AN ANALYSIS OF THERMAL COMFORT INDICES BASED ON THE TEMPERATURE - HUMIDITY INDEX OF ZARIA, KADUNA STATE, NIGERIA

BY

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DECLARATION

I hereby declare that this thesis entitled "An Analysis on Thermal Comfort indices Based on Temperature – Humidity Index in Zaria, Kaduna State, Nigeria" is record of my own research work under the supervision of Dr. B.A. Sawa and Mr. A.M. Yamusa

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this work has been submitted for the award of degree in any other university

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CERTIFICATION

This dissertation entitled "An Analysis of Thermal Comfort Based on Temperature – Humidity Index in Zaria, Kaduna State, Nigeria", by Garba Abdulkareem, meets the regulations governing the award of the degree in Masters of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This research work is dedicated to my Mother and late Father, my Brothers and Sisters.

ACKNOWLEDGEMENT

Firstly, I give thanks to God Almighty who gave me the life, strength and all the opportunities to undergo this programme.

My profound gratitude goes to my supervisors, Dr. B.A Sawa and Mr. A.M. Yamusa for their immeasurable support, commitment, criticisms and comments during the period of the study.

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ABSTRACT

The study revealed that the temperature and relative humidity range vary across the period of the study, in which 1998 has the highest maximum temperature range of 10^{o}C. And 1994 has the lowest minimum temperature range of 5.4^{o}C. this is associated with relatively large increase in daily maximum temperature than min temperature. Similarly, the Analysis of variance (ANOVA) for temporal variation in Temperature, Relative humidity and Temperature – Humidity Index, revealed 'f' calculated as greater than 'f' tabulated at 0.05 significance level. Temperature has f-calculated =4.12, RH=7.85 and THI=4.52. This is a clear indication that there is temporal variation in Temperature, Relative humidity and Temperature – Humidity Index. And the Time Series analysis established the trend in temperature, relative humidity and temperature – humidity index with a positive slope trend line equation of y=0.063× + 2409 for temperature, y=0.094× + 4327 for relative humidity and y=0.092× + 2997 for THI. This implies that on the average, in every additional year, temperature, RH and THI are increasing by their respective trend line equation. Relating THI and human comfort, it was observed that on monthly basis some THI values were within the 22 – 27 degrees Celsius comfort limit which indicates comfort periods while others were either below 22 degrees Celsius or above 27 degrees Celsius which indicates discomfort periods. Based on annual THI, is was observed that throughout the study period, the comfort limit was constantly higher than 22 – 27 degrees Celsius comfort limit for Zaria, thus there was thermal discomfort conditions throughout the study period. Also the result of correlation analysis with p-value .000, .001 and .000 for temperature, relative humidity and THI respectively, indicates that temperature, relative humidity and temperature - humidity index are correlated, which show that there is significant relationship between them. The study was conducted using secondary data. Daily minimum and maximum temperature and relative humidity data from 1975 to 2010 were sourced from the Institute of Agricultural Research Metrological Unit (I.A.R) Zaria. Data such as the monthly range of temperature and relative humidity were derived by subtracting lowest record of temperature and relative humidity from the highest record respectively; Data were also presented using line graphs and tables. Data were also analyzed using simple descriptive statistics and inferential statistics. The aim of this study was to determine the relationship between temperature, humidity and comfort index of Zaria metropolis. The objectives of the study include determining the monthly and annual range of temperature and relative humidity in the study area, examine the mean temporal variation in temperature, relative humidity and temperature – humidity index (THI), establishing the trend in temperature, relative humidity and temperature – humidity index, and finally, to examine the impact of THI on human comfort. Based on the findings in this research, it is recommended that the study area should establish a Specialized Research Programmes (SRP) in the aspect of thermal comfort indices, to encourage tree planting, urban planning to create space for free air movement, greening the environment. All these are measures to improve human comfort index in the area. They can be implemented through funding of such research by association of climate scientist and other organizations that have concern with climate change issue.

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Chapter One: Introduction

1.1 Background of the Study

Thermal comfort has been defined by many scholars including Associations of climate scientist, in various ways. For example; American Society for Heating, Refrigerating and Air conditioning Engineers (ASHRAE, 1981), defined thermal comfort as "the condition of the mind in which satisfaction is expressed with the thermal environment." As such, it will be influenced by personal differences in mood, culture and other individual, organizational and social factors. Based on the above definitions, comfort is not a state of condition, but rather a state of mind. Thus positive comfort conditions are those that do not distract by causing unpleasant sensations of temperature and humidity while in negative terms it's a state in which we are not conscious of being too hot or too cold.

Hensen, Dings and Van (1987), also defined thermal comfort as "a state in which there are no driving impulses to correct the environment by the behavior". Thermal comfort is defined as the physical state of the body rather than that of the environment (Fanger, 1970).

The definition of thermal comfort leaves open as to what is meant by condition of mind or satisfaction, but it correctly emphasizes that the judgment of comfort is a cognitive process involving many inputs influenced by physical, physiological, psychological, and other factors. However, thermal comfort has very important effect on people performing outdoor recreational activities. Since their effects are directly seen on human psychology, it has been accepted as an influential factor on man's intellectual, manual and perceptual performance.

Comfort index simply means that during those hours which fall under comfortable class, temperature, humidity and wind speed conditions are optimum for people to carry out light to

moderate physical activities without the constraints of weather (excluding rainfall). In other words, under the temperature conditions requisite for "comfortable" class, one feels naturally comfortable without the aid of any anthropogenic support system. Thus when it is said that certain months or periods of time include most hours under comfortable class, it implies that in these months or periods one feels comfortable in natural ambient surroundings and does not require temperature altering mechanisms such as fans, coolers or air conditioners. The concept of comfort index is most relevant to people who spend a substantial time outdoors during a day. These include pedestrians, cyclists, vendors, shopkeepers near roadside and most people from the lower strata of society who live in makeshift houses. Increasing ambient temperatures have been observed to be strongly related to mortality. It also directly affects the environmental pollution as "uncomfortable" conditions will require more usage of air conditioners in vehicles on roads which in turn leads to increased fuel consumption and increased emissions. Consequently, cooling energy demand in cities and towns are also dependent on this index

On the other hand, thermal sensations are different among people even in the same environment. Even though the sensors render the same results regardless of the geographical position where a measurement is being taken, this is not the case for all persons (McIntyre, 1980) Indeed, persons staying in very similar spaces, subjected to the same climate, and belonging to a common culture, issue very different opinions on thermal comfort due to the combination of a large number of factors that affect the perception of human beings. Subjects' diagnosis is therefore an indispensable tool to achieve an overall evaluation of the study parameters. Conventionally, thermal discomfort is treated as a subjective condition while thermal sensation is an objective sensation. Satisfaction with the thermal environment is a complex subjective response to several interacting and less tangible variables. In other words, there is really no

absolute standard for thermal comfort. In general, comfort occurs when body temperatures are held within narrow ranges, skin moisture is low, and the physiological effort of regulation is minimized. Comfort also depends on behavioral actions such as altering clothing, altering activity, changing posture or location, changing the thermostat setting, opening a window, complaining, or leaving a space. (American Society of Heating, Refrigeration and Air – Conditioning Engineers, (AHRAE, 2001).

Macpherson, (1962), defined the following six factors as those affecting thermal sensation: four physical variables: air velocity, air temperature, relative humidity, mean radiant temperature and two personal variables (clothing insulation and activity level, i.e. metabolic rate)

Ati (2002) defined temperature as the degree of sensible heat or cold within the atmosphere while relative humidity, as the ratio of the observed humidity mixing ratio to that which would saturate the air at the same temperature. In spite of the achievement of scientist through modern technology the comfort of human population is still influenced to a great extent by these two thermal indices: temperature and humidity.

Thermal comfort indices are diverse and usually applicable only in certain conditions, as defined by environmental ranges. This range of applicability is however only specified for some indices. Furthermore, analyses of these indices by ASHRAE, (1981) and Fanger, (1970), often conclude that they are applicable in a much narrower range of environmental conditions than claimed.

Many thermal indexes have been widely used to express the human comfort level on areas or time periods by the combination of meteorological and physiological data based on environmental conditions.

From records of previous studies and indices considered for Nigeria, it was suggested that temperature – humidity index (THI) is important as an index of thermal comfort in the tropics because it has the advantage of providing the combined effect of temperature and humidity on comfort within a narrow range of environmental conditions. The index also has the capability of giving direct rather predictive results of thermal comfort conditions relying only on temperature and humidity values. THI is also used to calculate human thermal conditions so as to assess the relationship between meteorological variables, such as air temperature and relative humidity.

Mcbride and Buiting (1971) maintained that the apparatus for measuring and indicating the comfort index of an ambient atmospheric environment is subject to variations in dew point and dry bulb temperature. The temperature so indicated is the measured comfort index. In this study, Human comfort level therefore, is the range of temperature and humidity conditions that most people will find comfortable most times. These same thermal indices have been used to study how this relationship affects human health and activities. For example, Giles, Balafouts, and Maheras, (1990) analyzed how heat waves in Greece affected citizens of Athens and Thessaloniki, who experienced little relief even during the night hours.

A combination of high temperature and high relative humidity to most people could be stressful and detrimental to health. It is obvious from the study conducted by Giles, Balafouts and Maheras (1990) that factors that could be responsible for human thermal discomfort in any environment, temperature and humidity could be among others since its effect could be felt directly or indirectly. But the extent of its impact can vary based on location, region or zone.

1.2 Statement of the Research Problem

With the current rate at which the concerns of the effects of thermal comfort indices on man and his livelihood has translated into research, many researchers have attempted to understand the views, severity and implication of these effects as well as seeking to understand how people cope with them. (Jauregui, 1993). Temperature and humidity are sensitive environmental problems that are attributed to our mismanagement of environmental resources and ozone depletion (Ogbuene, 2012).

The climate of an area is largely determined by the influence of a succession of meteorological systems. The city has to a large extent, concentration of anthropogenic heat and moisture sources. Wei-wu, et al (2004)

An understanding of the nature of thermal comfort index of a region or area is very important. This ensures a pleasant and healthy environment for the dwellers and to support the climate scientist in their task of ensuring that various ways of coping strategies and mitigation methods are put in place

The climate is always changing. Some climatic changes are small, and could practically not be noticed from one year to another. However, others like extreme heat, cold periods or drought can adversely affect the comfort of people. If the constituents in the atmosphere blocked out some of the incoming sunlight or prevent and additional quantity of terrestrial infrared energy from escaping into the space, global climate could be altered (Abhishek and Colls, 2010).

Ogunsote and Prucnal (1988) compared various thermal indices to determine which one is most reliable in the prediction of thermal stress in Zaria. The thermal indices compared were the Mahoney scale, Evans scale, Bioclimatic chart and the Effective Temperature (ET). The

indices were ordered by ranking them according to their ability to predict thermal stress using frequency analysis, ordinal and interval-level analysis. They designed questionnaire to record thermal stress on a five-point scale along with other information such as location, date, time, age, sex, weight and dressing of subjects; and climatic conditions; wind, cloud cover and shading. The thermal stress experienced for various conditions and the predicted thermal stress for the same conditions were recorded using the thermal indices. They compared the recorded and predicted thermal stress and found out that Evans scale; which incorporates the effects of relative humidity, air movement, metabolic rate and clothing as the best index for the prediction of thermal stress in a wide range of environmental conditions. Two comfort limits; 22-27 and 20-25 were used to obtain different but related scales.

Their predicted thermal stress was only applicable to the majority and not the whole population of Zaria.

The problem with their method was that thermal stress was applicable to the majority and not the whole population. And the field study only covered 3months.

It is on this backdrop that this study focused on analysis of thermal comfort based on the temperature – humidity index of Zaria for a period of 36 years. Comfort limits; 22 – 27 degrees Celsius was also adopted as the temperature and humidity range for Zaria (tropical area). This study was therefore based on the following research questions:

i. What is the temperature and humidity range for Zaria?
ii. Is there any temporal variation in the distribution of temperature, relative humidity and temperature – humidity index in the study area?

iii. What is the trend in temperature, relative humidity and temperature – humidity index?

iv. How have the thermal indices impacted on human comfort?

1.3 Aim and Objectives

The aim of this study is to determine the relationship between temperature, humidity and comfort index of Zaria metropolis. This was achieved through the following specific objectives to:

i. Investigate the monthly and annual minimum and maximum temperature and humidity range for Zaria
ii. examine the temporal variation in temperature, humidity and temperature - humidity index of the study area
iii. establish the trend in temperature, relative humidity and temperature – humidity index.
iv. examine the impact of THI on human comfort.

1.4 Research Hypotheses

The Hypotheses formulated in the study is two folds.

1. Ho = There is no significant difference in temporal variation in temperature, relative humidity and temperature – humidity index (THI) in Zaria.

11. Ho = There is no significant relationship between Temperature, Relative humidity and Temperature – Humidity Index (THI)

1.5 Scope of the Study

In terms of spatial extent, this study is limited to Zaria metropolis in Kaduna state. The data were sourced for 36 years (1975 - 2010). The study analyzed temperature and humidity range, trends, and it focused only on temperature – humidity index (THI) as a measure of human thermal comfort conditions. It also used comfort limits of 22 – 27 degrees Celsius for the Tropical Areas.

1.6 Justification of the Study

The need to examine the issue of Thermal comfort indices such as temperature and relative humidity in Zaria becomes imperative considering the fact that temperature and relative humidity in the study area are largely seasonal and vary highly from year to year. The diurnal range of temperature varies from 9.4^{o}C to 6.7^{o}C. The mean daily maximum temperature is about 26.7^{o}C to 28.9^{o}C while the relative humidity is very high in August about 70-80 percent (Hore, 1979). Four distinct seasons are observed, dry season "Harmattan," November to February, Hot season, March to April, Thunderstorm and rain season, May to June and wet season, July to October. However, these thermal comfort indices vary and this is a factor of the present global climate change, which awakened the interest of this study.

The major focus of this study seeks to provide insight into human thermal comfort index in Zaria. The study hopes to investigate the temperature and humidity range for the study area, and to also examine the trend of temperature and humidity, and the impact of temperature – humidity index inclusive. The trend will show how the changes in temperature and humidity influence comfortable periods of the months over the period of the study. The information

gathered can give information about forecasting future values of temperature and humidity and temperature – humidity index.

Chapter Two: Conceptual Framework and Literature Review

2.1 Introduction

This chapter looked at an overview of the historical background of thermal comfort, its conceptual advances (including classification of thermal comfort, indices of thermal comfort, theories and factors that influence thermal comfort. The review also include use of index of thermal comfort (THI), use of standard comfort limits for the tropics and the various impact of temperature, humidity on thermal comfort.

2.2 Historical Background of thermal Comfort

Socrates around (400BC) had some thoughts on the climatic suitability of houses on how to build to ensure thermal comfort. Vitruvius (1st century BC) also wrote about the need to consider climate in building design, for reasons of health and comfort. this however had very little influence on the practice of architecture. Up to the industrial revolution thermal comfort was not a practical issue as there were only tool at disposal to influence it. When it was cold a fire was lit to ameliorate the condition. When it was hot, the use of hand held fan was the only relief, or larger fans operated by obedient servants. The heat storage capacity of caves was sometimes used for cooling or in some cultures man made tunnels for ventilating towers were used for similar purposes

According to Bedford (1961) and Markus and Morris (1980), work on thermal comfort started as early as 1733 AD when Arbuthnot pointed out the chilling effects of wind through dispersal of the layer of warm, moist air around the body. Heberdeen (Early 19th century) recognized that air temperature is not the only cause of thermal sensation that humidity is a

contributing factor. The first very serious studies on thermal (especially the effect of high temperature was carried out by Haldane in England (1905). The research came from engineers where it was possible to overheat or overcool buildings.

Heating technology improved from the late 18th century on wards. .and mechanical cooling became possibility early 20th century..

In early 1920s Houghton and Yaglogou (1923) attempted to define thermal comfort zone in England. Motivation came from Industrial hygiene, the limits of environmental conditions.. Analytical works on thermal comfort started in the United States in mid 1930s. Harrington and Gagge (1937) made significant contributions.

It was in 1956 that other serious studies on local thermal comfort background began, when Kerka and Humphreys began their studies of indoor environment. Ever since then man has had special interest in controlling indoor environment.

1963 was the first bring together finding on the various thermal comfort studies. Mechanical cooling became possibility early 20th century. Twenty first century researches on thermal comfort include that of ASHRAE (2004) 55 Standard, which dwelled on thermal environmental conditions for human occupancy and ISO 7730 (2005) that is International Standard Organization which analyzed the determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.

2.3 Thermal Comfort Approaches

There close relationship between human and the thermal environment. This means that there is relationship between human and the thermal environment requires a more comprehensive

consideration. However, range of comfort conditions of people laid the foundation for relating thermal comfort indices with comfort range for people in the tropical areas.

Although, there is no absolute standard of thermal comfort, of course this is not surprising, as human can and do live in a range of climates from the tropics to high latitudes. Since this is so, it becomes obvious that perception of the environment is affected by thermal indices such as temperature, relative humidity, air velocity etc. A controversy between the heat balance approach and the adaptive approach have dominated the development of thermal comfort science

2.3.1 Heat Balance Approach

The current International thermal comfort Standard has combined the theory of heat transfer with physiology of thermoregulation to determine a range of comfort temperatures which people can find comfortable. The range is determined by "Predicted Mean Vote" derived from studies of individuals. The purpose of this is to advance technology for the public through research, standards, writing etc.

2.3.2 Adaptive Approach

This is based on field surveys of thermal comfort and can be used to demonstrate how tolerant of temperature changes people can be than the laboratory experiments. When people consciously or unconsciously act to attract heat balance of the body, the action may change metabolic heat production in individuals. However, measurement of comfort level can be complex but it is achievable using thermal indices proposed over the years. E.g., Effective Temperature (ET), Temperature – humidity index (THI), Relative Stress Index (RSI). Heat Index (HI)

This chapter looked at an overview of the historical background of thermal comfort, its conceptual advances (including classification of thermal comfort, indices of thermal comfort, theories and factors that influence thermal comfort. The review also include use of index of thermal comfort (THI), use of standard comfort limits for the tropics and the various impact of temperature, humidity on thermal comfort.

2.4 Advances in Thermal Comfort Determinations

A substantial step toward discerning the underlying issues of thermal comfort can be achieved through several indices of comfort and mathematical models, especially by relating thermal variable e.g. air temperature and humidity to the prediction of thermal comfort and discomfort. Results of several regional and national studies on thermal comfort have appeared in geographical, meteorological and ecological literature for example studies on temperature and humidity (Arundel, Sterling, Biggin, 1986; Gomez, Gil, Jabaloyes, 2004; Watkinson and Hulme, 2004; Kiang, Adimi, Soika, Nigro, Singhasivanon, et al (2006)

Today outdoor human thermal comfort conditions are widely defined and determined using different approaches. These approaches are foundation upon which many conceptual advances relevant to thermal comfort studies which address pertinent issue to understanding environmental conditions, for example Fanger, 1970; Physiologically Equivalent Temperature (PET), and The Man-Environment heat Exchange model. Blazejczyk, 2005; simple and complex calculations indices (Temperature humidity Index (THI). Thom, 1959; Predicted Mean Vote (PMV), Gagge *et al.*, 1971) Standard Effective Temperature (SET). Matzarakis, Rutz and Mayer, 2000; computerized models

In spite of the large quantity of thermal comfort calculation indices, they can be classified into two main groups, these include: Complex Indices which are more recent, promoted by the late development of computing techniques, and rely on the human energy balance" (Ali –Toudert, 2005).

Simple Indices, such as THI, which take the combined effects of a few meteorological parameters e.g. air temperature; and relative humidity; and "ignore the decisive role of human physiology, activity, clothing and other personal data (height, weight, age, sex). The values of THI could give simple and precise results by which some opinion about the condition can be gained as in other studies such as Jauregui (1991).

2.5 Approaches to Quantification of Thermal Comfort Level

There are various approaches for quantifying comfort levels in terms of temperature and other meteorological variables. The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE, 1955) developed the concept of "effective temperature" as "an empirically determined index of the degree of warmth perceived on exposure to different combinations of temperature, humidity and air movement".

Epstein and Moran (2006) argued that different bioclimatic indices have been proposed to integrate the effect of environment on the human thermal comfort. These indices can be categorized into three different groups' viz. "rational indices", "empirical indices", and "direct indices". Rational indices are based on heat balance equation of the human body which accounts for the environmental variables such as ambient temperature, radiation temperature, humidity and air movement as well as metabolic processes and clothing insulation for human body. Most commonly used indices are physiological equivalent temperature (PET)

Hoppe, (1999) included Universal Thermal Climate Index (UTCI) in his thermal comfort studies. Empirical indices are based on objective and subjective strain response data obtained on individuals and group of individuals exposed to various levels and combinations of environmental and metabolic heat stress factors e.g. Effective Temperature and Wet Bulb Globe Temperature. Yaglou and Minard (1957) argued that direct indices are based on direct measurements of environmental variables.

Popular direct indices include Discomfort Index (DI) of Thom, (1959) which defines proportional effect of dry bulb temperature and wet bulb temperature (in ^{0}F) over human thermal comfort, Wind Chill Index which was created by Siple and Passel (1945) and later on refined by Steadman and the apparent temperature of Steadman or heat index .

Epstein and Moran (2006), argued that while rational and empirical indices are more comprehensive, they are also difficult to implement as they evolve many variables and some of them require invasive measurements. Direct indices, on the other hand, are more practical and applicable to indicate thermal stress as they require simple monitoring of environmental variables which makes them user-friendly. Mohan and Bhati (2009) analyzed thermal comfort classification with the assessment of direct indices for different megacities in India which addressed a suitable methodology to represent the thermal comfort conditions of a given city in terms of their assessment. This could help compare the climatic conditions of various cities broadly for the purpose of tourism, health and energy resource management. Here thermal comfort index was adopted to demonstrate the proposed methodology that includes cumulative representation of all indices including uncomfortability to assess the overall local climate and for relative ranking of the cities. The cumulated indices methodology was chosen due to the fact that the routine meteorological parameters such as temperature, wind speed and relative humidity

were adequate and readily available. All these indices signify that essentially, wind and relative humidity play pivotal role in determining how cool or warm it might appear for a given temperature level. This is because the rate at which heat is dissipated from the human body through skin determines how warm one feels in summer season or how cold one feels in winter. Thus, there can be a difference between the actual ambient temperature and one that the human body feels. It is important to have knowledge of this "apparent temperature" as it often aids in scheduling outdoor activities and deciding optimum temperature levels in many workplaces. This can be quantified in terms of a "Comfort Index".

2.6 Temperature – Humidity Index

Temperature Humidity Index (THI) is a measure developed by Earl (1959), which has been in use since then. The index accounts for the combined effects of environmental temperature and relative humidity, and is a useful and easy way to assess the risk of heat stress. It however, has some limitations. It does not indicate the effect of other environmental conditions on thermal comfort. However, Epstein and Moran (2006) conducted a study on thermal comfort and heat stress indices. They reported that the level of risks corresponding to given heat stress were classified according to the THI values as follows (safe) 27^{o}C (heat fatigue is possible with prolonged exposure to activity) 32^{o}C (sunshine and heat exhaustion are possible with prolonged activity

Gawith, Doening and Karacostas, (1999) using the temperature humidity index (THI) and a THI threshold of 84, above which the majority of a mid-latitude population would feel discomfort, found for Thessaloniki that the frequency of hours of discomfort will increase markedly by 2050. Only a few years exceed 50 hours at present but over 100 years will exceed the THI 84 threshold by 2050.

Oludoyin and Adelekan (2013) studied the spatial and temporal variations in thermal climate of Nigeria, using the values of the indices Effective Temperature (ET) Relative Strain Index (RSI) and Temperature – Humidity Index (THI). They estimated the values of these indices from the respective records of Temperature and relative humidity for each station, and for different period. However, the value of indices of thermal climate (THI) that is above or below threshold for comfortable was 15 – 24^{o}C. Therefore, heat was said to occur when THI is greater than 24^{o}C. Cold stress occurs with THI less than 15^{o}C

2.7 Factors Influencing Thermal Comfort

Researchers have shown that thermal indices have effect on human thermal comfort and they include; air temperature, relative humidity, radiation, air velocity. From the works of Heisler and Wang (2002) environmental condition are important factors influencing human thermal comfort. They are summarized as follows:

2.7.1 *Radiation*

Radiation is the net exchange of radiant energy between two bodies across an open space. The human body gains or losses radiant heat, for example, when exposed to an open fire, the sun or a window on a cold winter day. The rate of radiant transfer depends on the temperature differential, the thermal absorptive of the surfaces, and the distance between the surfaces

2.7.2 *Air Temperature*

Air temperature becomes a great distraction if it is either too hot or too cold. If people are sweating a lot, their main focus would be both uncomfortable and their perception of worrying about sweating, getting water to drink and getting up and moving to help evaporate some heat. All of these can't be good for concentration towards one's daily activities.

Excessive sweating can lead to painful muscle spasm called heat cramp, or to, heat exhaustion, which has many symptoms including excessive thirst, dizziness and nausea. Both can be treated by drinking cool water and resting in a cool place. But, heat stroke requires urgent medical attention a body's thermostat stops working, so sweating is significantly reduced and the body's temperature becomes very hot (sometimes over 40^0C). (bbc.com.uklinks, BBC Health; Retrieved May 17, 2008). Several investigations have shown that variation in the heat indices especially temperature; have significant relations with human mortality (Kalkstein and Smoyer, 1993; Alcamo, Moreno, Nov'aky, Bindi, Corobov, et al, 2007; Lin, Ho, Wang, 2011). With global increase in temperature, especially from the 1960s and the tendency for further warming (Le Treut, Somerville, Cubasch, Ding, Mauritzen et al, 2007), as well as the concern for the increased urbanization in developing countries, concerns for thermal comfort have become important in the programme of the World Meteorological Organization (Taha, 1997). Of other environmental conditions, temperature is the most obvious, thus affecting human comfort index. Luber and Prudent (2009) described global temperature increase due to the effect of the urban 'built' environment as a major cause of Urban Heat Island (UHI). It absorbs heat during the day and radiates it out at night, raising nighttime minimum temperatures, which have been epidemiologically linked to excess mortality (U.S Environmental Protection Agency, 2006)

2.7.3 *Relative Humidity*

Humidity affects thermal comfort indirectly by altering the rate of evaporation of sweat in warm environments. The fraction of the body surface wet with perspiration, necessary to maintain the evaporative cooling for temperature regulation is a measure of the stain indirectly caused by humidity. In cold environments low humidity may cause discomfort from dehydration

of the skin surface and membrane of eye, nose and throat (Gagge, 1979: Kalkstein and Valimont, 2008).

Barradas (1991) argues that during the process of transpiration plants release water vapour to the surrounding, making humidity to increase and temperature decrease. Therefore, temperature becomes a great distraction if it is either too high or too low. All of these can't be good for concentration towards one's daily activities

2.7.4 *Air Velocity*

Air motion significantly affects body heat transfer by convection and evaporation. Air movement or velocity results from free (natural) and forced convection as well as from the occupants bodily movements. The faster the motion the greater the rate of heat flow by both convection and evaporation. When ambient temperatures are within acceptable limits, there is no minimum air movement that must be provided for thermal comfort. The natural convection of air over the surface of the body allows for the continuous dissipation of body heat. When ambient temperatures rise, however, natural air flow velocity is no longer sufficient and must be artificially increased, such as by the use of fans. Insufficient air motion promotes stuffiness and air stratification.

Stratification causes air temperatures to vary from floor to ceiling. When air motion is too rapid, unpleasant drafts are felt by the room occupants. The exact limits to acceptable air motion in the occupied zone are a function of the overall room conditions of temperature, humidity, and Mean Radiant Temperature (MRT), along with the temperature and humidity conditions of the moving air stream. A noticeable air movement across the body when there is perspiration on the skin may be regarded as a pleasant cooling breeze. When the surrounding surface and room air

temperatures are cool, however, it will probably be considered a chilly draft. The neck, upper back, and ankles are most sensitive to drafts, particularly when the entering cool air is 3^0F (1.5^0C) or more below normal room temperature. Every 15 fpm increase in air movement above a velocity of 30 fpm is sensed by the body as a 1^0Ç temperature drop. Air systems are usually designed for a maximum of 50 fpm in the occupied zone, but that is typically exceeded at the outlet of air registers.

Cool air can impinge on an occupant in two general cases: Air that is warm when introduced into the room may cool off before reaching the occupant, or the air is intended to cool the occupant under overly warm ambient conditions. In either case, when the temperature of the air impinging on an occupant is below the ambient temperature, the individual becomes more sensitive to air motion and may complain of drafts. Therefore, careful attention must be given to air distribution as well as velocity. The tendency of warm air to rise can greatly affect occupant comfort due to convective air motion, and thus influences the correct placement of the heat source in a room. Air outlet design is determined by the air distribution pattern it is intended to create.

2.7.5 *Clothing*

Another determinant of thermal comfort is clothing. In the majority of cases, building occupants are sedentary or slightly active and wear typical indoor clothing. Clothing, through its insulation properties, is an important modifier of body heat loss and comfort. The insulation properties of clothing are a result of the small air pockets separated from each other to prevent air from migrating through the material. Newspaper, for example, can serve as good insulation if several sheets are separated so that there are layers of air between the layers of paper; this can be used as crude, but effective, emergency blanket to cover the body. Similarly, the fine, soft down

of ducks is a poor conductor and traps air in small, confined spaces. In general, all clothing makes use of this principle of trapped air within the layers of cloth fabric.

Other factors that may have some effect on thermal comfort are age, sex, body shape, state of health, ethnic grouping, diet, sleep, colour of clothing, acclimatization, availability of fresh air, transients, colour of a space enclosure and noise. The way the minor factors listed above affect comfort is not well understood. Fanger, Breum, and Jerkings (1975), among others, however claims that the effect of ethnic grouping, colour of a space enclosure and noise are negligible. An indication of the relative importance of these other factors, is the fact that when all the six major factors are within the acceptable and optimal range, about 70% of the population would be comfortable

2.8 Literature Review.

In the past, many works have been conducted on finding practical methods for predicting the effects of a particular thermal environment in terms of comfort or discomfort. However, some of these studies were based on either indoor, outdoor, steady- state or transient thermal comfort. This present study has adopted a conceptual framework that link thermal comfort and human range of comfort level with meteorological elements. Reviews and summaries of this were made by Hardy (1970), Fanger (1972), Benzinger (1979), McIntyre (1980) and ASHRAE (1985). From these references there is much evidence from thermal sensation studies that environmental parameters have strong relationship with thermal comfort. These relationships are the basis for methods like Fanger's (1972) Comfort Equation and the work of Gagge and Gonzalez (1973). For Western and South Pacific Islands, McGregor (1995), has shown that climate change related increase in temperature and humidity will result in changes in frequency, duration and intensity of physioclimatically stressful periods.

Most thermal comfort studies carried out have been devoted to determining thermally comfortable temperatures in various settings, in climates ranging from temperate to tropical. Several studies on the thermal comfort in an equatorial (tropical) climate were carried out as early as in the 1950s. Webb (1959), conducted a study in Singapore and derived an equatorial comfort index which was based on the dry and wet bulb temperature and wind speed. Ellis (1952) also carried out a study in Singapore and concluded in his that the levels of thermal comfort were similar for acclimatized European and Asian men and women.

After that, McNail et al (1967) derived a linear relationship between activity levels and sweat rate

Later, Fanger (1970) described thermal comfort as the balance between heat flow from the body in a given thermal environment and heat flow required for optimum comfort (i.e neutral). Again, Fanger (1972) described the general thermal comfort as a material and energy balance being the bases of the actual general thermal comfort research.

Cain et al (1983) studied the impact of temperature and relative humidity on perception of air quality. And then Fang and Fanger (1998) carried out an experiment using chamber with clean air heated to 18^{o}C and 30% relative humidity

2.9 Heat Balance Thermal Approach.

For a pure steady- state steady-state conditions are rarely encountered in practice. For example, Madsen (1987) found indoor temperature fluctuations between 0.5 ^{0}C and 3.9 ^{0}C (during 24hours with a constant set point) which depended on the combination of heating and control system. Sometimes it may even be advantageous to allow the environmental conditions to change.

This was demonstrated in a field experiment (Hansen, 2004) where it was found that decreasing the acceleration heating of the room thermostat in a dwelling resulted in lower fuel consumption. This led however to considerably increased variations in indoor temperature, but it was not clear at the time whether these fluctuations would be acceptable or not to inhabitants

Following these results the tolerated range of temperatures decreases with increasing fluctuation rates. This seems to be contradicted by work of Wyon, Bruun, Olesen, Kjerulf-Jensen and Fanger (1971) who performed experiments in which the amplitude of the temperature swings was under the subjects' control. They found that subjects tolerated greater amplitudes when the temperature changed more rapidly. In their view this was due to purely physical reasons, as rapid changes of ambient temperature cause skin temperature, and hence thermal sensation, to lag

further behind in time and this effectively reduced the experienced temperature fluctuations. It was also found that subjects tolerated greater amplitudes when performing mental work than when resting. McIntyre and Griffiths (1974) later pointed out that due to a much smaller rate of change of the mean radiant temperature, when compared with the air temperature, and unusual acceptability criteria (spontaneous dial voting when the temperature was too hot or too cold) the tolerated range in operative temperature was actually smaller than normally found in steady-state conditions.

2.10 Cyclical Temperature Change

Later experiments of Wyon, Asgeirsdottir, Kjerulf-Jensen, and Fanger (1973) were designed to investigate the effects on comfort and performance of predetermined ambient temperature swings under more normal working conditions. The subjects (N = 16; student age; M = 1.2 met; Icl = 0.6 clo; v < 0.1 m/s) were exposed to sinusoidal swings around the average preferred ambient temperatures with peak to peak amplitudes in the range 2 to 8 K and periods ranging from 32 to 8 minutes (i.e. 1.9 to 7.5 cycles/hour), resulting in fluctuation rates between 15 K/h and 60 K/h. Certain complications resulted in considerable damping (up to 75%) of the amplitude of the temperature swings below head level. Also the actual amplitudes of the mean radiant temperatures were lower than half of the intended amplitudes. The authors state that for these reasons the experiments are probably best regarded as an investigation of air temperature swings at head height. From the results they concluded: "Large temperature swings caused increased discomfort" and "Large ambient temperature swings appear to have a stimulating effect that is to be preferred to the apparently opposite effect of small temperature swings, but a constant, optimally comfortable temperature, where this can be achieved, would still seem to be preferable to either". To be able to compare these results with the other references, Wyon’s raw

data was examined. This revealed that 80% of the votes were in the comfort zone for all swings with intended peak to peak amplitudes of 4 Kelvin or less. As indicated above, this actually suggests maximum acceptable peak to peak amplitudes of operative temperature fluctuation for the whole body in the range 1 to 2 Kelvin. Experiments with large ambient temperature swings were also conducted by Nevins, Nevins, Gonzalez, Nishi, and Gagge. (1975). The subjects (N = 18; different ages; M = 1.2 met; Icl = 0.6 clo; rh = 50%; v = 0.25 m/s) were exposed to ambient temperature (Ta = Tr) swings with a peak to peak amplitude of 10 K and an average fluctuation rate of 19 K/h (0.9 cycles/hour). The mean ambient temperature was 25 ^{0}C.

From the results it was concluded that the preferred ambient temperatures for comfort agreed well with the results of earlier steady-state experiments (on which for instance ASHRAE 1974) is based) and that there was no clear evidence of an increased or decreased range of acceptable ambient temperatures due to fluctuation. An examination of Nevins' raw data however suggests maximum acceptable peak to peak amplitude of about 2.8 K. This is a little less than the width of the comfort zone for steady-state conditions. It should be noted that when unacceptable temperatures are left out, a rate of temperature change of 19 K/h would have resulted in a fluctuation frequency of about 3.4 cycles/hour or alternatively 0.9 cycles/hour would have resulted in an average rate of change of 5 K/h.

2.11 Energy-Plus Thermal Comfort

In a recent evaluation by Doherty and Arens (1988) it was shown that these models are accurate for humans involved in near-sedentary activity and steady-state conditions. From the fact that the skin thermoreceptors not only sense temperature but also the rate of temperature change and that thermal comfort depends on an integrated value of central and peripheral temperatures

Hwang and Lin (2007) conducted a survey in order to determine the thermal comfort range of Tourist in Taiwan. They used results from a field study based on 1644 interviews in the outdoor environment. The basic information on the person's activity level and clothing were obtained. Secondly, objective measurements of ambient air temperature, globe temperature (measured by standard globe), air humidity, air velocity and global radiation were carried out, which were then used together with the activity and clothing level to calculate the (Physiological Equivalent Temperature). Also the interviewed person was asked to subjectively evaluate thermal sensation vote (TSV), thermal preference, and thermal acceptability. TSV ranged from -3 to $+3^0$C indicating cold, cool, slightly cool, neutral, slightly warm, warm and hot. Moreover, thermal acceptability indicated whether respondents considered the current thermal environment "acceptable" or "unacceptable

Yuk Yee and Oliver (1995) opined that a number of indices have been advised to assess human comfort under a variety of atmospheric conditions. In the USA the most widely used, particularly by the broadcast media, are wind-chill for cold conditions and Heat Index for hot. Both provide measures of instantaneous conditions and are useful as weather stress guide. Thereafter, the Clothing (CLO), a measure of comfort that provides an indication of the clothing required under a given set of conditions is examined as a potential alternative comfort index to those in current use. Derived many years ago, the CLO expresses the resistance to heat transfer by clothing and is expressed relative units of thermal insulation. Derived CLO values are compared with values of Heat Index and wind-chill for the same data set at a selected station and significant relationships are obtained. The result indicates that CLO value could be used as an alternative to the current weather stress. The CLO, however, may be used as a guide to relative

comfort representing long-term average as well as extreme, instantaneous atmospheric conditions. It serves as climatic index by providing a seasonal clothing index

Nyuk and Shan (2003) concluded from their field study conducted in Singapore, that for classrooms mechanically ventilated by fans the acceptable temperature ranges are from 27.1ºC to 29.3ºC, implying that the ASHRAE (1981) Standard 55 is not applicable in the free running buildings in the tropical climate. The neutral temperature was recorded to be 28.8ºC by regression analysis of Thermal Sensation Votes (TSV) on operative temperature.

2.12 Thermal Comfort (Sub-Saharan Africa)

Researchers such as Eludoyin and Adelekan (2013) Conducted a research on air temperature, relative humidity, climate regionalization and thermal comfort of Nigeria using tropical wet and dry-climates, along with thermal indices such as temperature humidity index (THI), Relative Strain Index (RST) and Effective Temperature (ET). They concluded that variation in both temperature and relative humidity increased from South towards the North, and that variation in ET is greater in the Sahel (Nguru) and a station in the Sudan Savanna (Potiskum) But in terms of THI, this region was shown to be thermally comfortable, while the montane location was also classified as most comfortable

Abdulrahim, Richard, Olajide and Emmanuel (2012) examined thermal stress and physiological comfort in Maiduguri, Nigeria using thermal heat stress index as a measure of human comfort. Dry-bulb temperature, Relative humidity, and Air velocity were measured in three observatory sites (class room, under neem (azadirachta indica) tree and under direct sunlight within the Faculty of Engineering University of Maiduguri, Nigeria between the hours of 7.00 am and 5.00 pm on some days from October to December 2010 in order to establish the physiological responses to thermal stress and disorder. The data were analyzed using Effective

Temperature (ET) and Relative Stress Index (RSI). The mean ET obtained vary from 23.58^{o}C to 31.18^{o}C, while the RSI values vary from 0.12 to 0.49 for the period just after the raining season. And for the harmatan period, the mean ET vary from 19.31^{o}Cto 29.09^{o}C, while the RSI values vary from-0.01 to 0.38. The results showed that the three locations are generally comfortable during the morning hours and become uncomfortable as the day progresses. The class room was found to be the most comfortable during the period of the investigation while the location under the sun recorded the highest level of discomfort in both seasons.

2.13 Adaptive Thermal Approach (tropical humid climate)

A thermal study was conducted in the sub-Saharan Africa by Harris and Ogbonna (2006). The study was carried out at Jos, Nigeria, a city in the tropical-savannah region. From this study, a mean relative humidity value of 72.1% was recorded. The neutral temperature obtained by regression analysis of Predicted Mean Vote (PMV) was 26.3ºC.

2.14 Thermal Comfort (Tropical Humid Climate)

Ogunsote (2002) used Effective Temperature Index (ETI) which takes the combined effect of temperature, humidity, air velocity and clothing, to compare various comfort limits and to determine which one is most reliable in the prediction of thermal stress in Zaria. He designed a mental assessment test using rating scales which has the advantage of providing the actual climatic conditions of the environment. Various subjects rated comfort under varying conditions; in different places, on different days and at different times. Thermal stress experienced for various conditions were recorded and then he predicted the thermal stress for the same conditions using nine comfort limits; 19-25, 20-23, 20-24, 20-25, 20-26, 20-27, 22.5-25.5, 22-27 and 24-29 degrees Celsius. The ranking of the various comfort limits was done based on their ability to predict thermal stress. From his observed comfortable conditions, comfort limit that tend to

predict cold discomfort would accumulate negative errors of prediction while comfort limit that tend to predict hot discomfort will accumulate positive errors of prediction. The highest correlation was shown by comfort limits 20-25, therefore, he concluded that the optimal comfort limits was consistently lower than the 22-27 degrees recommended by Koenigsberger, Ingersoll, Mayhew and Smokolay (1974). His summary indicated that the optimum comfort limits for thermal stress using Effective Temperature for Zaria are 20-25 degrees Celsius, and the comfort limits recommended by Koenigsberger, Ingersoll, Mayhew and Smokolay are comparably poor in predicting thermal stress in the study area

This study used 22 - 27^{o}C comfort limit and THI values for the period of 36 years to estimate thermal comfort range for Zaria. No questionnaire was used because the study involved investigating the quality of THI on thermal comfort conditions In Zaria and not quantifying thermal comfort. .

Chapter Three: Study Area and Methodology

3.1. Introduction

This chapter presents the study area in terms of its location, position and the general characteristics of the area (climate, relief and drainage, vegetation, geology, soils, people and population). It also describes the method used in data collection and analysis

3.2 The Study Area

3.2.1 Location

The study area, Zaria (Fig. 3.1), is located between Latitudes 11°3'N and $11^0$15'N and Longitudes 7°30'E - $7^0$45’E. It lies on the North Central Highland at a height of about 670 meters above mean sea level, in the central part of northern Nigeria and more than 644 kilometers away from the Atlantic Ocean. (Ogbaji, 2006).

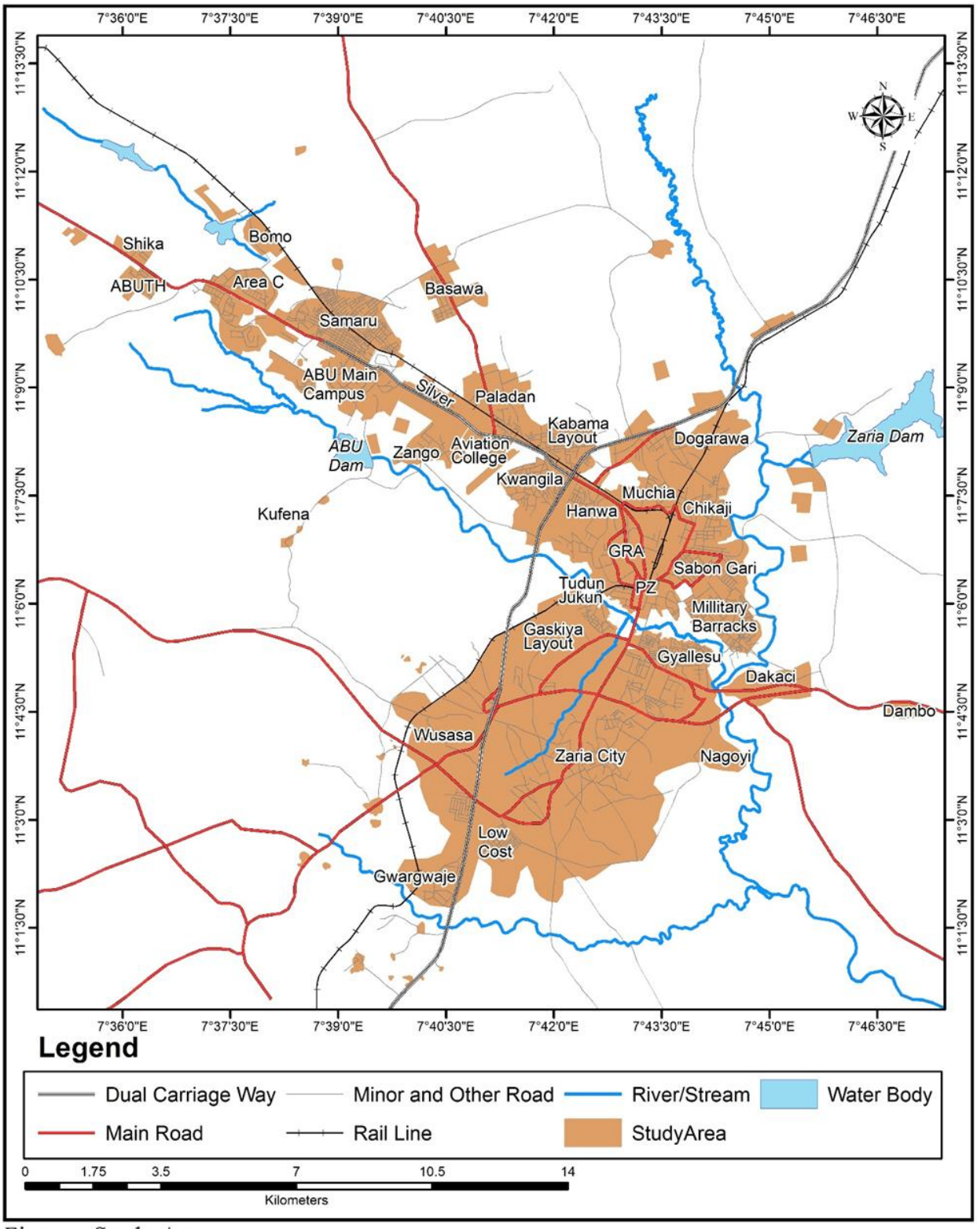


Fig 3.1: Zaria Showing the Study Sites

3.2.2 Climate of Zaria

Zaria possesses a tropical continental climate. It lies within a region which has a tropical savanna climate with distinct wet and dry seasons. According to Thornwaites's moisture index, the climate of Zaria is the dry sub-humid type (Ogbaji, 2006). The annual rhythm of weather in Zaria follows the annual march of the surface position of the Inter Tropical Discontinuity (ITD) over Nigeria it is approximately from WNW to ESE. It reaches its northernmost and southernmost positions in August and January respectively. The gross features of rainfall patterns in this region, as in other part of the country are usually in association with what is often called the Inter Tropical Discontinuity (ITD) (Nicholson, 1981; Kanote, 1984; Hayward and Oguntoyinbo, 1987; Oladipo, 1993). The movement of the ITD North-wards across the country between January and August, and its retreat from the southern fringe of the Sahara desert after August, causes much of Nigeria to experience seasonal rainfall. (Olaniran and Summer, 1989; Olaniran, 2002; Ojo, Ojo and Oni, 2001)

The ITD itself is the boundary at the ground level between the dry Tropical continental (cT) air of northern origin and the cool, moist Tropical maritime (mT) air of southern origins. These two air masses pass through and are responsible for the seasonal changes in Zaria. Sticky hot weather condition-prevails during the northwards movement of the ITD because of small diurnal temperature range, high relative humidity with little or scanty showers of rainfall. While the southern movement is associated with dry and cold weather condition because of great diurnal temperature range and low relative humidity with no rainfall (Ogbaji, 2006)

On the basis of these two air masses it has two distinct season: the dry or harmattan season (October to March) and wet season (April to September). October usually marks the end

of the wet season and the beginning of dry season. While April marks the onset of the rain and the end of the hot season. When the onsets of the wet season the daily maximum temperature drops, and the diurnal range of temperature becomes low. July and August in Zaria are the months of mildest weather. (Oshaji, 2000)

The diurnal range of temperatures during this period varies from about 9.4ºc to 6.7ºc. The mean daily maximum temperature is about 26.7ºc to 28.9ºc. Cloudiness reaches a maximum in August and consequently the hours of sunshine are least. The average duration of sunshine in August varies from three to six hours. The relative humidity is very high in August about 70-80 percent (Hore, 1970).

The beginning of the dry season is marked by an abrupt drop in the moisture content of the surface air and a change in the direction of the surface winds. Relative humidity drops from 60-65 percent in October to about 25-30 percent in November. Daily minimum temperatures drop more rapidly than the maximum. Consequently the diurnal range of temperatures increases rapidly. The sky is mostly clear in November which permits longer hours of sunshine. In early November, mornings and nights become cooler and pleasant. Dust haze begins to appear and increases in frequency as the *'harmattan'* wind is being introduced. In December to January, the thickness of this haze and dust layer of the '*harmattan'* rarely exceeds a height of 1,524 meters. Sometimes visibility becomes very poor (Hore, 1970)

3.2.3 Relief and Drainage,

The study area forms part of the dissected Zaria – Kano plains, which is an extensive peneplain developed on crystalline metamorphic rocks of the Nigerian basement complex. There is however, some inselbergs such as Kufena hill and some low quartzite ridges in the west that

remains upstanding. There are widespread steep sided gullies which resulted from downward cutting of deposits of earlier cycles. Major inselbergs include Kufena hill, Turunku inselberg. Dutsenwai hill. Others include those of Hange, Dumbi, Farakwai, Tukur – Tukur and Madarkaci (Smith 1970).

The plain on which the region is located varies in height from 620 meters to 6500 m, reflecting both a regional slope to the south and a local relative relief of 35 – 45 m. The causes of these differences according to Thorp (1970) may be associated with the type of landuse, vegetation cover, the cohesion and permeability of the regolith and varying intensity in erosion energy

The drainage system is based on the river Galma, a major tributary of the River Kaduna. It has a drainage basin of over 6902 km^2 area. The Galma has an average gradient over the plain of 1m per 3 km. It carries water throughout the year unlike many of its tributaries which dry up during January to May. There are numerous other streams covering the region. Prominent among which are Kubanni, Saye among others. The streams can be divided into two types which are based on their drainage system. There are those that begin from Funtua watershed and those from the watershed dividing the Chad and Kuduna – Niger drainage systems. Both sets are characterized by high stream frequency and drainage densities.

3.2.4 Vegetation

Zaria lies within the northern Guinea Savannah type of vegetation which implies that it has a woodland vegetation type. Through the clearing of vegetation for cultivation, firewood, as well as overgrazing the natural or climatic vegetation of Zaria have been changed to that of derived savannah type which is characterized by shrubs, stems and trees along with some tuft

covers and some clusters of trees along river course (Alkali, 2009). Trees species here include *Magnifera indica* dotting everywhere, *Parkia clappertoniana, Tamarinda indiana, Butyrispernum spp* and several others which are found to be useful to man. During the rainy season, the vegetation is thick and greenish but are dry and brownish during the dry season with little of these plants retaining their leaves. The dominant shrubs around the area is *Isoberlina doka* with an average height of 50 cm. other less frequent shrub species include *Pilliostigma spp., Terminacea avicennides*

The common grass communities in the study area are mostly *Andropogan spp.* (Kwabe, 1987), which are almost completely absent during the long dry season. However, the grasses sprout during rainy season, but no sooner than rainy season ceased than they become dry. In this same Savannah zone there is the presence of *Isobelina doka, tomentoss and Vapaca togoensis* with a well-developed grass layer. (Jackson,1970).

The vegetation is deciduous in nature because they shade their leaves in the cool dry season to prevent excessive loss of water through transpiration. They have long tap roots that go deep in search of water and broad trunks as in baobab to store water, along river side palms can be found. The vegetation cover changes seasonally, as such it is green and luxuriant during rainy season and yellowish- brown in the dry season.

3.2.5 Geology

Zaria is underlain by three groups of rocks all of which belong to the Precambrian basement complex of Nigeria. These groups of rock include:

a. Gneiss of variable composition, which include granite rocks gegmatite or schists, which have been thoroughly weathered at various depths and are found to form most of the superficial materials which are generally called drift.
b. Quartz, schist and quartzite which form a narrow bed of low rounded hill and valley topography. They are found in the north-south trending belt.(forming ridges)
c. Gneiss or porphyritic granites are characterized by inselbergs of different shapes and sizes; these are often referred to as the older granite. They cover a small area with largest outcrop forming the Kufena group of inselbergs. (Alkali,2009)

3.2.6 Soils

Zaria soil is grouped to be among the leached ferruginous tropical soils. Most of the soil is 30-40% rich in clay, which have the ability to retain moisture. They are inherently rather poor that they cannot sustain much food production to meet the ever increasing population of Zaria. Kowal and Omolokun, (1971)

Also, most of its soil forms a hard surface cap under the impact of heavy rain. The scanty vegetation cover enhances surface run off due to low infiltration. This concurrently causes pollution of rivers and other environmental problems to the people. (Niniola,1999)

3.2.7 People and Population

Zaria consist mainly of the Hausa-Fulanis, though there are many other ethnic groups which includes Yorubas, Igbos as well as other Atyaps, Mangus, Efiks, Nupes, Urogbos and many other ethnic groups. The Indigenes are majorly Muslims who practice Islam. Cultural practices in this area can hardly be separated from the religious practices for example, seclusion (Purdah) is linked to both cultural and religious traditions. It means women are restricted to the

home and can only move out with their husband's permission. The practice of early marriage and denial of access to education for the girl child is also both cultural and religious, this in turn limit the decision making authority of the women. In these communities the men are known as both the provider (breadwinner) and the decision makers

Families in the Zaria area can be divided into two types of units, a simple unit consisting of an individual married adult and his children and a composite unit which is also known as economic unit. It consists of two or more male adult usually married staying together in a compound setting, in some cases they cooperate to secure income from a farm. In order of decision- making power, the subordinate have minor rights and basic decisions are taken by the head of the units (Nwachukwu, 1990).

The population of Zaria has increased exponentially over the years. Presently, Zaria is next to the state capital Kaduna, based on the most recent population figures. Zaria and Sabon-Gari are the two local government areas. These two local government areas have a total population of 695,069 with the male population of 363,061 and female population of 332,008 (NPC 2006). This is a great increase compared to the figures of 284,318 for Zaria Local Government Area in 1991 consisting of 150,501 male and 133,817 females and Sabon-Gari Local Government Area having 224,067 including 118,788 males and 105279 females (NPC, 1991) and the 110,000 population figure. (Mortimore, 1970)

3.3 Research Methodology

This essentially deals with the method that was employed in this research work. It includes the types of data required, their sources, the method of data collection and analysis.

3.3.1 Preparatory Stage and Reconnaissance Survey

As a platform for a research of this nature, a preparatory stage was undertaken which include the collection of maps, Journals, literatures from books etc. A reconnaissance survey was later carried out which provided a preliminary knowledge of the extent of the study area in terms of boundary limit and other relevant information.

3.3.3 Sources of Data

All the data used for this research were from secondary sources. Literatures were obtained from secondary sources through consultation of related journals, books, citations, reference from the library, conference papers, on-line publications and other related materials. The researcher personally went to the Institute for Agricultural Research's Metrological Unit and requested for and obtained the temperature and relative humidity records for the required period.

3.3.2 Types of Data Collected

3.3.3.1 Secondary Data

The data used in this study include: monthly minimum, maximum, and average temperature in degrees centigrade (^{o}C) and relative humidity (%) from1975 to 2010

3.3.4 Data Analysis

A total of 36 years daily records of temperature and relative humidity data were sourced. Each of the daily maximum and minimum temperatures was summed up and divided by the number of days in that month to derive the mean monthly maximum and minimum temperature values. The mean monthly maximum and minimum temperature was used to obtain annual maximum and minimum temperature.

For relative humidity, the mean monthly relative humidity was also derived by dividing the total daily relative humidity by the number of days in that month. The mean annual relative humidity was obtained from the mean monthly relative humidity values.

Temperature Humidity Index was use to calculate the monthly average values of THI for Zaria for the period of the study using (THI) = 0.8T +HT /100. Olaniran (1982) and Unger (1999) reported that the formula used in computation of THI has been found valid and generally acceptable for use in Nigeria and the tropics, and so this has been selected for the study. THI was calculated by using monthly mean values of temperature and relative humidity.

Where 0.8 and 100% are constant.

$T = \bar{X}\ T^{0c}$ for ^{0}C

$H = \bar{X}$ H% for RH%

An average monthly (THI) single value was derived by multiplying 0.8 with temperature value plus the total sum of relative humidity and temperature value divide by 100%. And for the average annual (THI), the monthly averages for (THI) values across twelve months were added and the total was divided by twelve months.

Objective one: To determine the monthly and annual temperature and humidity range for Zaria. The lowest record was subtracted from the highest record respectively. Tables were used to present the monthly minimum and maximum temperature range in Zaria for 36 years duration. Line graphs were used to present the annual minimum and maximum temperature and relative humidity range

Objective two: To examine the temporal variation in temperature, relative humidity and temperature – humidity index. Simple line graphs were used to present temporal variations in temperature, relative humidity and temperature – humidity index. One way Analysis of Variance (ANOVA) was computed to test if there are any significant differences in the temporal variation in Temperature, Relative humidity and Temperature – Humidity Index in Zaria. This tests hypothesis 1. Mean temporal variability in temperature, relative humidity and THI was calculated using the formula: F = MST / MSE:

Where: F = MST / MSE

F = Anova Coefficient

MST = Mean Sum of Squares of temperature, relative humidity and THI due to treatment

MSE = Mean Sum of Squares of temperature, relative humidity and THI due to Errors

MST was obtained by dividing SST / P – 1 where: $SST = \sum m (x - x)^2$

Where SST = Sum of Squares of temperature, RH and THI due to treatment

P = Total number of Population

N = Total number of Sample in a population

MSE was obtained as MSE = SSE / N – 1)

$SSE = \sum (n - 1) S^2$

Where: SSE is sum of squares of temperature, RH and THI due to errors

S is equal to Standard deviation of the samples

N equal total number of observation

Object three: To establish the trend in temperature, relative humidity and temperature – humidity index (THI). This was achieved using Time Series Analysis to establish the trend in temperature, relative humidity and temperature – humidity index to indicate the direction and magnitude of change. Trend lines and linear trend line equations were fitted for each time series. Simple line graphs were used to present the trend in temperature, relative humidity and temperature – humidity index

Objective Four: To examine the impact THI on human comfort. The comfort limit 22 – 27^{o}C was used to estimate THI values in the study area, thus, Correlation analysis was used to see if temperature, humidity and temperature – humidity index were correlated to determine if there is any relationship between them at 0.05 significant level. This tests hypothesis ii

Temperature data were broken into intervals of 8 years so as to fit in a sizable table. This was done by grouping 36 years study period into 8 years interval and 4 years interval. From these, a total of five tables were obtained.

Relative humidity data was grouped into 10 years intervals because the values did not include either minimum or maximum relative humidity, but just the range. However, the choice of 22 – 27^{o}C as comfort range for Zaria was done based on Koenigsberger et al (1974) who recommended this comfort limits for the tropical areas.

Chapter Four: Results Presentation and Discussion

4.1 Introduction

This chapter deals with presentation and discussion of the results of this study.

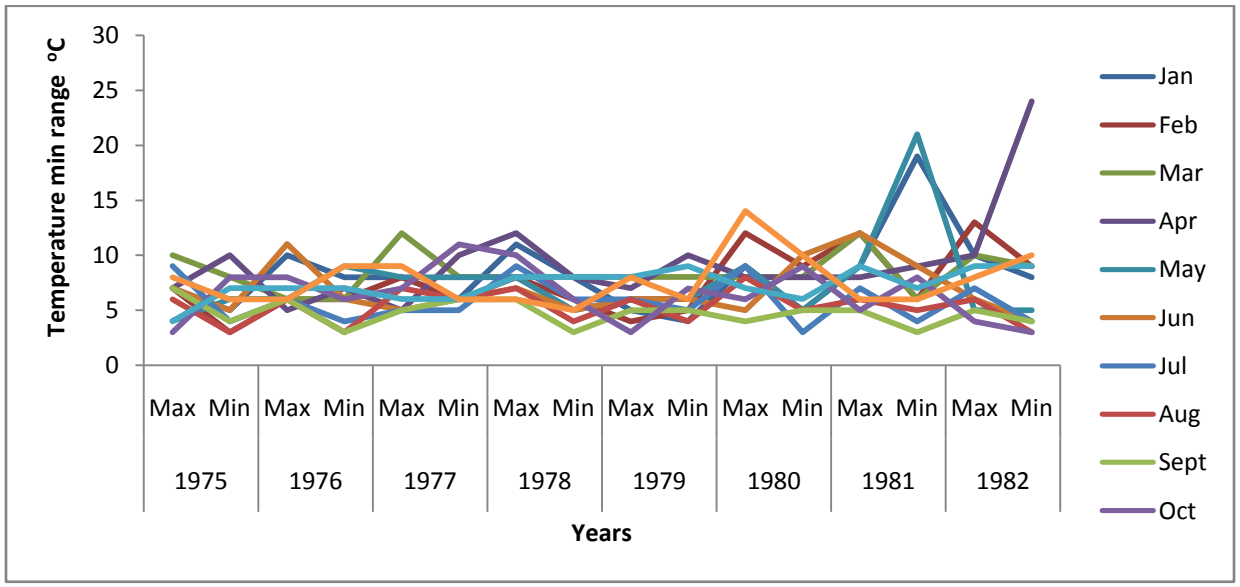
4.2 Maximum and Minimum Temperature Ranges

Based on the daily data the maximum and minimum temperature ranges for the study period are presented in (figures 4.1 to 4.6 annual temperature range) and relative humidity ranges in figures 4.7 to 4.10 and annual range of relative humidity in figure 4.11

4.2.1. Maximum and Minimum temperature ranges (1975 - 1982)

The maximum and minimum temperature ranges from 1975 – 1982 are presented in Figure 4.1

Figure 4.1 Maximum and Minimum Temperature Range (1975 – 1982) ^{o}C



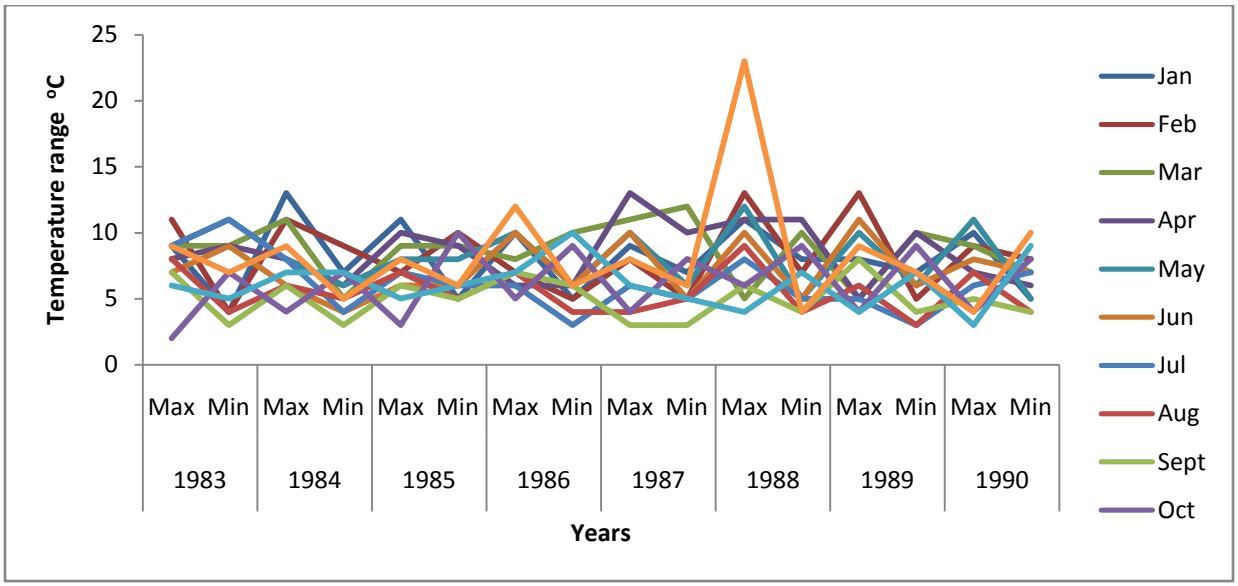
The result in figure 4.1 indicates that 1977, 1978, 1980 and 1981 had maximum annual temperature range of 12^{o}C which occurred in March for 1977, April for 1978, February for 1980, and then February, March and June for 1981. However, 1982 has the highest maximum range of

temperature of 13°C which occurred in the month of February. In terms of minimum temperatures, 1975, 1976, 1978, 1980, 1981, 1982, all had 3°C. These results have shown that the highest temperature range did not occur in the same months of the various years that had the highest temperature range. This may be attributed to the increasing solar radiation during those particular months with high temperature range. Huang (2008) observed that radiation effects on concrete surfaces increase the surrounding air temperature in the surrounding urban open space, resulting to urban heat island

4.2.2. Maximum and Minimum temperature ranges (1983 - 1990)

The maximum and minimum temperature ranges from 1983 – 1990 are shown in Figure 4.2

Figure 4.2 Maximum and Minimum Temperature Range (1983 – 1990) °C



The result in figure 4.2 indicates that from 1983 to 1990 the temperature range vary on monthly bases. However, the year with the month with the highest range of temperature is 1988, which has 23°C and it occurred in December, followed by 1984 which has 13°C. It occurred in

January. Similarly, 1987 also has 13^{o}C in April, 1989, 13^{o}C in February. Then 1990 and 1985 has 11^{o}C respectively. For Minimum temperature range, it has been observed that throughout the years from 1983 to 1990, 3^{o}C constantly remained the lowest temperature range peculiar with certain years and months. For example 1983 has minimum temperature range of 3^{o}C, and it occurred in the month of September. 1984 has 3^{o}C in September, 1986, 3^{o}C in July and 1987, 3^{o}C in September. Finally 1989 has 3^{o}C in July and August.

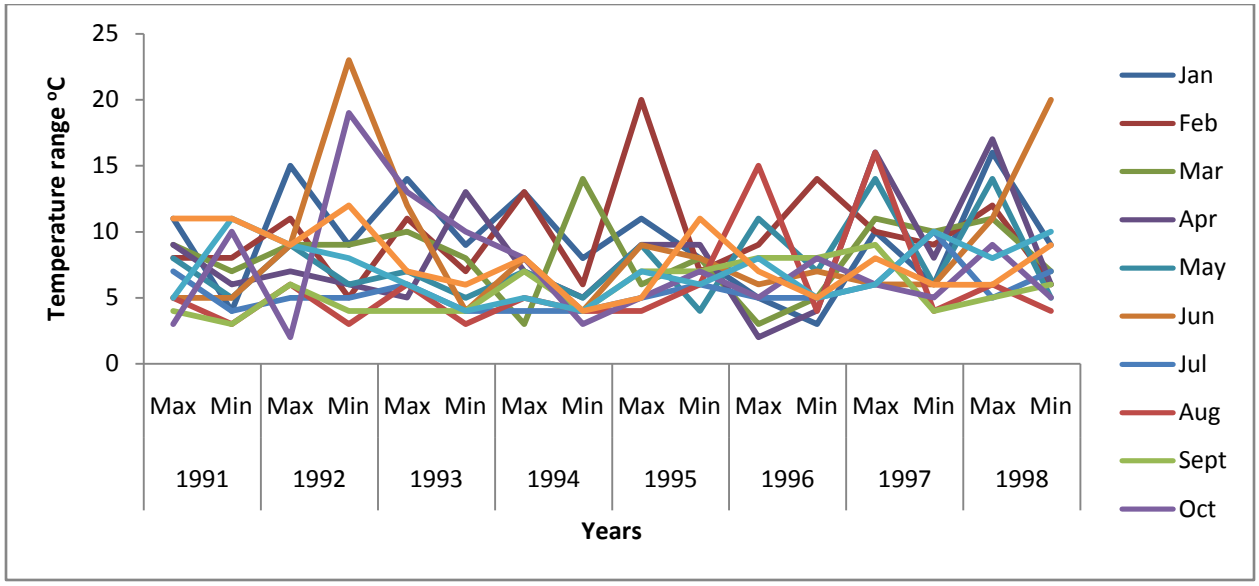
These results have shown that the temperature range within 1983 to 1990 exhibited variations, as a result of the nature of the tropical humid climate. Over the past 50years, observed surface warming over land has been associated with relatively larger increase in daily minimum temperature than in maximum temperature (Karl et al, 1993)

4.2.3 ***Maximum and Minimum temperature ranges (1991 - 1998)***

The maximum and minimum temperature ranges from 1991 – 1998 are presented in Figure 4.3

The results in figure 4.3 shows that across 1991 to 1998 maximum and minimum temperature range vary. Based on this, the highest maximum temperature range occurred in 1995 with a temperature range of 20^{o}C, in February. Closest to the highest range is 16^{o}C for 1997 and 1998 respectively. In 1997 16^{o}C range occurred in April and August. In 1998 16^{o}C range occurred in January.

Figure 4.3 Maximum and Minimum Temperature Range (1991 – 1998) ^{O}C



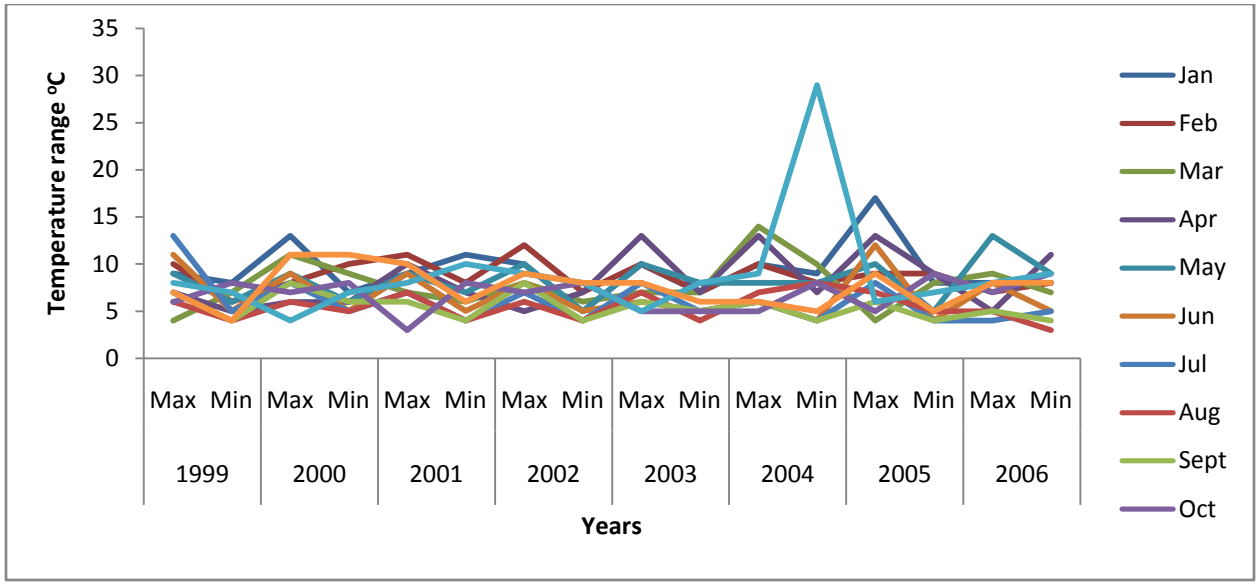
However, with the exception of 1995, 1997 and 1998, all other years has 3^{o}C as the lowest minimum temperature range. These results are close to Easterling et al, (1997), who reported that the decrease or increase in the observed area diurnal temperature range is not spatially uniform in observation. This study area is not an exception.

*4.2.4. **Maximum and Minimum temperature ranges (1999 - 2006)***

The maximum and minimum temperature ranges from 1999 – 2006 are indicated in Figure 4.4

The result in figure 4.4 gave a clear picture of the nature of minimum and maximum temperature range of the study area from 1999 to 2006. From this observation, the highest maximum temperature and lowest minimum temperature can explained from the table. However, year 2004 has the highest maximum temperature range of 14^{o}C, which occurred in March. Except for 2002 with a temperature range of 12^{o}C, which occurred in February, and 2001 with 11^{o}C, which

Figure 4.4 Maximum And Minimum Temperature Range (1999 – 2006) ^{O}C

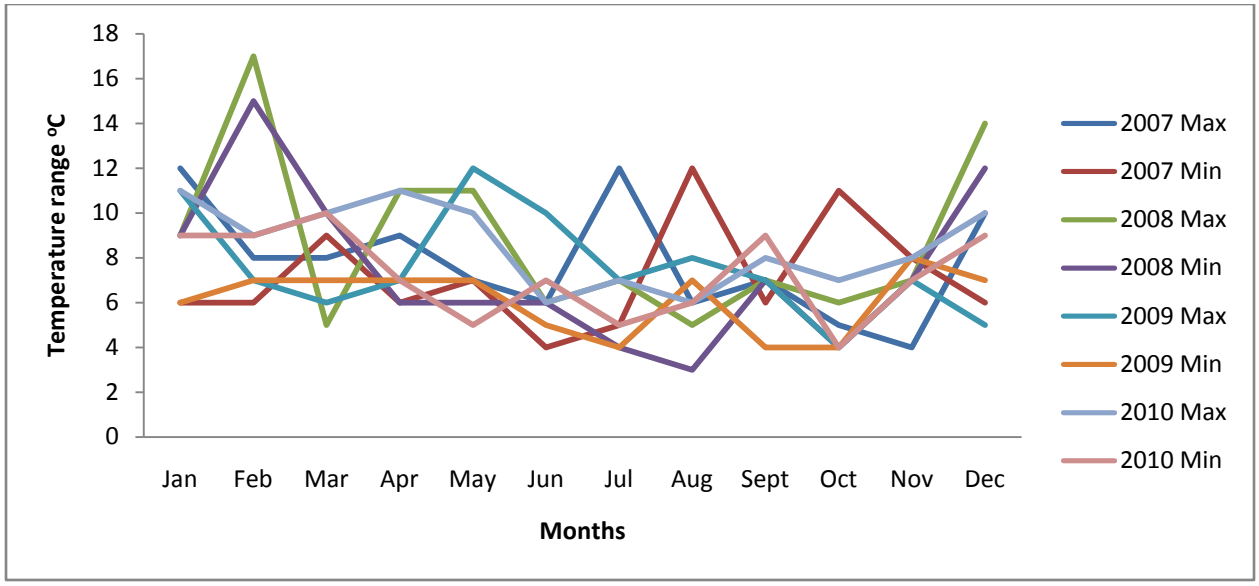


occurred in January and February respectively, all the remaining years such as 1999, 2000, 2003, 2005 and 2006 have the same range of 13^{o}C in various months. For the minimum temperature range across 1999 to 2006, the lowest minimum range of temperature is associated to year 2006 with 3^{o}C, which occurred in August. These results have revealed the characteristics of the tropical humid climate of the study area. This could also be attributed to Dai et al (2001) and Stone Weaver (2002, 2003) who observed that Anthropogenic forcing by greenhouse gasses and sulphate aerosols in general circulation Models caused small 0.2^{o}C decrease in Global Diurnal Temperature Range (DTR) Over twentieth century.

4.2.5 ***Maximum and Minimum temperature ranges (2007 - 2010)***

The maximum and minimum temperature ranges from 2007 – 2010 are shown in Figure 4.5

Figure 4.5 Maximum And Minimum Temperature Range (2007 – 2010) ^{O}C

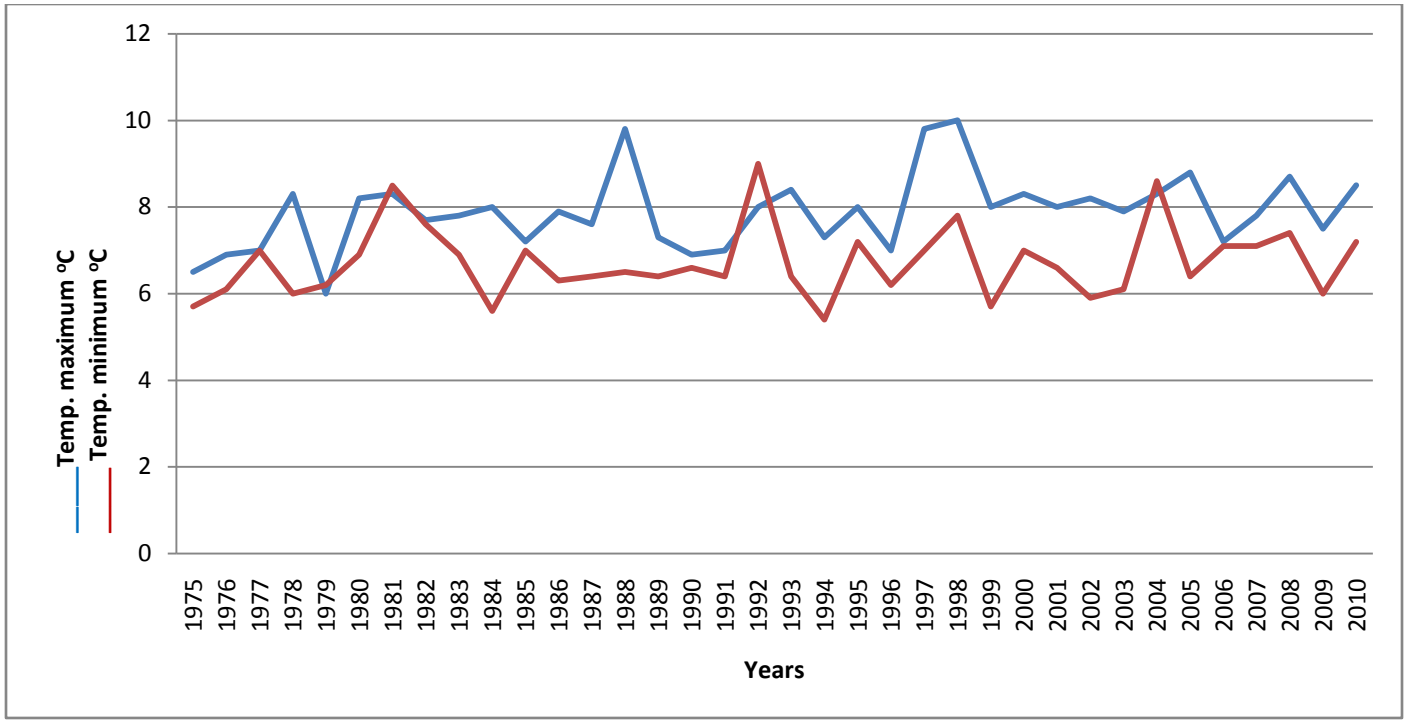


The result in figure 4.5 indicates that the highest maximum temperature from 2007 to 2010 occurred in 2008 with 17^{o}C in the month February. 2007 and 2009 have 12^{o}C respectively, and 2010 has 11^{o}C in January and April. However, these results have revealed that the study area within 2007 to 2010 have similar characteristics of temperature range. This was supported by Easterling et al (1997), who reported that the effect of urbanization on trends in maximum and minimum temperature has been estimated to be very small on global scale.

4.2.6. Annual Temperature Ranges (1975 – 2010)

The annual temperature ranges from 1975- 2010 are presented in figure 4.6

Figure 4.6 Annual Temperature Range (1975 To 2010)



The result in figure 4.6 shows that 1998 has the highest maximum temperature range of 10^{o}C, followed by 1997 and 1988 which both have 9.8^{o}C respectively. In terms of minimum annual temperatures range, 1994 has the lowest minimum temperature of 5.4^{o}C, followed by 1984 which has temperature range of 5.6^{o}C (see Appendix I 'a-i' for annual temperature range). This result revealed increase and decrease in minimum and maximum temperature range. Bragnanza et al, (2003) observed that changes in minimum and maximum temperature range have been associated with changes in global mean temperature.

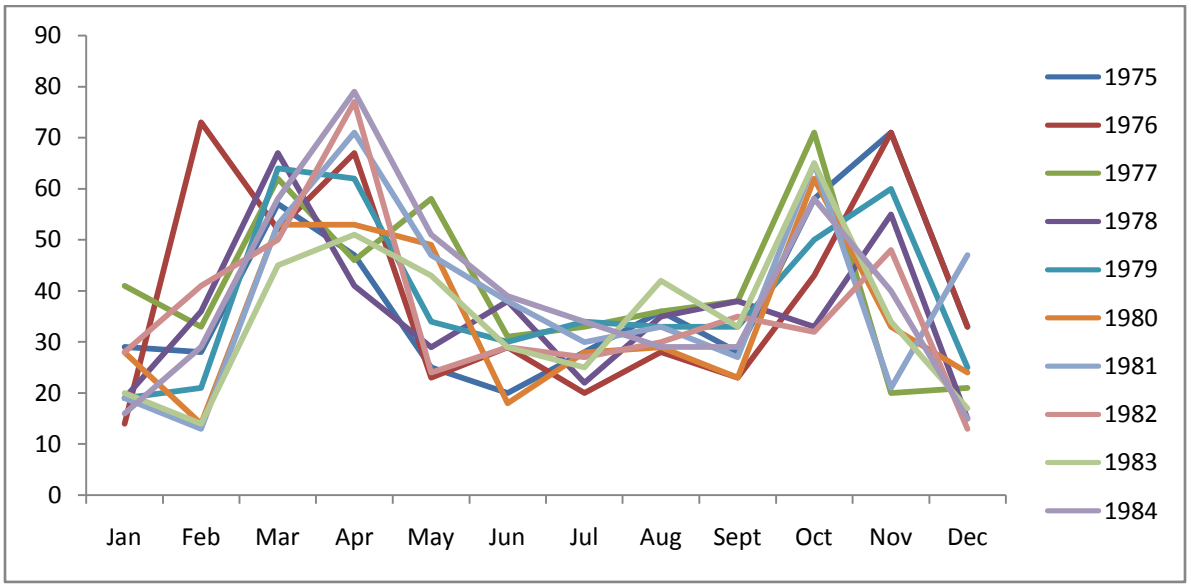
4.3 Range of Relative Humidity Zaria (1975 To 1984)

The Relative humidity ranges of the study area are presented in figures 4.7 to 4.11

4.3.1 Range of Relative Humidity in Zaria (1975 – 1984)

The range of Relative Humidity in the study are is shown in Figure 4.7

Figure 4.7 Range of Relative Humidity % in Zaria (1975 – 1984)

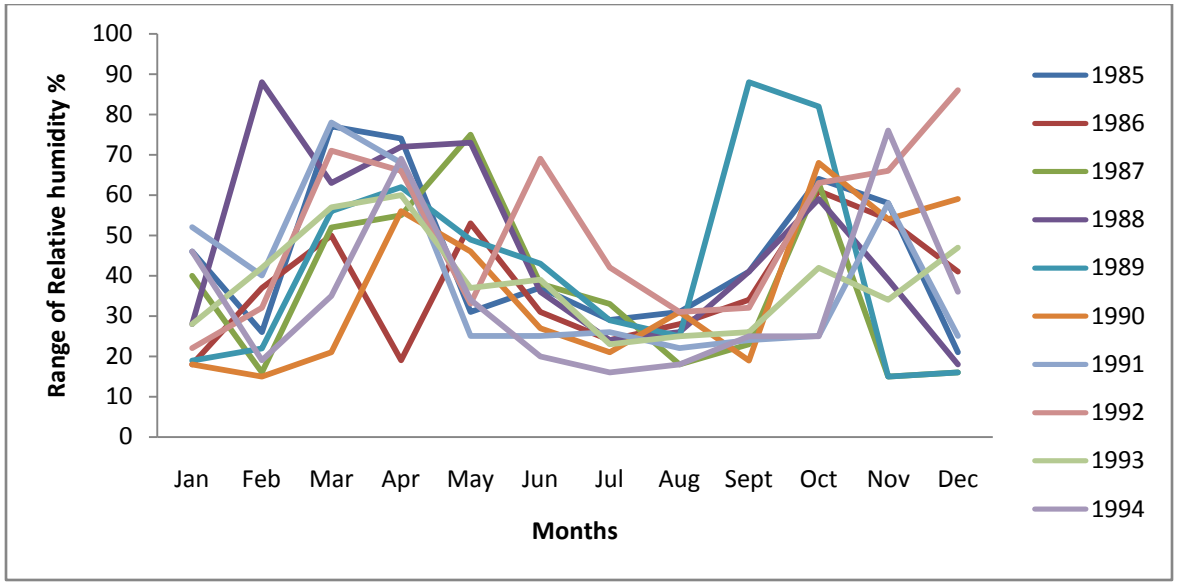


The result in figure 4.7 shows that the highest range of relative humidity occurred in year 1984 with 79%, followed by 1982 with 77%, 1976, 73%, 1975, 1977 and 1981 with 71% respectively. Then 1978 with 67%, 1983 with 65% and 1979 with 64%. Within this span of years 1975 – 1984, the lowest range of relative humidity occurred in 1982 with 13% in December. These results have revealed differences in relative humidity from 1975 to 1984. Therefore, according to McIntyre (1980) the difference in air relative humidity of 20% and 70% can be undetectable within a comfort zone.

4.3.2 Range of Relative Humidity in Zaria (1985 – 1994)

The range of Relative Humidity in the study are is shown in Figure 4.8

Figure 4.8 Range of Relative Humidity % in Zaria (1985 – 1994)

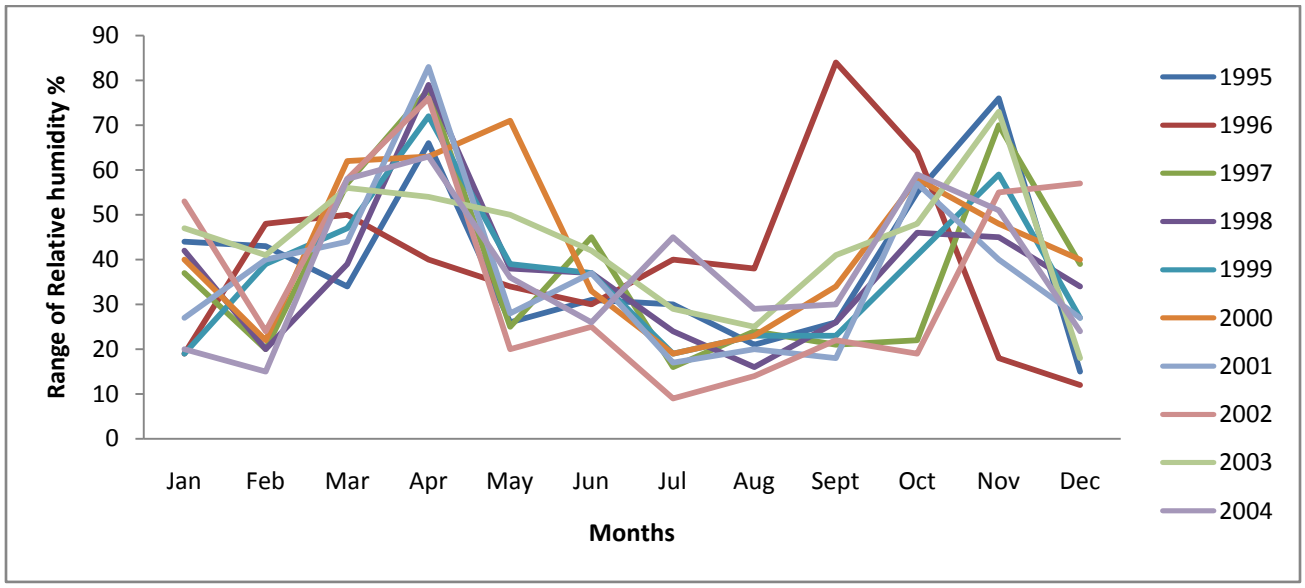


The result in figure 4.8 shows that within the period of 1985 – 1994, the highest range of relative humidity occurred in 1988 and 1989, with values of 88% respectively. The following years have disparity in their values. 1992, 86%, 1991, 78%, 1985, 77%, 1994, 76%, 1987, 75%, 1990, 68%, 1986,61%. Based on observation of these values for respective year, it can said that the lowest range of relative humidity occurred in 1987, 1989 and 1990 with 15% respectively. These results have revealed the true characteristics of the tropical humid climate that the area possessed. This means that have months in which relative humidity is high as well as temperature. This was supported by Bauman et al (1996) who observed that relative humidity affects people thermal sensation under increased metabolic rate. This observation was in agreement with earlier study carried out by McNail et al, (1967). However, both authors did not register any considerable effect of higher air relative humidity within 20% and 90% and temperature range of 15.6^{o}C and 40.6^{o}C

4.3.3 Range of Relative Humidity in Zaria (1995 – 2004)

The range of Relative Humidity in the study are presented in Figure 4.9

Figure 4.9 Range of Relative Humidity % in Zaria (1995 – 2004)

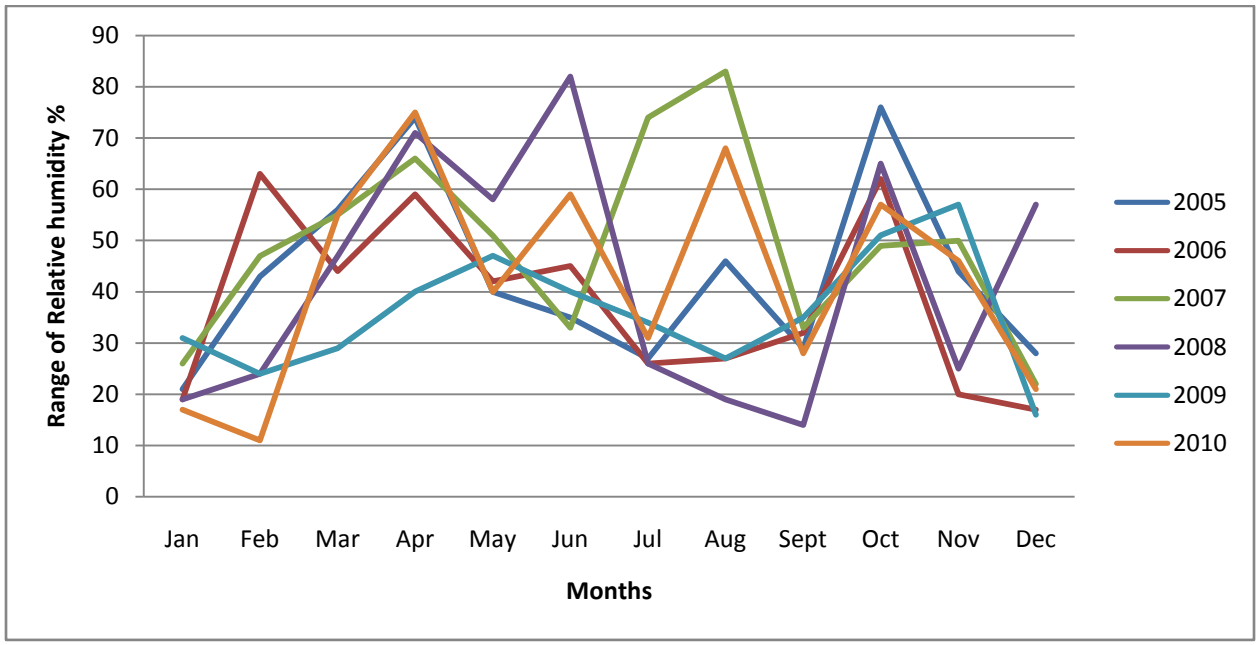


The result in figure 4.9 indicates 1996 as the year with the highest range of relative humidity of 84%, followed by 2001 with 83%, 1997 with 78%, 1998, 79% and 1995 with 76%, 2003 has 73%, 1999 has 72% then 2000 with 71% and 2004 has 63%. From this observation, a conclusion was drawn that 2002 has a record of having the lowest range of relative humidity of 9%. These results have revealed that high or low rate of evapo-transpiration or movement of water vapour from water bodies or change in season may have led to the variability in relative humidity, and this can have effect on the people in the study area. This is in line with ISO 7730 (2005), which observed that for moderate environment, the rise of 10% in relative humidity is comparable to an increase in operative temperature by 0.3^{o}C which has impact on thermal sensation.

4.3.4 Range of Relative Humidity in Zaria (2005 – 2010)

The range of Relative Humidity in the study are presented in Figure 4.10

Figure 4.10 Range Of Relative Humidity % in Zaria (2005 – 2010)

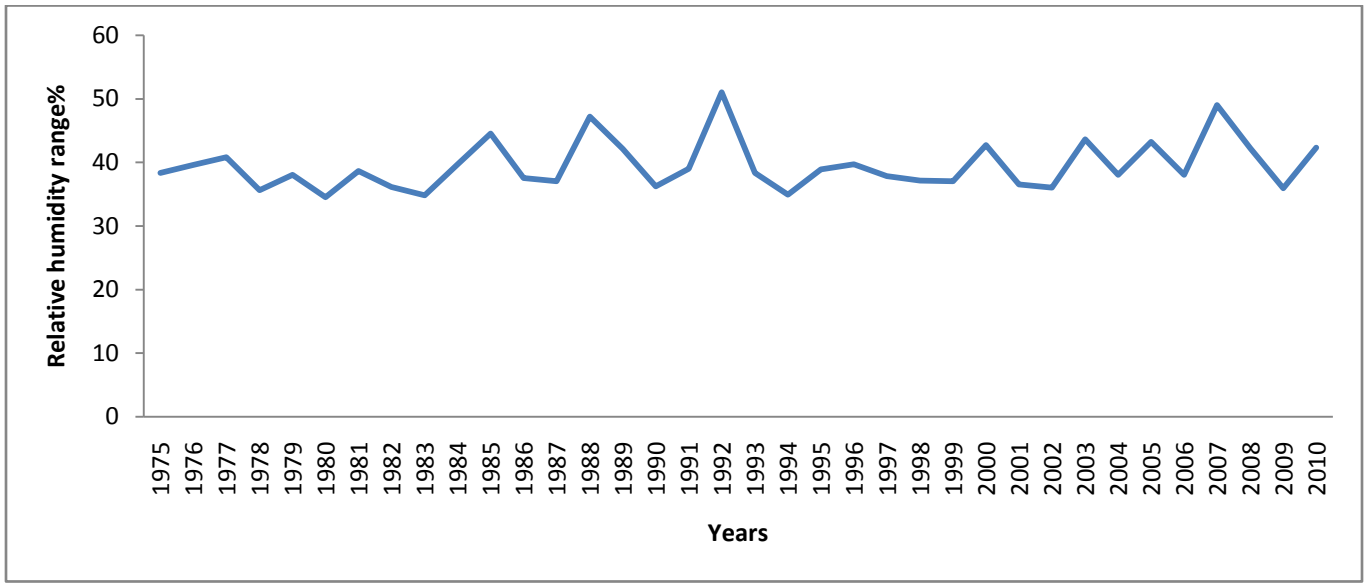


The result in figure 4.10 shows that among the years from 2005 – 2010, the highest range of relative humidity occurred in 2007 with 83%, followed by 2008 with 82% , 2005 has 76%, 2010, 75% then 2006 has 62% while the lowest occurred in 2010 with 11%. Followed by 2008 with 14%, 2009, 16%, 2006, 17%, 2005, 21% and 2007 with 22% relative humidity. The results revealed that from 2007 – 2010, there were years such as 2007, 2008 and 2005 that have months with high relative humidity. The implication is that high relative humidity sometimes causes drying of the nose and inability to expel sweat effectively if the air temperature is high. This is not far from Cain et al (1983) who observed that the combination of high relative humidity of 70% and a high temperature above 25.5^{o}C exacerbate odour problems

4.3.5 Annual Range of Relative Humidity (1975 – 2010)

The annual range of relative humidity 1975- 2010 are shown in figure 4.11

Figure 4.11 Annual Range of Relative Humidity (1975 To 2010)



The result in figure 4.11 shows that from 1975 to 2010, the annual range of relative humidity was not uniform. Therefore, it can be seen from table 4.11 that the highest range of relative humidity occurred in 1992 with 51%, followed by 1988 with 47.2%, then 1985 with 44.5% and 1977 with 40.8. It was further observed that the lowest range of relative humidity occurred in 1980 which has 34.5%. These results have revealed that low or high relative humidity can both lead to discomfort. This is in line with Fang et al, (1998), who reported that high or low relative humidity can both produce discomfort conditions, as high relative humidity reduces the body's ability to lose heat through perspiration. (See Appendix II 'a-f' for annual relative humidity range)

4.4 Temporal Mean Monthly Variation in Temperature, Relative Humidity and Temperature – Humidity Index (THI) of the Study Area

4.4.1 ***Temporal Mean Monthly Variation in Temperature (1975 – 2010).***

The temporal mean monthly variation in temperature is given in figure 4.1

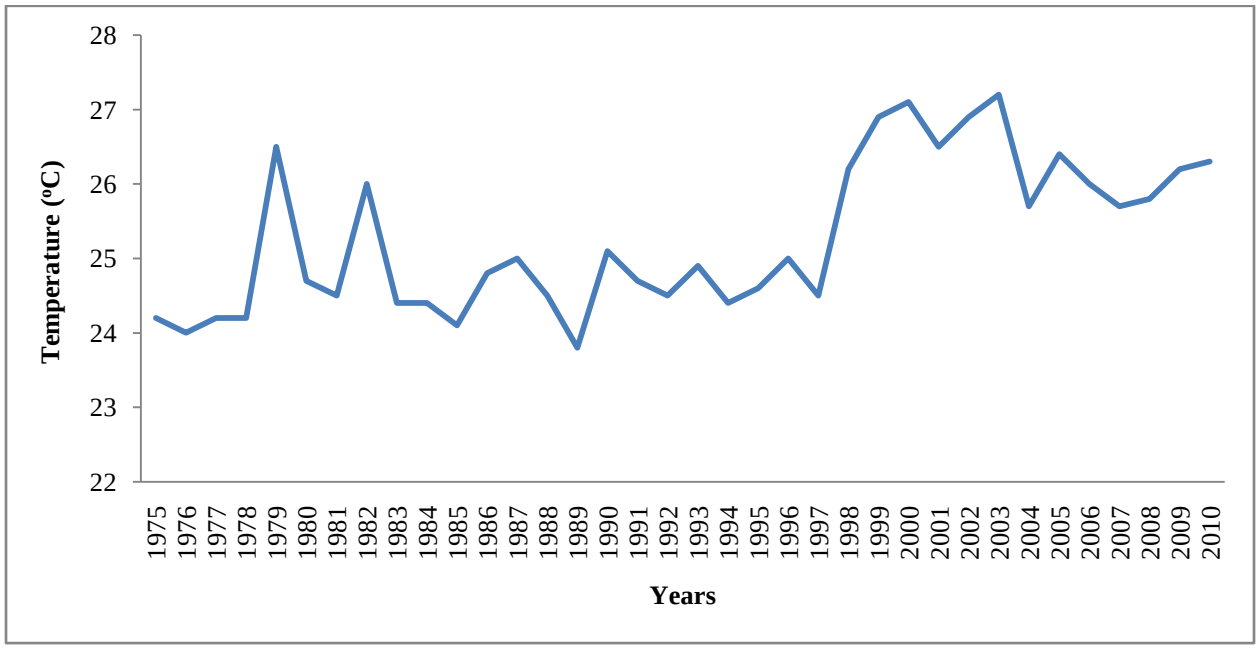


Figure 4.1 temporal mean monthly variations in temperature (1975 – 2010)

From figure 4.1 it can be observed that there were years with high temperature values while others have low values. This means that temperature is rising and falling. The highest temperature occurred in 2003 with 27.2^{o}C, followed by 2000 which had 27.1^{o}C. 2002 and 1999 had 26.9^{o}C respectively. However, the lowest recorded temperature occurred in 1990 which had 23.8^{o}C Furthermore, from 1975 – 1978 temperature fluctuated within 24.2^{o}C, before rising to 26.5^{o}C in 1979. It later decreased to 24.7^{o}C in 1980, 24.5^{o}C in 1981. In 1982 temperature rose to 26^{o}C, but it decreased to 24.4^{o}C in 1983 and 1984 respectively. 1985 had 24.1^{o}C, 1986, 24.8^{o}C, 1987, 25^{o}C. From 1988 – 1997 temperature did not rise above 25^{o}C as the case in 1990 and 1996

that both had 25°C. Again from 1998 – 2010 temperature did not rise higher than 27°C. \Here, temperature characteristics are typical of a Tropical humid environment. The result obtained from the study area revealed that the natural environment have variability in temperature. Adelaja (1991) observed that environmental temperature outdoor or indoor act on the body through the nerve receptor and activates the physiological mechanisms that reduce or increase the elimination or production of heat in relation to the character of the stimuli. By implication, it means the study area would inevitably witness periods of high or low temperature.

4.4.2 The Temporal Mean Monthly Variation in Relative Humidity of the Study Area

4.2 ***Temporal mean monthly variation in relative humidity for 1975 to 2010***

The temporal mean monthly variation in relative humidity (1975 to 2010) is presented in Figure 4.2

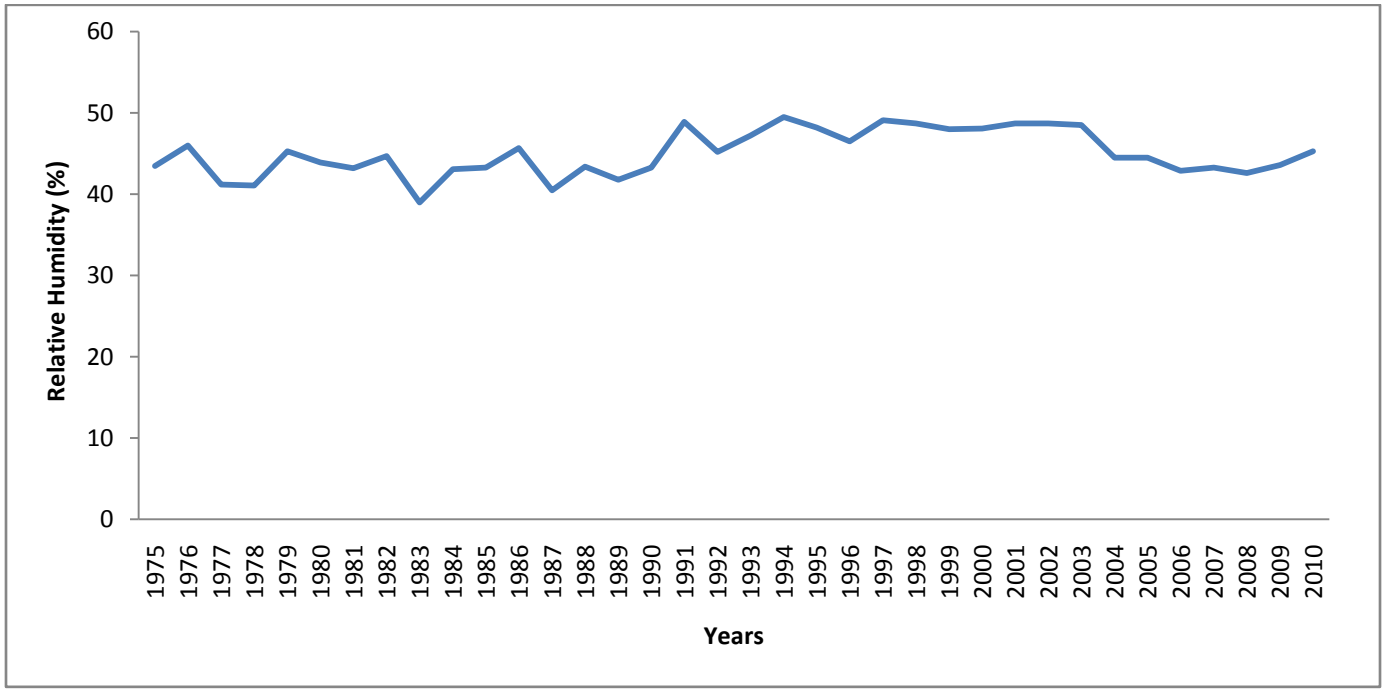


Figure 4.2 Temporal Mean Monthly Variations in Relative Humidity (1975 to 2010)

Figure 4.2 shows that the highest relative humidity of 49% occurred in 1994 while the lowest, which is 39%, occurred in 1983. The onset of rise in relative humidity began in 1975 in which its relative humidity was 43.5. By 1976 relative humidity rose to 46 but it decreased steadily to 41.2 in 1977 and 41.1 in 1978. Again in 1979 relative humidity rose to 45.3 but due to un-static nature of relative humidity in the study area, it decreased to 43.9 in 1980 and 43.2 in 1981. In 1982 relative humidity rose slightly to 44.7 but in 1983 it drastically decreased to 39. In 1984 relative humidity increased to 45.1, in 1985 to 43.3, in 1986 to 45.7. Relative humidity decreased to 40.5 in 1987 and increased to 43.4 in 1988. There was decrease in relative humidity to 41.8 in 1989 and but it rose to 43.3 in 1990

It was further observed that high relative humidity prevailed from 1991 with 48.9% right through to 2003 which had 48.5%, with exception of 1992 which had 45.2%. Relative humidity decreased remarkably to 44.5% in 2004 and 2005 respectively. In 2006 relative humidity was 42.9%. However, slight increase in relative humidity of 43.3% occurred in 2007. As relative humidity fluctuation continued, there was a decrease of 42.6% in 2008. Thereafter, relative humidity rose to 43.6% in 2009 and then to 45.3% in 2010. This results have revealed that relative humidity in the study area have exhibited an unremarkable temporal variability. And most of the time, high temperature periods are associated with lower values of relative humidity. According to Yimaz and Toy (2007), the difference in relative humidity between Urban areas and there corresponding country sides is the windless nature of the urban centers. Zaria Metropolis is therefore, not an exception

4.4.3 Temporal Mean Monthly Variation in Temperature – Humidity Index (THI)

4.3 Temporal mean monthly variation in temperature humidity index for 1975 - 2010

The temporal mean monthly variation in temperature humidity index 1975 - 2010 is shown in figure 4.3

Figure 4.3 shows that THI is not stable across the study period. 1975 had 30.5 THI and 30.3 for 1976. As for 1977 and 1978 they had lower THI of 29.2 respectively, compared to the previous year. Subsequently there was a significant increase in THI to 33.8 in 1979. But it decreased to 30.8 in 1980 and 30.4 in 1981. The unstable nature of THI led to an increase to 32.6 in 1982 but it eventually decreased to 29.1 in 1983,

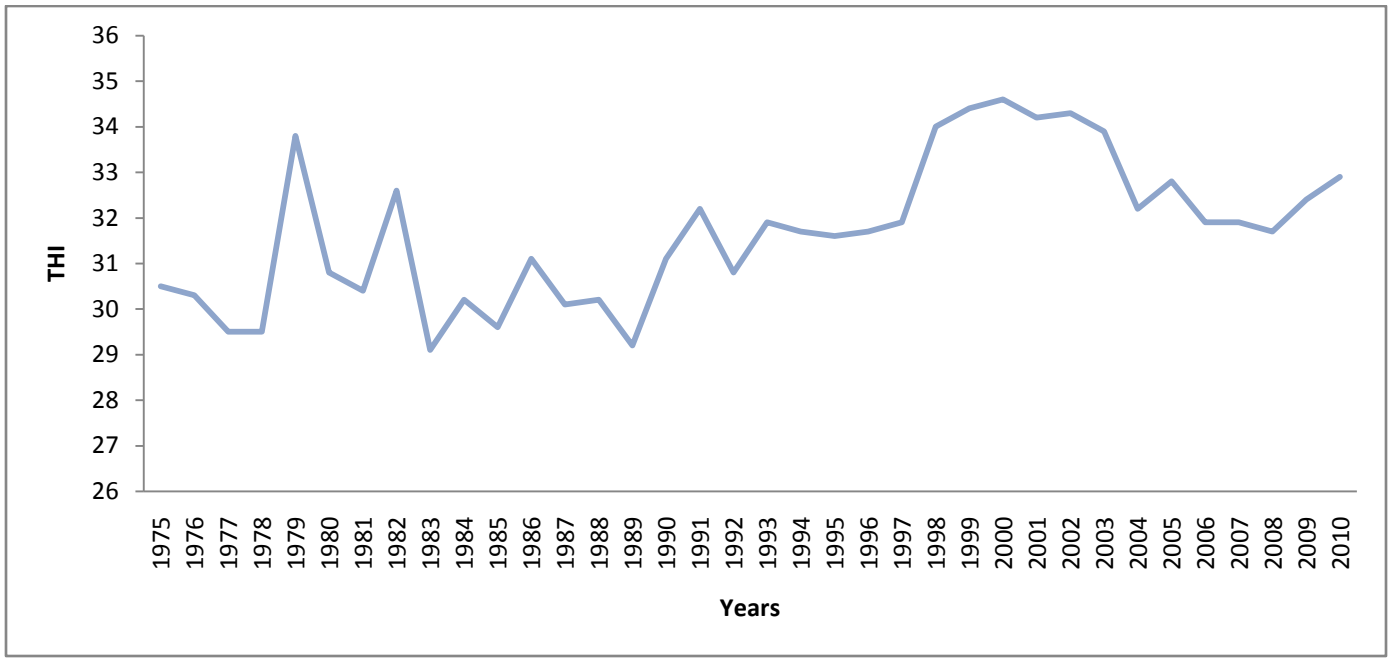


Figure 4.3 Temporal Mean Monthly Variations in Temperature - Humidity Index (1975 to 2010)

although it rose to 30.2 in 1984, slightly above the THI of 1983. However, the fluctuation is vivid in the subsequent years. For example, 29.6 THI prevailed in 1985, 31.1 in 1986, 30.1 in

1987, 30.1 in 1988, 30.2 in 1989, 29.2 in 1990, 31.1 in 1991, 32.2 in 1992, 30.8 in 1993, 31.9 in 1994, 31.9 in 1995, 31.7 in 1996, 31.6 in 1997, 31.7 and 1998, 31.8

The highest THI of 34.6 occurred in 2000 while the lowest is 29.1 which occurred in 1983, followed by 1989 with 29.2 THI.1999 had 34.4 THI and 2002 had 34.3. From 1998 to 2003 THI did not rise above 34.6, likewise, in 1983 in which THI did not decrease below 29.1 But from 2004 to 2010 THI fluctuated in-between 32 and 31. The result obtained from the study area is in line with that of Oludoyin and Adelekan (2013) who reported that the highest mean THI (26.3^{o}C) occurred in Lokoja (Guinea Savanna) the variability of THI in the study area may be due to increase in temperature and relative humidity. Again, these results are not too different from the result of Toy and Yilmaz (2007). However, in the study area, the results further revealed sight variability in THI. The causes of this slightly THI differentials between periods of the study may not be far away from what Idzikowka, (2010) attributed to the causes of the warmer nature of most cities in Rome.

4.5 Trends in Mean Temperature, Relative Humidity and Temperature – Humidity Index (THI)

Linear trend lines and trend line equations each for Temperature, Relative humidity and Temperature – Humidity Index were established to show the direction and magnitude of change. The results are presented in figure 4.4 to 4.6

4.5.1 Trends in Mean Temperature over Zaria (1975 - 2010)

Trends in Mean Temperature of the study area is given in figure 4.4

Figure 4.4 shows both the pattern and trend line of temperature from 1975 to 2010. Temperature values are not uniform throughout the study period. The trend line exhibits a positive slope which means temperature is increasing from one year to another.

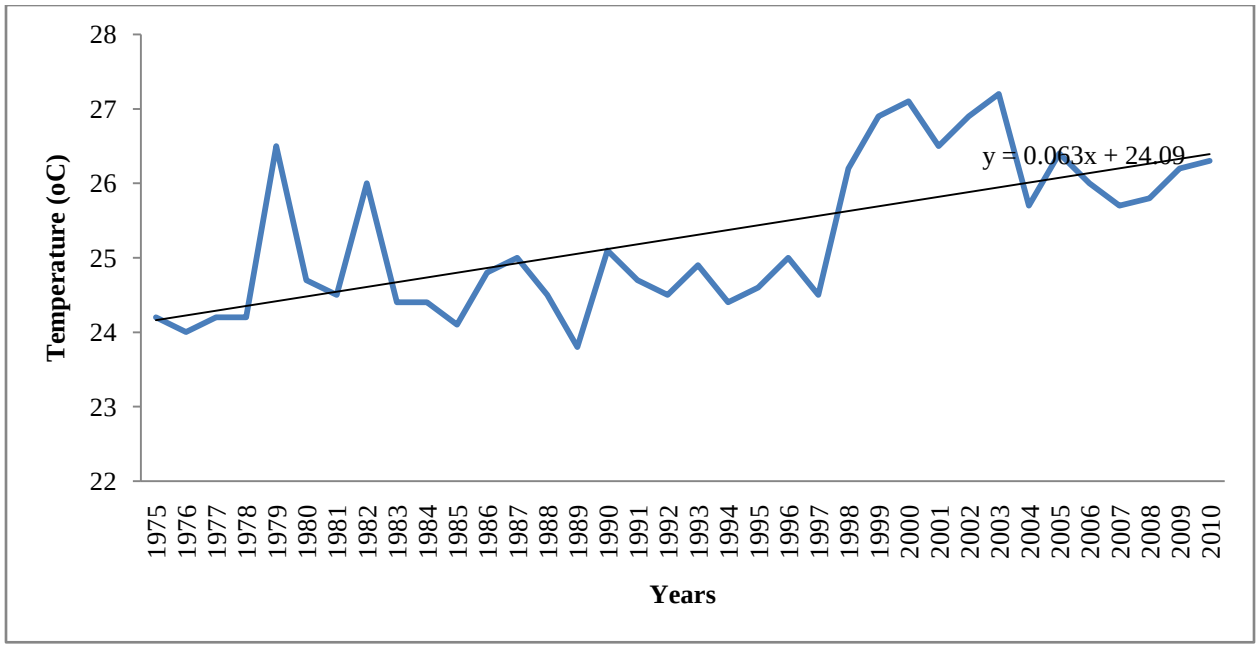


Figure 4.4 Trends in Mean Temperature for 36years (1975 to 2010)

The slope value of the trend line as revealed in this equation shows that, from year to another, temperature increases by 0.06. The value of the intercepts of the equation of temperature indicates that on the average, in every additional year, temperature is linearly increasing by the respected value above. This result shows that temperature characteristics are typical characteristics of a Tropical humid environment. These record is not far from what Abdulhamid (2011) recorded in wet season in Kano

4.5.2 ***Trend in Mean Relative humidity (1975 to 2010)***

Trends in Mean Relative Humidity of the study area is presented in figure 4.5

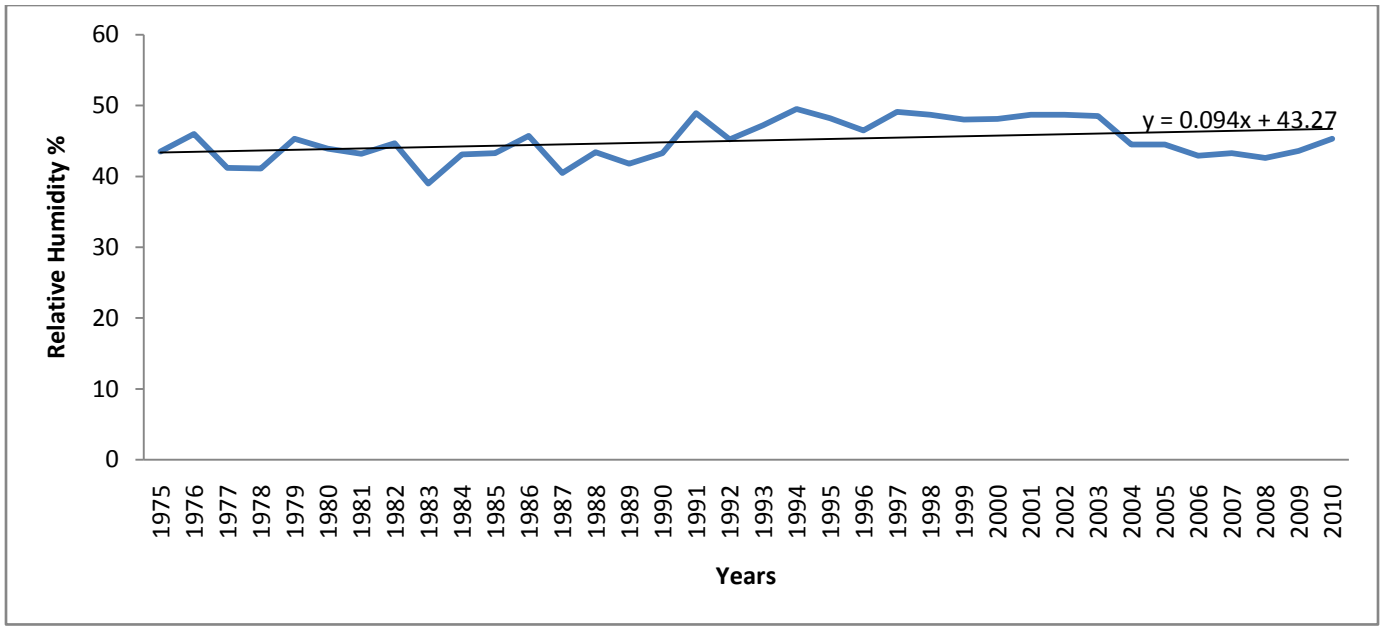


Figure 4.5 Trends in Mean Relative Humidity for 36years (1975 to 2010)

Figure 4.5 shows both the pattern and trend line of relative humidity from 1975 to 2010. Relative humidity fluctuated throughout the study period. The trend line exhibits a positive slope which means relative humidity is increasing from one year to another. The slope value of the trend line as revealed in its equation shows that, from year to another, relative humidity increases by 0.09. The value of the intercepts of the equation of relative humidity indicates that on the average, in every additional year, relative humidity is linearly increasing by the respected values above. These results show that relative humidity did not exceeded 49% which only occurred in 1994. And as the case may be, the area is a Tropical Humid environment as classified by Ayoade (1971). This is because relative humidity of the area is not far from Ayoade (1971) statistic.

4.5.3 ***Trend in Mean Temperature – Humidity Index of Zaria (1975 - 2010)***

Trends in Mean THI of Zaria is shown in Figure 4.6

Figure 4.6 shows both the pattern and trend line of temperature – humidity index from 1975 to 2010. Temperature – Humidity Index fluctuated throughout the study period. The trend line exhibits a positive slope which means temperature – humidity index is increasing from one year to another.

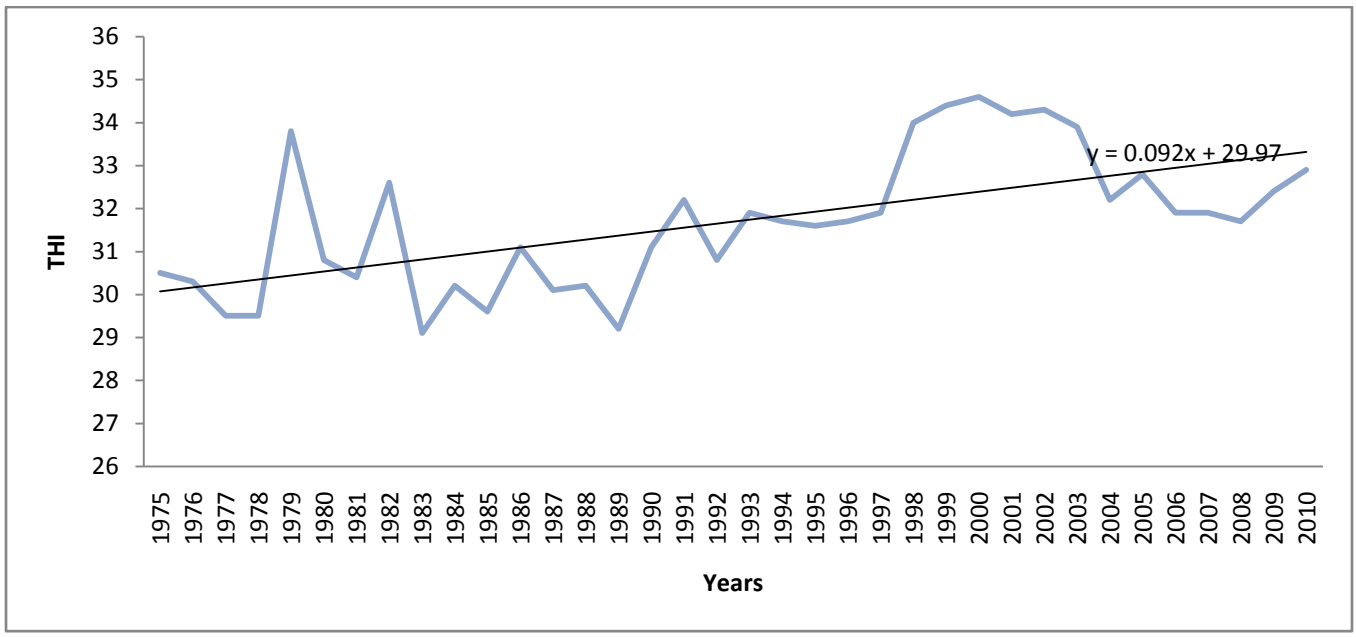


Figure 4.6 Trends in Mean Temperature – Humidity Index for 36 years (1975 to 2010)

The slope value of the trend line as revealed in its equation shows that, from year to another, temperature – humidity index increases by 0.09 The value of the intercepts of the equation of temperature – humidity index indicates that on the average, in every additional year, temperature – humidity index is linearly increasing by the respected values above.

This result clearly indicates that even though other factors affect this index in the study area, for most of the year the index exceeded 22 – 27 degrees Celsius comfort limit for the tropics. This further indicates clearly the characteristics of the study area. This implies that high temperature and high relative humidity affects the thermal character of the study area.

Giles, Balofouts and Mahera (1990) observed that a combination high temperature and relative humidity can be stressful to most people and detrimental to health. From this observation, to an extent, increase in temperature and relative humidity leads to increase in THI. It means that comfort conditions of the people in the study area are influenced by the nature of THI..

4.6 Impact of Temperature and Relative Humidity on Temperature – Humidity Index (THI)

4.8.1 Monthly THI period of comfort and discomfort for the study period.

Temperature – Humidity Index formula was used to estimate the monthly THI values. From it, the THI values that were in-between 22 – 27 degrees Celsius comfort limit (tropical areas) were termed as comfort periods while those below 22 degrees Celsius or above 27 degrees Celsius were termed as discomfort periods. Appendix v shows average monthly THI.

However, the monthly THI period of comfort and discomfort of 2007 only is shown in table 4.12. The selection of 2007 was randomly done, in order to show the monthly pattern of THI and comfort limits 22 -27 degrees Celsius. This pattern is similar to other months of the years of the study period.

Table 4.12 Monthly Temperature – Humidity Index (THI) and Human Comfort

m/yr (2007)	THI	Comfort Limit
Jan	**20**	**Discomfort**
Feb	**23.3***	**Comfort**
Mar	**27.8**	**Discomfort**
Apr	**36.6**	**Discomfort**
May	**39.4**	**Discomfort**
Jun	**38.2**	**Discomfort**
Jul	**39.1**	**Discomfort**
Aug	**39**	**Discomfort**
Sept	**38.3**	**Discomfort**
Oct	**34**	**Discomfort**
Nov	**25.1***	**Comfort**
Dec	**22.3***	**Comfort**

Table 4.12 shows that on monthly basis the study area experiences both comfort and discomfort periods. For example in 2007 comfort period prevailed in February which had 23.3 THI, followed by November with 25.1 and then December which had 22.3, all of which are within 22 – 27^{o}C comfort limit for Zaria (tropical area). From observation, the study period 1975 to 2010 had similar pattern of monthly THI periods of comfort and discomfort. This change was a result of the nature of characteristics of the study area

Certain urban characteristic including structure and geometry can affect the pattern of movement and distribution of the air temperature and solar radiation with important implications for thermal comfort (Jonsson,2004

4.6.1 **Annual THI periods of comfort and discomfort for the study period.**

Temperature – Humidity Index formula was also used to estimate THI for each year. The THI values that fell in-between 22 – 27 degrees Celsius comfort limit (tropical area), were termed as comfort periods in the study area while the THI values that were below 22 degrees Celsius or above 27 degrees Celsius were termed as discomfort periods. Furthermore, appendix v shows the average annual THI which were derived from average monthly THI. The annual discomfort periods were derived from the annual THI values.

However, the annual THI periods of comfort and discomfort is presented in table 4.16

Table 4.16 shows that throughout the period of the study 1975 to 2010, the study area experienced thermal discomfort, unlike that of monthly THI comfort and discomfort periods which had shown that some particular months are characterized by comfort while other are characterized by discomfort periods. However, annual THI

Table 4.13 Annual Temperature – Humidity Index (THI) and Human Comfort

Years	THI	Comfort limit	22-27^{o}C
1975	30.5	Discomfort	
1976	30.3	Discomfort	
1977	29.5	Discomfort	
1978	29.5	Discomfort	
1979	33.8	Discomfort	
1980	30.8	Discomfort	
1981	30.4	Discomfort	
1982	32.6	Discomfort	
1983	29.1	Discomfort	
1984	30.2	Discomfort	
1985	29.6	Discomfort	
1986	31.1	Discomfort	
1987	30.1	Discomfort	
1988	30.3	Discomfort	
1989	29.2	Discomfort	
1990	31.1	Discomfort	
1991	32.2	Discomfort	
1992	30.8	Discomfort	
1993	31.9	Discomfort	
1994	31.7	Discomfort	
1995	31.6	Discomfort	
1996	31.7	Discomfort	
1997	31.9	Discomfort	
1998	34	Discomfort	
1999	34.4	Discomfort	
2000	34.6	Discomfort	
2001	34.2	Discomfort	
2002	51.4	Discomfort	
2003	38.5	Discomfort	
2004	32.2	Discomfort	
2005	32.8	Discomfort	
2006	31.9	Discomfort	
2007	31.9	Discomfort	
2008	31.7	Discomfort	
2009	32.4	Discomfort	
2010	32.9	Discomfort	

periods of comfort and discomfort had shown that THI from 1975 -2010 was constantly above 22 – 27 degrees Celsius which is the comfort limit for Zaria. (Tropical humid area) see Appendix V. in addition these results implies that THI is dynamic over the study area. These

results, however, are also in concordant with those from Luterbacher et al. (2007), who pointed that out an overall THI increase in the Mediterranean basin in the period 1951–2007, and also that of THI dynamics in the study area were not spatially and temporally homogeneous.

4.7 Hypotheses Testing

This section tests hypotheses of the study. This is to show if temporal variation in temperature, relative humidity and THI exist within the study period (1975 – 2010)

4.7.1 Test for Temporal Variation in Temperature

Analysis of variance (ANOVA) statistical technique was employed at 0.05 significant level to test Temporal variation in Temperature. The result for hypothesis (1) is presented in Table 4.14

Table 4.14 ANOVA Results for Temporal Variation in Temperature (1975 – 2010)

Variance	Sum of Squares	DF.	Mean Square	F	P
Between Groups	35.68	3	11.89	4.12	0.014
Within Groups	92.39	32	2.89		
Total	128.07	35			

The result in table 4.14 shows that ‘f calculated = 4.12 and ‘f’’ tabulated = 2.92. Since ‘f’ calculated is greater than ‘f’ tabulated the null hypothesis is rejected. Therefore, the temporal variation in temperature between periods of the study is statistically significant. This is clear indication that there is a temporal variability in temperature over Zaria.

4.7.2 Test for Temporal Variation in Relative Humidity

The results for test of temporal variation in relative humidity is presented in Table 4.15

Table 4.15 ANOVA Results for Relative humidity (1975 – 2010)

Variance	Sum of Squares	DF.	Mean Square	F	P
Between Groups	324.8	3	108.3	7.85	0.000
Within Groups	441.4	32	13.8		
Total	766.3	35			

The result shown in Table 4.15 shows that 'f calculated = 7.85 and 'f'' tabulated = 2.92. Since 'f' calculated is greater than 'f' tabulated, the null hypothesis is rejected. Therefore, the temporal variation in relative humidity between periods of the study is statistically significant. This is clear indication that there is a temporal variability in Relative humidity in Zaria.

4.7.3. Test for Temporal Variation in THI.

The results for statistical test of temporal variation in THI are shown in Table 4.16.

The result shown in Table 4.16 shows that 'f calculated = 4.52 and 'f'' tabulated = 2.92. Since 'f' calculated is greater than 'f' tabulated, the null hypothesis is rejected. Therefore, the temporal variation in temperature – humidity index between periods of the study

Table 4.16 ANOVA Results for Temperature – Humidity Index (1975 – 2010)

Variance	Sum of Squares	DF.	Mean Square	F	P
Between Groups	148.6	3	49.5	4.52	0.009
Within Groups	350. 7	32	11.0		
Total	499.3	35			

is statistically significant. This is clear indication that there is a temporal variability in Temperature – Humidity Index in Zaria.

4.8 Determination of the Relationship between Temperature, Relative humidity and Temperature – Humidity index for Zaria

Hypothesis (11) is presented in Table 4.17

Table 4.17 Correlation Result for determination of the Relationship between Temperature, Relative humidity and Temperature – Humidity Index (THI)

Variables	N	Mean	S.D	Pearson correlation	p-value
Temperature	36	25.2750	1.01485	.858**	.000
Humidity	36	45.7389	4.67909	.876**	.001
THI	36	31.9472	2.21881	1	.000

**. Correlation is significant at the 0.01 level (2-tailed)

The result presented in Table 4.17 shows that there is positive relationship between Temperature, Humidity and Temperature Humidity Index. Temperature, relative humidity and Temperature humidity index has A p-value of.000, .001 and .000 respectively. These values are

less than 0.05α level of significance. The p-value signifies that there is a significant relationship between Temperature, humidity and temperature humidity index in the study area. The implication is that the three climate parameters exhibit near perfect correlation in the study. This implies that temperature, relative humidity and THI are directly related to each other. Hence, the study proved that slight increase or reduction in temperature and relative humidity would affect THI. This would in turn affect comfort range of 22-27 degrees Celsius selected for the study

CHAPTER FIVE: SUMMARY, CONCLUSION AND RECOMMENDATIONS.

5.1 INTRODUCTION

This chapter presents summary of the findings, conclusion and recommendations.

5.2 SUMMARY

This study focused on thermal comfort based on temperature – humidity index (THI) in Zaria for the period of 35 years (1975 – 2010). It was done to determine temperature and relative humidity range in the study area by taking their daily maximum and minimum values. It also sought to examine the temporal variation in temperature, relative humidity and temperature – humidity index (THI), using one way analysis of variance (ANOVA) at 0.05 significant level, and to establish the trend in temperature, relative humidity and temperature – humidity index using Time Series analysis, and also to examine the impact of temperature and relative humidity on THI, in order to determine if there is any relationship between them.

The types of data required were Daily minimum and maximum temperature and Relative humidity data for 36yrs (1975 – 2010). The source of data was secondary, which was obtained from Metrological Unit of Institute for Agricultural Research (IAR) ABU Zaria. Data were presented in percentages, tables and Line Graphs. Data were also analyzed using descriptive statistics and inferential statistics. This includes; Analysis of Variance (ANOVA), Time Series and Correlation analysis were statistical tools used in analyzing the data

Results show that the temperature and relative humidity range vary across the period of the study, in which 1998 has the highest maximum temperature range of 10^{o}C, and 1994 has the lowest minimum temperature range of 5.4^{o}C. Similarly, the Analysis of variance (ANOVA) for temporal variation in Temperature, Relative humidity and Temperature – Humidity Index,

revealed ‘f’ calculated as greater than ‘f’ tabulated at 0.05 statistical significance level. Temperature has f-calculated =4.12, RH=7.85 and THI=4.52. This is a clear indication that there is temporal variation in Temperature, Relative humidity and Temperature – Humidity Index.

Time Series analysis established the trend in temperature, relative humidity and temperature – humidity index with a positive slope trend line equation of y= 0.063× + 2409 for temperature, y= 0.094× + 4327 for relative humidity and y=0.092× + 2997 for THI.

Relating THI and human comfort, it was observed that on monthly basis some THI values were within the 22 – 27 degrees Celsius comfort limit while others were either below 22 degrees Celsius or above 27 degrees Celsius which indicates discomfort periods. The remaining years of the study followed the same pattern. Based on annual THI and human comfort, throughout the study period, the comfort limit was consistently higher than 22 – 27 degrees Celsius comfort limit for Zaria, thus the results revealed a thermal discomfort situation. Also the result of correlation analysis with p-value of .000, .001 and .000 indicate that temperature, relative humidity and temperature - humidity index are correlated, therefore they have a significant relationship. The comfort limit recommended by Koenigsberger et al (1974) has been found reliable in determining monthly and annual comfort and discomfort periods in the study area.

5.3 CONCLUSION

This study was an effort to analyze thermal comfort based on the temperature – humidity index (THI) of Zaria. Therefore, from the results of this research, it was concluded that the result of objective one revealed that the monthly and annual range of Temperature and Relative Humidity vary across the period of the study (1975-2010). Highest maximum temp range of 10

degrees Celsius was recorded for 1998 while lowest minimum temp of 5.4 degrees Celsius was recorded for 1994, across 36yrs. The analysis further revealed that there is temporal variability in Temperature, Relative humidity and Temperature – Humidity Index over Zaria. The study also showed that on the average, in every additional year, throughout 36years study period, temperature, relative humidity and temperature – humidity kept increasing as indicated by their respected values of linear trend line equation : temp=0.06, RH = 0.09, THI = 0.09. However, based on correlation analysis the study revealed that there is significant relationship between temperature, Relative humidity and THI, which implies that the higher the temperature and relative humidity the higher the THI. The index also has effect on comfort range of the study area.

Finally, the temperature – humidity index (THI) can be employed to study the level of indoor thermal comfort in case studies, particularly in tropical countries with a high level of humidity and outdoor temperature.

5.4 RECOMMENDATIONS

From the foregoing, our natural environment and the elements therein are by no means beyond our control even though there is a limit to the control man has over them. Temperature – Humidity Index (THI) is one of the thermal indices that affect human thermal comfort index. The effect is apparent in the continuous thermal discomfort in the study area. The effect of THI on human comfort cannot be avoided completely but it can be minimized by:

i. Urban planning: When town is too congested heat increases. Therefore, houses should be built based on consideration of space for free movement of air

ii. Housing Design: Structures of houses, like the colour of roofs should be less heat absorbent and the windows should be wide enough to allow proper ventilations

iii. Substantial tree planting would provides shades, and greening of areas for recreational activities (micro climate) and Specialized Research Programmes (SRP) in the aspect of thermal comfort indices in the area. This can be implemented through funding of such research by association of climate scientist and other organizations that have concern with climate change issue.

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APPENDIX I (a)

MAXIMUM AND MINIMUM TEMPERATURE (^{O}C) RANGE AND THIER AVERAGES (1975 – 1977)

m/y	1975						1976						1977					
	MAX			MIN			MAX			MIN			MAX			MAX		
	max	min	Range	max	min	range	Max	min	range	Max	min	range	max	min	range	max	min	range
Jan	29	22	7	15	10	5	34	25	10	18	10	8	32	25	8	16	9	6
Feb	35	28	7	18	13	5	37	31	6	21	15	6	34	26	8	17	11	6
Mar	38	28	10	24	16	8	37	31	6	23	15	6	37	25	12	24	16	8
Apr	38	31	7	27	17	10	37	32	5	24	17	7	39	34	5	26	16	10
May	33	29	4	24	19	6	34	28	6	25	16	9	37	29	8	25	17	8
Jun	34	27	7	22	17	5	32	21	11	23	17	6	33	28	5	23	17	6
July	31	22	9	22	18	4	30	24	6	21	17	4	33	26	5	23	17	6
Aug	30	24	6	21	18	3	31	25	6	20	17	3	31	24	7	22	16	6
Sept	32	25	7	21	17	4	32	26	6	21	18	3	32	27	5	21	10	11
Oct	33	28	3	20	12	8	31	25	6	21	18	3	33	26	7	15	9	6
Nov	34	28	4	18	11	7	32	25	7	18	9	9	34	28	6	15	9	6
9De6c	33	25	3	16	10	6	34	25	9	15	8	7	32	23	9	15	9	6
Avr			6.5			5.7			6.9			6.1			7			7

APPENDIX 1 (b)

MAXIMUM AND MINIMUM TEMPERATURE (^{O}C) RANGE AND THEIR AVERAGES (1978 – 1980)

m/y	1978						1979						1980					
	MAX			MIN			MAX			MIN			MAX			MAX		
	max	min	Range	max	min	range	max	min	range	max	min	range	max	min	range	max	Min	range
Jan	35	24	11	11	8	8	33	27	5	18	11	4	36	27	9	16	11	5
Feb	37	29	8	19	13	6	36	32	4	19	13	5	37	25	12	20	11	9
Mar	38	30	8	23	15	8	39	30	9	24	16	8	40	32	8	23	15	8
Apr	38	26	12	25	17	8	39	32	7	26	15	10	40	32	8	26	18	8
May	35	27	8	22	17	5	35	29	6	24	18	6	36	27	9	24	19	5
Jun	32	25	7	22	17	5	33	27	6	23	17	6	32	27	5	23	13	10
July	31	22	9	23	17	6	31	25	6	22	17	5	35	25	9	21	18	3
Aug	31	24	7	22	18	4	31	25	6	22	18	4	32	24	8	21	16	5
Sept	31	25	6	20	17	3	32	27	5	21	16	5	32	24	4	21	16	5
Oct	34	23	10	21	15	6	34	30	3	21	13	7	34	28	6	22	13	9
Nov	33	25	8	19	11	8	35	27	8	21	12	9	35	28	7	22	11	6
Dec	32	26	6	15	10	8	33	25	8	15	9	6	35	21	14	16	6	10
Avr			8.3			6			6			6.2			8.2			6.9

APPENDIX 1 (c)

MAXIMUM AND MINIMUM TEMPERATURE (^{O}C) RANGE AND THEIR AVERAGES (1981 – 1983)

m/y	1981						1982						1983					
	MAX			MIN			MAX			MIN			MAX			MIN		
	max	min	Range	max	min	range	max	min	range	max	min	range	Max	min	range	max	Min	range
Jan	33	24	9	20	7	19	35	25	10	16	8	8	29	18	9	16	12	4
Feb	37	25	12	18	12	6	36	22	13	20	11	9	37	26	11	21	15	6
Mar	38	26	12	22	16	6	38	28	10	24	15	9	38	29	9	23	14	9
Apr	39	31	8	25	16	9	38	28	10	39	15	24	41	33	8	25	15	9
May	35	26	9	23	2	21	36	30	5	24	19	5	39	29	9	26	15	11
Jun	37	25	12	27	18	9	34	28	6	23	18	4	39	28	7	25	16	9
July	31	24	7	21	17	4	34	25	7	23	18	4	33	24	9	26	15	11
Aug	31	25	6	22	17	5	30	24	6	21	18	3	33	25	8	18	14	4
Sept	32	27	5	21	18	3	32	27	5	21	17	4	32	25	7	19	16	3
Oct	35	30	5	22	13	8	33	29	4	20	17	3	33	21	12	17	10	7
Nov	33	24	9	17	10	7	34	25	9	19	10	9	34	28	6	15	10	5
Dec	33	27	6	15	9	6	34	26	8	22	12	10	34	25	9	16	9	7
Avr			8.3			8.5			7.7			7.6			7.5			6.9

APPENDIX 1 (d)

MAXIMUM AND MINIMUM TEMPERATURE (^{O}C) RANGE AND THEIR AVERAGES (1984 – 1986)

m/y	1984						1985						1986					
	MAX			MIN			MAX			MIN			MAX			MAX		
	max	min	Range	max	min	range	max	min	range	max	min	range	max	min	range	max	Min	range
Jan	33	20	13	15	8	7	35	24	11	17	12	5	35	24	10	15	10	5
Feb	35	24	11	19	10	9	33	26	7	20	10	10	39	32	7	18	13	5
Mar	39	32	11	24	16	5	39	30	9	25	16	9	38	30	8	23	13	10
Apr	38	27	8	25	20	6	38	28	10	26	17	9	40	34	6	24	18	6
May	35	27	8	24	18	6	37	29	8	25	17	8	38	28	10	24	18	6
Jun	34	28	6	22	18	4	33	27	6	21	15	6	34	24	10	23	17	6
July	32	24	8	21	17	4	31	24	7	20	14	6	30	24	6	21	18	3
Aug	32	26	6	22	17	5	31	24	7	18	13	5	30	23	7	21	17	4
Sept	31	25	6	20	17	3	31	25	6	20	15	5	31	24	7	22	16	6
Oct	32	28	4	21	14	7	33	30	3	20	10	10	33	28	5	21	12	9
Nov	33	26	7	17	10	7	35	30	5	17	11	7	35	28	7	20	10	10
Dec	31	22	9	15	10	5	35	25	8	16	10	6	33	21	12	16	10	6
Avr			8			5.6			7.2			7			7.9			6.3

APPENDIX 1 (e)

MAXIMUM AND MINIMUM TEMPERATURE (^{O}C) RANGE AND THEIR AVERAGES (1987 – 1989)

m/y	1987						1988						1989					
	MAX			MIN			MAX			MIN			MAX			MAX		
	max	min	Range	max	min	range	max	min	range	max	min	range	max	min	range	max	Min	range
Jan	35	26	9	17	10	7	35	24	11	17	9	8	29	21	8	14	7	7
Feb	37	29	8	19	14	5	38	25	13	20	13	7	36	23	13	16	11	5
Mar	40	29	11	26	14	12	38	33	5	26	16	10	37	32	5	22	12	10
Apr	40	27	13	26	16	10	39	28	11	26	15	11	39	34	5	25	15	10
May	40	30	10	25	18	6	39	27	12	25	20	5	36	26	10	22	16	6
Jun	35	25	10	23	18	5	34	24	10	23	18	5	35	24	11	23	17	6
July	32	26	6	23	18	5	31	23	8	22	17	5	31	26	5	21	18	3
Aug	31	27	4	22	17	5	30	21	9	21	17	4	30	24	6	21	18	3
Sept	32	29	3	22	19	3	32	25	6	21	17	4	32	24	8	21	17	4
Oct	33	29	4	21	13	8	33	27	6	21	12	9	32	28	4	20	11	9
Nov	35	29	6	15	10	5	34	30	4	15	8	7	33	29	4	16	9	7
Dec	34	26	8	16	10	6	33	20	23	14	10	4	33	24	9	16	9	7
Avr			7.6			6.4			9.8			6.5			7.3			6.4

APPENDIX 1 (f)

MAXIMUM AND MINIMUM TEMPERATURE (^{O}C) RANGE AND THEIR AVERAGES (1990 – 1992)

m/y	1990						1991						1992					
	MAX			MIN			MAX			MIN			MAX			MAX		
	max	min	Range	max	min	range	max	min	range	max	min	range	Max	min	range	max	Min	range
Jan	36	26	10	15	10	5	34	23	11	16	12	4	34	19	15	17	8	9
Feb	35	26	9	19	11	8	39	31	8	22	14	8	36	25	11	18	13	5
Mar	39	30	9	23	16	7	38	29	9	25	18	7	38	29	9	24	15	9
Apr	39	32	7	26	20	6	39	30	9	26	20	6	39	32	7	25	19	6
May	36	25	11	25	20	5	35	27	8	24	19	5	36	27	9	25	19	6
Jun	35	27	8	24	17	7	33	28	5	23	19	4	37	28	9	23	18	23
July	31	25	6	22	15	7	31	24	7	22	18	4	30	25	5	22	17	5
Aug	32	25	7	22	18	4	30	25	5	21	18	3	30	24	6	21	18	3
Sept	33	28	5	21	17	4	33	29	4	22	19	3	32	26	6	21	17	4
Oct	34	30	4	22	14	8	33	30	3	22	12	10	28	26	2	29	10	19
Nov	35	32	3	21	12	9	34	29	5	22	11	11	34	25	9	20	12	8
Dec	36	32	4	20	10	10	34	23	11	22	11	11	34	25	9	21	9	12
Avr			6.9			6.6			7			6.4			8			9

APPENDIX 1 (g)

MAXIMUM AND MINIMUM TEMPERATURE (^{O}C) RANGE AND THEIR AVERAGES (1993 – 1995)

m/y	1993						1994						1995					
	MAX			MIN			MAX			MIN			MAX			MAX		
	max	min	Range	max	min	range	max	min	range	max	min	range	max	min	range	max	Min	range
Jan	33	19	14	17	18	9	35	22	13	18	10	8	34	23	11	15	7	8
Feb	37	26	11	18	11	7	36	23	13	19	13	6	36	20	20	17	10	7
Mar	38	28	10	22	14	8	39	36	3	23	9	14	38	32	6	23	15	8
Apr	39	34	5	32	19	13	39	32	7	25	20	5	39	30	9	23	14	9
May	38	31	7	25	20	5	36	29	7	24	20	5	37	28	9	19	15	4
Jun	40	28	12	23	19	4	34	26	8	22	18	4	37	28	9	22	14	8
July	32	26	6	22	18	4	31	27	4	22	18	4	32	27	5	24	18	6
Aug	30	24	6	21	18	3	30	25	5	22	18	4	31	27	4	23	17	6
Sept	32	28	4	22	18	4	32	25	7	21	17	4	33	26	7	24	17	7
Oct	44	31	13	22	12	10	33	25	8	20	17	3	34	29	5	21	14	7
Nov	35	29	6	16	12	4	32	27	5	24	10	4	32	25	7	18	12	6
Dec	33	26	7	17	11	6	30	22	8	14	10	4	37	32	5	23	12	11
Avr			8.4			6.4			7.3			5.4			8			7.2

APPENDIX 1 (h)

MAXIMUM AND MINIMUM TEMPERATURE (^{O}C) RANGE AND THEIR AVERAGES (1996 – 1998)

	1996						1997						1998					
	MAX			MIN			MAX			MIN			MAX			MAX		
	max	min	Range	max	min	range	max	min	range	max	min	range	max	min	range	max	Min	range
Jan	35	30	5	12	19	3	37	28	10	16	10	6	38	22	16	18	9	9
Feb	38	29	9	25	11	14	34	24	10	18	9	9	39	27	12	21	15	6
Mar	38	35	3	23	18	5	36	27	11	24	14	10	39	28	11	24	17	7
Apr	38	36	2	24	20	4	41	25	16	24	16	8	41	24	17	26	20	6
May	39	28	11	25	18	7	36	22	14	24	18	6	37	23	14	25	20	5
Jun	32	26	6	23	16	7	32	26	6	23	17	6	39	28	11	32	12	20
July	30	25	5	22	17	5	32	22	6	22	12	10	34	29	5	24	17	7
Aug	38	23	15	22	18	4	39	23	16	22	18	4	35	29	6	25	21	4
Sept	32	24	8	25	17	8	33	24	9	22	17	4	39	28	5	25	19	6
Oct	33	28	5	22	14	8	34	28	6	20	10	5	33	243	9	25	20	5
Nov	36	28	8	15	10	5	36	30	6	16	10	10	36	28	8	25	15	10
Dec	36	29	7	14	9	5	35	27	8			6	36	30	6	23	14	9
Avr			7			6.2			9.8			7			10			7.8

APPENDIX 1 (i)

MAXIMUM AND MINIMUM TEMPERATURE (^{O}C) RANGE AND THEIR AVERAGES (1999 – 2001)

m/y	1999						2000						2001					
	MAX			MIN			MAX			MIN			MAX			MAX		
	max	min	Range	max	min	range	max	Min	range	max	min	range	max	min	range	max	Min	range
Jan	37	28	9	20	12	8	38	25	13	21	14	7	36	27	9	23	12	11
Feb	39	29	10	22	16	6	44	36	8	25	15	10	39	28	11	21	13	8
Mar	40	36	4	27	20	7	44	33	11	27	18	9	40	33	7	24	18	6
Apr	40	33	7	27	22	5	42	36	6	27	21	6	40	30	10	27	20	7
May	40	31	9	26	20	6	41	32	9	27	21	6	38	29	9	27	20	7
Jun	36	27	11	26	21	5	35	26	9	25	20	5	35	26	9	25	20	5
July	39	26	13	24	19	5	34	26	8	25	20	5	33	26	7	24	20	4
Aug	32	26	6	24	20	4	31	25	6	24	19	5	33	26	7	24	20	4
Sept	34	27	7	24	20	4	33	25	8	25	19	6	33	27	6	24	20	4
Oct	34	28	6	24	16	8	35	28	7	24	16	8	34	31	3	23	15	8
Nov	38	30	8	21	14	7	35	31	4	19	12	7	36	28	8	22	12	10
Dec	34	27	7	17	13	4	36	25	11	24	13	11	36	26	10	20	14	6
Avr			8			5.7			8.3			7			8			6.6

APPENDIX 1 (j)

MAXIMUM AND MINIMUM TEMPERATURE (^{O}C) RANGE AND THEIR AVERAGES (2002 – 2004)

m/y	2002						2003						2004					
	MAX			MIN			MAX			MIN			MAX			MAX		
	max	Min	Range	max	min	range	max	min	range	max	min	range	max	min	range	max	Min	range
Jan	32	22	10	18	13	5	38	28	10	20	13	7	37	27	10	20	11	9
Feb	39	27	12	22	15	7	39	29	10	23	16	7	36	26	10	21	13	8
Mar	40	32	8	26	20	6	40	33	7	25	18	7	40	26	14	24	14	10
Apr	40	35	5	28	21	7	45	32	13	27	20	7	42	29	13	28	21	7
May	41	31	10	27	22	5	41	31	10	28	20	8	38	30	8	25	17	8
Jun	36	28	8	25	20	5	35	29	6	26	21	5	34	28	6	22	18	4
July	34	27	7	24	20	4	35	27	8	25	20	5	33	27	6	22	18	4
Aug	32	26	6	24	20	4	31	24	7	24	20	4	33	26	7	25	17	8
Sept	34	26	8	24	20	4	33	27	6	25	20	5	34	28	6	22	18	4
Oct	34	27	7	24	16	8	35	30	5	25	20	5	37	32	5	24	16	8
Nov	35	26	9	21	13	8	35	30	5	23	15	8	38	29	9	39	10	29
Dec	36	27	9	19	11	8	35	27	8	18	12	6	36	30	6	19	14	5
Avr			8.2			5.9			7.9			6.1			8.3			8.6

APPENDIX 1 (k)

MAXIMUM AND MINIMUM TEMPERATURE (^{O}C) RANGE AND THEIR AVERAGES (2005 – 2007)

m/y	2005						2006						2007					
	MAX			MIN			MAX			MIN			MAX			MAX		
	max	Min	Range	max	min	range	max	min	range	Max	min	range	Max	min	range	max	min	range
Jan	38	21	17	19	11	8	38	30	8	19	11	8	35	23	12	17	11	6
Feb	40	31	9	24	18	9	40	33	7	23	15	8	39	31	8	19	13	6
Mar	41	37	4	27	19	8	40	31	9	23	16	7	41	33	8	25	16	9
Apr	41	28	13	27	18	9	40	35	5	27	16	11	41	32	9	26	20	6
May	39	29	10	25	20	5	40	27	13	26	17	9	37	30	7	24	17	7
Jun	37	25	12	23	19	4	35	27	8	23	18	5	34	28	6	22	18	4
July	34	26	8	23	19	4	33	29	4	23	18	5	33	21	12	23	18	5
Aug	32	25	7	23	18	5	32	27	5	22	19	3	32	26	6	26	14	12
Sept	34	28	6	22	18	4	33	28	5	22	18	4	34	27	7	22	16	6
Oct	35	30	5	22	13	9	35	28	7	23	14	9	37	32	5	22	11	11
Nov	38	32	6	19	12	7	35	27	8	17	8	9	37	33	4	19	11	8
Dec	38	29	9	17	12	5	33	25	8	16	8	8	37	27	10	17	11	6
Avr			8.8			6.4			7.2			7.1			7.8			7.1

APPENDIX 1 (l)

MAXIMUM AND MINIMUM TEMPERATURE (^{O}C) RANGE AND THEIR AVERAGES (2008 – 2010)

m/y	2008						2009						2010					
	MAX			MIN			MAX			MIN			MAX			MAX		
	max	Min	Range	max	min	range	max	min	range	Max	min	range	max	min	range	max	min	range
Jan	33	24	9	18	19	9	38	27	11	18	12	6	39	28	11	18	19	9
Feb	38	21	17	24	9	15	39	32	7	19	12	7	40	31	9	22	13	9
Mar	41	36	5	26	16	10	40	34	6	23	16	7	41	31	10	26	16	10
Apr	41	30	11	24	18	6	40	33	7	26	19	7	42	31	11	26	19	7
May	39	28	11	24	18	6	40	28	12	26	19	7	39	29	10	24	19	5
Jun	36	30	6	23	17	6	38	28	10	23	18	5	35	29	6	23	16	7
July	33	26	7	22	18	4	34	27	7	22	18	4	32	26	7	22	17	5
Aug	33	28	5	21	18	3	33	35	8	25	18	7	33	27	6	23	17	6
Sept	34	27	7	29	22	7	34	27	7	22	18	4	35	27	8	28	19	9
Oct	35	29	6	22	12	10	34	30	4	22	18	4	35	28	7	23	19	4
Nov	37	30	7	18	11	7	36	29	7	20	12	8	36	28	8	21	14	7
Dec	38	24	14	24	12	12	36	31	5	16	9	7	35	25	10	18	9	9
Avr			8.7			7.4			7.5			6			7.2			7.2

APPENDIX II (a)

RANGE OF RELATIVE HUMIDITY IN ZARIA (1975 – 1980)

m/y	1975			1976			1977			1978			1979			1980		
	H	L	R	H	L	R	H	L	R	H	L	R	H	L	R	H	L	R
Jan	37	8	29	22	8	14	49	8	41	29	10	19	23	4	19	36	8	28
Feb	33	5	28	77	4	73	39	6	33	45	9	36	29	8	21	20	6	14
Mar	66	6	57	58	6	52	66	4	62	75	8	67	72	8	64	59	6	53
Apr	76	29	47	72	5	67	56	9	46	82	51	41	72	10	62	62	9	53
May	77	52	25	77	54	23	81	23	58	84	55	29	87	53	34	91	42	49
Jun	76	56	20	87	58	29	89	58	31	100	62	38	87	57	30	84	66	18
Jul	97	69	28	91	71	20	93	60	33	93	71	22	100	66	34	95	67	28
Aug	99	63	36	100	72	28	95	59	36	100	65	35	98	65	33	100	71	29
Sept	92	64	28	87	64	23	94	56	38	98	60	38	96	63	33	84	61	23
Oct	84	26	58	100	57	43	89	18	71	80	47	33	80	30	50	86	24	62
Nov	84	13	71	82	11	71	34	14	20	70	15	55	74	14	60	52	19	33
Dec	42	9	33	41	8	33	33	12	21	25	10	15	33	8	25	32	8	24
Avr			38.3			39.6			40.8			35.6			38.7			34.5

APPENDIX II (b)

RANGE OF RELATIVE HUMIDITY IN ZARIA (1981 – 1986)

m/y	1981			1982			1983			1984			1985			1986		
	H	L	R	H	L	R	H	L	R	H	L	R	H	L	R	H	L	R
Jan	26	7	19	35	7	28	31	11	20	25	9	16	55	9	46	33	15	18
Feb	18	5	13	50	9	41	20	6	14	30	1	29	30	4	26	41	4	37
Mar	59	6	53	56	6	50	51	6	45	63	5	58	85	6	77	61	11	50
Apr	76	5	71	84	7	77	56	5	51	85	6	79	81	7	74	65	46	19
May	100	53	47	77	53	24	82	39	43	98	47	51	83	52	31	85	32	53
Jun	94	56	38	87	58	29	87	58	29	91	52	39	99	62	37	84	53	31
Jul	99	69	30	95	68	27	95	70	25	95	61	34	100	71	29	95	71	24
Aug	98	65	33	96	66	30	94	52	42	91	62	29	100	69	31	96	68	28
Sept	91	64	27	95	60	35	96	63	33	95	66	29	100	59	41	88	54	34
Oct	88	23	65	85	53	32	80	15	65	84	26	58	85	21	64	85	24	61
Nov	31	10	21	58	10	48	43	9	34	54	14	40	65	7	58	67	15	54
Dec	58	11	47	22	9	13	28	11	17	31	16	15	37	16	21	49	8	41
Avr			38.6			36.1			34.8			39.7			44.5			37.5

APPENDIX II (c)

RANGE OF RELATIVE HUMIDITY IN ZARIA (1987 – 1993)

m/y	1987			1988			1989			1990			1991			1992			1993		
	H	L	R	H	L	R	H	L	R	H	L	R	H	L	R	H	L	R	H	L	R
Jan	49	9	40	38	10	28	37	18	19	28	10	18	53	1	52	33	11	22	39	11	28
Feb	23	7	16	95	7	88	27	5	22	21	6	15	49	9	40	34	2	32	46	4	42
Mar	58	6	52	65	2	63	62	6	56	24	3	21	83	5	78	73	2	71	66	9	57
Apr	58	3	55	81	9	72	67	5	62	62	6	56	77	9	68	73	7	66	68	8	60
May	80	5	75	80	7	73	79	30	49	89	43	46	88	63	25	83	50	33	77	40	37
Jun	90	58	38	91	55	36	95	52	43	89	62	27	91	66	25	86	17	69	97	58	39
Jul	98	65	33	96	72	24	95	66	29	90	69	21	93	67	26	97	55	42	91	68	23
Aug	95	77	18	98	72	26	94	69	25	99	68	31	95	73	22	94	63	31	97	72	25
Sept	87	64	23	90	49	41	96	8	88	84	65	19	85	61	24	93	61	32	87	61	26
Oct	87	24	63	83	24	59	87	5	82	88	20	68	85	60	25	86	23	63	80	38	42
Nov	31	16	15	54	15	39	26	11	15	66	12	54	85	27	58	84	18	66	57	23	34
Dec	31	15	16	36	18	18	27	11	16	68	9	59	37	12	25	98	12	86	66	19	47
Avr			37			47.2			42.1			36.2			39			51			38.3

APPENDIX II (d)

RANGE OF RELATIVE HUMIDITY IN ZARIA (1994 – 2000)

m/y	1994			1995			1996			1997			1998			1999			2000		
	H	L	R	H	L	R	H	L	R	H	L	R	H	L	R	H	L	R	H	L	R
Jan	57	11	46	61	17	44	33	14	19	46	9	37	45	3	42	30	11	19	49	9	40
Feb	23	4	19	56	13	43	56	8	48	26	6	20	22	2	20	47	8	39	28	6	22
Mar	42	7	35	42	8	34	68	13	50	62	5	57	45	6	39	55	8	47	65	3	62
Apr	74	5	69	78	12	66	70	30	40	83	5	78	82	3	79	75	3	72	71	8	63
May	91	57	34	85	59	26	84	50	34	87	62	25	86	48	38	78	39	39	84	13	71
Jun	86	66	20	84	53	31	88	58	30	91	46	45	95	58	37	89	52	37	100	67	33
Jul	92	76	16	91	61	30	92	52	40	92	76	16	91	67	24	96	77	19	96	77	19
Aug	93	75	18	90	69	21	92	54	38	95	71	24	95	79	16	99	76	23	99	76	23
Sept	95	70	25	96	70	26	91	7	84	91	70	21	97	71	26	99	76	23	100	66	34
Oct	91	66	25	84	29	55	96	32	64	90	68	22	88	42	46	90	49	41	88	30	58
Nov	84	8	76	84	8	76	32	14	18	78	8	70	63	18	45	77	18	59	66	18	48
Dec	45	9	36	27	12	15	23	11	12	33	3	30	50	16	34	40	13	27	53	13	40
Avr			34.9			38.9			39.7			37.8			37.1			37			42.7

APPENDIX II (e)

RANGE OF RELATIVE HUMIDITY IN ZARIA (2001 – 2007)

m/y	2001			2002			2003			2004			2005			2006			2007		
	H	L	R	H	L	R	H	L	R	H	L	R	H	L	R	H	L	R	H	L	R
Jan	39	12	27	64	11	53	81	34	47	26	6	20	30	9	21	26	7	19	30	4	26
Feb	47	7	40	32	8	24	84	43	41	21	6	15	53	10	43	68	5	63	53	6	47
Mar	47	3	44	72	14	58	94	38	56	62	4	58	61	5	56	47	3	44	60	5	55
Apr	91	8	83	85	9	76	89	35	54	72	9	63	78	4	74	61	2	59	74	8	66
May	87	59	28	88	68	20	95	45	50	82	46	36	86	46	40	97	55	42	87	36	51
Jun	100	63	37	93	68	25	95	53	42	89	63	26	95	59	36	89	44	45	98	65	33
Jul	97	80	17	95	86	9	98	69	29	87	42	45	97	70	27	87	61	26	97	23	74
Aug	100	80	20	95	81	14	100	75	25	97	68	29	98	52	46	96	69	27	90	7	83
Sept	97	79	18	99	77	22	98	57	41	89	59	30	92	63	29	97	65	32	91	58	33
Oct	91	34	57	96	77	19	85	37	48	80	23	59	95	19	76	92	30	62	74	25	49
Nov	54	14	40	85	30	55	85	12	73	62	11	51	55	11	44	34	14	20	61	11	50
Dec	41	14	27	80	22	57	29	11	18	31	7	24	35	7	28	28	8	17	32	10	22
Avr			36.5			36			43.6			38			43.2			38			

APPENDIX II (f)

RANGE OF RELATIVE HUMIDITY IN ZARIA (2008 – 2010)

m/y	2008			2009			2010		
Jan	28	9	19	37	6	31	23	6	17
Feb	28	4	24	28	4	24	18	7	11
Mar	48	1	47	32	3	29	57	2	55
Apr	76	5	71	65	25	40	80	5	75
May	87	29	58	91	44	47	86	46	40
Jun	84	52	32	89	49	40	90	31	59
Jul	94	68	26	87	53	34	100	69	31
Aug	89	70	19	98	71	27	96	28	68
Sept	85	71	14	98	63	35	97	69	28
Oct	87	22	65	84	33	51	94	37	57
Nov	32	7	25	75	18	57	59	13	46
Dec	67	10	57	24	8	16	31	10	21
Avr			42.2			35.9			42.3

APPENDIX III

AVERAGE MONTHLY TEMPERATURE (^{o}C) OF ZARIA FROM 1975 TO 2010

Yr/m	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept.	Oct	Nov	Dec	Average
1975	19	24	27	28.5	26	25.5	23.5	23.5	25	24	23.5	21	24.2
1976	21	25	27	28	26.5	24	23.5	23.5	24	24	21.5	20.5	24
1977	21	22.5	25.5	29	28	25.5	25	24	25	24	21.5	20	24.2
1978	21	22.5	25.5	29	28	25.5	25	24	25	24	21.5	20	24.2
1979	22	25	27.5	28.5	27	25.5	24.5	24.5	46	25	23.5	20	26.5
1980	22	24	27.5	29.5	27	25	24.5	24	25	25.5	23	20.5	24.7
1981	22.5	24.5	27	28	26	26	24	24.5	24.5	25	21.5	21.5	24.5
1982	22	23	27.5	44.5	27.5	26	25	23.5	25	25	22	22	26
1983	19	25.5	25	29	28.5	26	26	23	23.5	23	22.5	22	24.4
1984	20	23.5	28.5	29	26.5	25.5	24	25	24	24.5	22	20.5	24.4
1985	23.5	22.5	28.5	28.5	27.5	24.5	22.5	22.5	23.5	23	22.5	20.5	24.1
1986	21.5	25.5	27.5	29.5	28	25.5	24	24	24	24.5	23	21.5	24.8
1987	21.5	24.5	27.5	29	29.5	26	25	24.5	25	24	22	21.5	25
1988	21	24	28.5	29	29	25.5	24	23.5	24	23.5	22	20	24.5
1989	17.5	20.5	26.5	28.5	26.5	25	24.5	23.5	24.5	23.5	22	24	23.8
1990	22	22.5	25.5	30	27.5	26	24.5	24.5	25.5	25.5	25	23.5	25.1
1991	22	25.5	28	29	26	25.5	24	24	25.5	25	22.5	20.5	24.7
1992	19	22.5	28	28.5	27.5	25.5	24	23.5	24.5	27.5	22.5	21	24.5
1993	19	23.5	27	30.5	28	26.5	24.5	24	25	25.5	24	21.5	24.9
1994	21.5	24	28	29	27.5	25.5	24.5	23.5	24.5	25	21.5	19	24.4
1995	19	21.5	27	27.5	25.5	24	26	24.5	25	25.5	21.5	28.5	24.6
1996	21	25.5	29.5	30.5	28.5	24.5	23.5	24	25	24.5	21.5	22.5	25
1997	22.5	21	27	28.5	26.5	25	24.5	24.5	25	25.5	23.5	21.5	24.5
1998	21.5	25	26.5	30	28.5	27	26	27	26.5	26	27	24.5	26.2
1999	24.5	27.5	30.5	31.5	30.5	27.5	26	25	26	26	25.5	23	26.9
2000	25	28	29.5	32.5	31	27	26	25	26.5	26.5	24.5	24	27.1
2001	23	24.5	29.5	30	29.5	27.5	26	26	26.5	26.5	24.5	24.5	26.5
2002	21.5	26	30	31	30	28	26.5	25	26.5	26.5	24	23	26.5
2003	24.5	27.5	29.5	31.5	30.5	27.5	26.5	26	26.5	27.5	26	23.5	27.2
2004	24	24	20.5	32	28	25.5	25	24.5	26	28	27.5	24.5	25.7
2005	22	28.5	31	30.5	28.5	26.5	25.5	25	26	25.5	24.5	23.5	26.4
2006	25.5	27.5	29	30	27.5	26.5	26	25	25.5	26.5	22	21.5	26
2007	21	25.5	28	30.5	28	25.5	25.5	25	26	26.5	25	23	25.7
2008	21.5	24	29.5	29.5	28.5	27	25.5	24.5	28	25.5	23.5	23	25.8
2009	24	26.5	29	30.5	28.5	27	25.5	25	26	26.5	23.5	23	26.2
2010	23.5	27	29	30.5	29	27	24.5	25	26	27	25	22.5	26.3

APPENDIX IV

AVERAGE MONTHLY RELATIVE HUMIDITY (%) OF ZARIA FROM 1975 TO 2010

Yr/month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1975	17	9.5	21.5	41.5	62.5	62.5	76	76	70.5	45.5	23.5	17	43.5
1976	15	20	15	34	59.5	69.5	74.5	74	68	70.5	34.5	18.5	46
1977	20	11.5	14	20.5	48.5	66.5	70	76	70.5	54.5	21.5	21.5	41.2
1978	19	11.5	14	20.5	48.5	66.5	70	76	70.5	54.5	21.5	21.5	41.1
1979	13.5	15	23.5	38	56	68.5	77	76.5	70.5	54.5	31.5	19.5	45.3
1980	16	14	17.5	31	60.5	69.5	75	77.5	68	55	24.5	19	43.9
1881	15	11	18.5	34.5	56.5	65	76	75.5	71	53.5	23	19	43.2
1982	18.5	19	18.5	45	56.5	66.5	71	76.5	70.5	59.5	20.5	15	44.7
1983	18.5	10.5	14	17.5	51.5	62.5	73	88.5	68.5	30	17.5	16	39
1984	14	11.5	21.5	38	60	62	71	70	70.5	56	22.5	20.5	43.1
1985	16	12	30.5	24	55.5	68	81	75.5	73	39	22.5	23.5	43.3
1986	20	18	28.5	39.5	49.5	63.5	75.5	76.5	71	53.5	30	23.5	45.7
1987	20	11	22.5	13.5	38	68	72.5	79.5	69.5	49	21	21.5	40.5
1988	20.5	16.5	17.5	38	50	67.5	75.5	78.5	72	41	21	23	43.4
1989	22	16	14.5	29	52.5	65.5	71.5	75.5	71.5	47.5	19	18	41.8
1990	16	11.5	9	34.5	59.5	68.5	72.5	74.5	68.5	53	29	23.5	43.3
1991	19	22	22.5	43.5	69	71.5	75	78	65.5	53		19	48.9
1992	19	11	19.5	35	57.5	65	75.5	79	72	51.5	33.5	25	45.2
1993	21	21	30	38	55	61.5	67.5	72	67.5	58.5		27.5	47.2
1994	20.5	13	23	42.5	56.5	64.5	74	81.5	79	71	37	31.5	49.5
1995	26	24	28	36	57.5	53.5	73.5	79	76	63.5	41	21	48.2
1996	20	20.5	31.5	44	59	63	69.3	78	73.5	60	23.5	16.5	46.5
1997	16	13	21	45.5	63	73	76.5	78	76	73	36.5	18	49.1
1998	15.5	11.5	11.5	36	67.5	73.5	79	85	79.5	71.5	29.5	24.5	48.7
1999	18	16	27.5	32.5	50.5	69	79.5	83	81	65.5	32.5	21.5	48
2000	27	14.5	13.5	37.5	51	72	78.5	83	77.5	63.5	34	26	48.1
2001	19	19.5	15.5	42.5	62	72.5	80	85	87	55.5	24	22.5	48.7
2002	20	15.5	26.5	57.5	68	60	56	54	60	50	65.5	52	48.7
2003	29	20	59.5	32	56	64	74	58	71.5	61	24.5	18.5	47.3
2004	12.5	12.5	14.5	41.5	57	80	72	77.5	69	46	25.5	27	44.5
2005	15	17.5	21.5	32.5	56	69.5	75.5	78.5	79	49.5	24	15.5	44.5
2006	14.5	17.5	16.5	20.5	61	65	72	75.5	75	60	22	16	42.9
2007	15.5	11.5	19.5	40	61	70	73.5	76	67.5	48.5	20.5	17	43.3
2008	17.5	10.5	17	28.5	54.5	64	73.5	77.5	71.5	55.5	22	19.5	42.6
2009	15	9	10	40	53	63.5	69.5	75.5	70	67	34	17	43.6
2010	16	11	15	31.5	61.5	69.5	76	77.5	73	69.5	28	16	45.3

APPENDIX V

AVERAGE MONTHLY TEMPERATURE – HUMIDITY INDEX OF ZARIA FROM 1975 TO 2010

M/y	Jan THI	Feb THI	Mar THI	Apr THI	May THI	Jun THI	Jul THI	Aug THI	Sept THI	Oct THI	Nov THI	Dec THI	Average
1975	18.4	21.4	27.4	34.6	37	36.3	36.6	36.6	37.6	30.1	24.3	20.3	30.5
1976	19.9	25	25.6	31.9	36.9	35.8	36.3	36.1	35.5	36.1	24.6	20.1	30.3
1977	21	20.5	23.9	29.1	35.9	37.3	37.5	37.4	37.6	32.2	21.8	20.3	29.5
1978	20.7	20.5	23.9	29.1	35.9	37.3	37.5	37.4	37.6	32.2	21.8	20.3	29.5
1979	20.5	23.7	28.4	33.6	36.7	37.8	38.4	38.3	69.2	33.6	26.2	19.9	33.8
1980	21.1	22.5	26.8	32.7	37.9	37.3	37.9	37.8	37	34.4	24	20.2	30.8
1981	21.3	22.2	27.3	32	35.4	37.7	37.4	38	36.9	33.3	22.1	21.2	30.4
1982	21.6	22.7	27	55.6	37.5	38	37.7	36.7	37.6	34.8	22.1	20.9	32.6
1983	18.7	23	23.5	28.2	37.4	37	39.7	38.7	34.8	25.3	21.9	21.1	29.1
1984	18.8	21.5	28.9	34.2	37.1	36.2	36.2	37.5	36.1	33.3	22.5	20.6	30.2
1985	22.5	20.7	31.4	29.6	37.2	36.2	36.2	34.9	35.9	27.3	23	21.2	29.6
1986	21.5	24.9	29.8	35.2	35.2	36.5	37.3	37.5	36.2	32.7	25.3	22.2	31.1
1987	21.5	22.2	28.1	27.1	34.8	38.4	38.1	39	37.3	30.9	22.2	21.8	30.1
1988	21.1	23.1	27.7	34.2	37.7	37.6	37.3	37.2	36.4	28.4	22.2	20.6	30.2
1989	17.8	19.6	25	31	35.1	36.3	37.1	36.5	37.1	29.9	21.7	23.5	29.2
1990	21.1	20.5	22.6	34.3	37.9	38.6	37.3	37.8	37.8	33.9	27.2	24.3	31.1
1991	21.7	26	28.7	35.8	38.7	38.6	37.2	37.9	37.1	33.2	23.5	20.2	32.2
1992	18.8	20.4	27.8	32.7	37.8	36.9	37.3	37.3	37.2	36.1	25.5	22	30.8
1993	19.1	23.7	29.7	35.9	37.8	37.4	36.1	36.4	36.8	35.3	24	23.1	31.9
1994	21.6	22.3	28.8	35.5	37.5	36.8	37.7	37.9	38.9	37.7	25.1	21.1	31.7
1995	20.1	22.3	29.1	31.9	35	32	39.9	38.9	39	36.5	26	28.7	31.6
1996	21	25.6	32.8	37.8	39.6	35	35	37.9	38.3	34.3	22.2	21.7	31.7
1997	21.6	19.5	27.2	35.7	37.8	38.2	38.3	38.7	39	39	27.3	21	31.9
1998	20.5	22.8	24.2	34.8	42	41.4	41.3	44.5	42.2	39.3	29.5	25.6	34
1999	24	26.4	32.7	35.4	39.8	40.9	41.4	40.7	41.8	37.8	28.6	23.3	34.4
2000	26.7	26.4	27.5	38.1	40.6	41	41.2	40.7	41.7	38	27.9	25.4	34.6
2001	22.7	24.3	28.1	36.7	41.8	41.9	41.6	42.9	44.2	35.9	25.4	25.1	34.2
2002	21.5	24.8	31.9	32	34.2	45.5	35	38	39.1	43.9	34.9	30.3	34.3
2003	35.2	22	41.1	34.1	35	36	40.8	34.2	40.1	38.7	27.1	23.1	33.9
2004	22.2	22.2	19.3	38.8	38.3	40.8	38	38.5	38.7	35.2	29	26.2	32.2
2005	20.9	27.7	31.4	34.3	38.7	39.6	39.6	39.6	41.3	33	25.4	22.4	32.8
2006	24	26.8	27.9	30.1	38.7	38.4	39.5	38.8	39.5	37.1	22.4	20.6	31.9
2007	20	23.3	27.8	36.6	39.4	38.2	39.1	39	38.3	34	25.1	22.3	31.9
2008	20.9	21.7	28.6	32	38.3	38.8	39.1	38.5	42.4	34.5	23.9	22.8	31.7
2009	22.8	23.5	26.1	36.6	37.9	38.7	38.1	38.8	39	38.9	26.7	22.3	32.4
2010	22.5	24.5	27.5	34	41	40.3	38.2	39.3	39.7	40.3	27	21.6	32.9