warri	23.02	26.62	29.82	29.26	25.33	97.53	84.09	71.17	72.00	92.90	22.89
Yelwa		27.23	31.13	33.24			59.19		41.10		
Yola	27.06	28.84	33.91	33.71	25.74	75.76	52.00	17.67	38.67	61.35	21.54
Total	21.57	27.00	30.61	31.78	24.60	73.61	58.19	46.04	45.05	67.31	20.38

Diurnal data (1971) (continued) used for the study

STATION	Effective Temperature Index 0900 LST	1200 LST	1500 LST	2100 LST	Temperature Humidity Index 0600 LST	0900 LST	1200 LST	1500 LST	2100 LST	Relative Humidity Index 0600 LST	0900 LST	1200 LST	1500 LST	2100 LST
Bauchi	23.50	25.33	25.80	19.27	18.77	24.42	26.86	27.50	22.55	-0.01	0.16	0.24	0.25	0.13
Benin	25.26	28.04	27.72	21.99	22.61	25.47	28.75	28.44	23.99	0.06	0.19	0.26	0.29	0.12
Bida	24.58	26.65	27.53	22.08	22.14	25.13	27.76	28.97	25.42	0.07	0.18	0.28	0.32	0.18
Calabar	25.22	26.76	26.61	23.11	23.89	25.42	27.30	27.15	25.11	0.07	0.18	0.27	0.27	0.12
Ikeja	24.98	27.03	27.01	22.01	22.60	25.10	27.60	27.62	23.77	0.06	0.19	0.30	0.29	0.11
Ilorin	24.09	25.47	27.27	19.42	21.17	24.39	27.00	28.56	23.33	0.02	0.15	0.24	0.31	0.11
Jos	19.96	21.39	21.51	16.03	16.24	20.33	22.20	22.41	18.30	-0.08	0.04	0.10	0.10	-0.02
Kaduna	22.42	24.88	25.34	18.25	17.92	22.91	26.01	26.71	21.00	-0.04	0.11	0.21	0.23	0.05
Kano	22.71	25.42	27.05	18.55	18.16	23.44	27.44	29.15	21.90	-0.02	0.14	0.27	0.27	0.09
Katsina	22.84	24.26	25.73	21.43	18.61	23.80	25.73	27.70	22.70	0.00	0.15	0.17	0.26	0.11
Lokoja	25.31	26.07	27.94	20.81	22.43	25.72	27.33	29.21	25.04	0.07	0.20	0.27	0.34	0.17
Maiduguri	24.51	22.60	27.12	18.97	18.73	25.66	24.00	29.31	22.01	0.00	0.21	0.15	0.31	0.09
Makurdi	25.18	25.47	27.74	19.64	21.64	25.67	27.35	29.07	23.81	0.05	0.20	0.25	0.33	0.13
Nguru	23.55	26.92			15.88	24.66	28.96			-0.05	0.18	0.30		0.00
Port-Harcourt	25.31	26.78	26.57	21.78	22.15	25.55	27.35	27.19	24.11	0.04	0.19	0.27	0.26	0.12
Potiskum	23.58	26.28	26.39	20.25	18.05	24.60	28.17	28.47	22.17	0.00	0.17	0.28	0.28	0.10
Sokoto	23.77	26.52	27.21		20.10	24.84	28.48	29.49		0.04	0.18	0.29	0.31	
Warri	25.53	27.31	26.96	22.73	22.90	25.76	27.96	27.55	24.66	0.07	0.20	0.34	0.29	0.20
Yelwa	24.40		27.54			25.00		29.21			0.18		0.32	
Yola	25.10	26.03	27.54	20.33	21.65	26.01	28.32	29.40	23.70	0.06	0.22	0.27	0.32	0.13
Total	24.08	25.87	26.69	20.22	20.36	24.70	27.14	28.13	22.99	0.02	0.17	0.25	0.28	0.11

Table 2. Diurnal data (2001) used for the study

	Mean Temperature					Relative Humidity					
	0600 LST	0900 LST	1200 LST	1500 LST	2100 LST	0600 LST	0900 LST	1200 LST	1500 LST	2100 LST	0600 LST
Bauchi	20.74	27.53		31.56	24.01	69.55	50.90		45.12	67.97	19.44
Benin	23.98	26.87		30.49	25.45	95.26	84.90		66.96	89.30	23.71
Bida	23.70	27.92		33.75	27.99	73.43	60.04		44.41	61.09	22.29
Calabar	23.74	26.72		29.51	25.69	96.30	85.11		70.21	87.47	23.53
IKEJA	24.41	27.36		29.97	26.12	95.23	83.26		70.14	89.39	24.13
Ilorin	22.59	26.29		31.97	26.42	89.17	73.64		48.65	67.63	22.11
Jos	16.75	22.98		25.68	18.97	70.64	50.54		45.63	65.58	16.16
Kaduna	19.87	26.02	30.04	31.16	23.90	66.78	49.07	40.15	37.60	56.42	18.74
Kano	20.31	26.28		32.48	25.46	64.10	47.27		34.44	52.17	19.03
Katsina	20.65	27.62		32.85	25.44	57.46	39.58		29.48	46.56	19.11
Lokoja		28.13		33.15			70.85		50.98		
Maiduguri	20.71	29.23		34.12	25.07	62.12	39.72		30.01	50.34	19.27
Makurdi	24.10	28.00		33.10		83.85	68.51		49.91		23.23
Nguru	22.25	29.14		34.25		50.86	36.76				20.10
Port-Harcourt	23.21	26.95		29.76	25.22	95.66	83.87		69.29	89.27	22.98
Potiskum		28.35		33.30			40.94		32.30		
Sokoto	22.64	28.18		34.99	27.43	56.10	43.88		31.18	47.02	20.61
Warri	24.33	27.48		29.86		95.68	83.96		72.79		24.08
Yelwa		27.92		34.34			56.53		41.59		
Yola	22.97	29.13		34.22	26.92	72.09	53.04		40.75	61.20	21.60
Total	22.17	27.47	30.04	32.19	25.31	76.13	59.09	40.15	46.92	66.51	21.18

Table 2 (continued). Diurnal data (2001) used for the study

	Effective Temperature Index (ETI)					Temperature-Humidity Index (THI)					Relative strain index (RSI				
	0600 LST	0900 LST	1200 LST	1500 LST	2100 LST	0600 LST	0900 LST	1200 LST	1500 LST	2100 LST	0600 LST	0900 LST	1200 LST	1500 LST	2100 LST
Bauchi	19.44	23.91		26.53	18.42	19.48	24.74		27.95	22.45	0.00	0.17		0.28	0.09
Benin	23.71	25.83		27.59	22.31	23.75	26.05		28.38	24.90	0.10	0.21		0.32	0.16
Bida	22.29	25.01		28.20	22.24	22.46	25.67		29.86	25.73	0.08	0.21		0.36	0.20
Calabar	23.53	25.70		27.03	22.12	23.56	25.91		27.67	25.02	0.10	0.21		0.29	0.16
Ikeja	24.13	26.17		27.48	22.86	24.17	26.43		28.12	25.56	0.12	0.24		0.32	0.19
Ilorin	22.11	24.54		27.21	20.86	22.14	24.89		28.56	24.65	0.06	0.17		0.30	0.16
Jos	16.16	20.26		21.90	14.38	15.87	20.63		22.70	17.67	-0.09	0.04		0.10	-0.05
Kaduna	18.74	22.66	25.09	25.67	18.84	18.64	23.33	26.37	27.16	21.81	-0.02	0.12	0.22	0.24	0.08
Kano	19.03	22.86		26.42	19.47	18.96	23.52		28.14	23.02	0.00	0.14		0.28	0.12
Katsina	19.11	23.36		26.28	20.10	19.03	24.28		28.15	22.74	0.01	0.17		0.28	0.12
Lokoja		25.98		28.38			26.47		29.78			0.24		0.37	
Maiduguri	19.27	24.55		27.16	19.26	19.23	25.68		29.24	22.59	0.02	0.21		0.31	0.11
Makurdi	23.23	25.68		28.23		23.34	26.21		29.67		0.11	0.23		0.36	
Nguru	20.10	24.32				20.19	25.47				0.05	0.21			
Port-Harcourt	22.98	25.83		27.14	21.99	23.01	26.07		27.83	24.67	0.08	0.22		0.30	0.15
Potiskum		23.94		26.81			24.96		28.70			0.19		0.30	
Sokoto	20.61	24.05		27.96	21.81	20.75	25.00		30.10	24.53	0.06	0.19		0.35	0.17
Warri	24.08	26.32		27.56		24.12	26.58		28.17		0.12	0.24		0.32	
Yelwa		24.75		28.34			25.46		30.17			0.20		0.36	
Yola	21.60	25.40		28.18	21.12	21.73	26.32		30.01	24.79	0.07	0.23		0.35	0.17
Total	21.18	24.54	25.09	27.11	20.44	21.20	25.19	26.37	28.54	23.59	0.05	0.19	0.22	0.31	0.13