USMANU DANFODIYO UNIVERSITY, SOKOTO

(POSTGRADUATE SCHOOL)

COMPARATIVE ANALYSIS OF THE PERFORMANCE OF SELECTED MODELS FOR THE ESTIMATION OF GLOBAL SOLAR RADIATION FOR KANO, KATSINA, AND SOKOTO, NIGERIA

A Dissertation

Submitted to the

Postgraduate School

USMANU DANFODIYO UNIVERSITY, SOKOTO, NIGERIA

In partial fulfillment of the requirements

For the award of the degree of

MASTER OF SCIENCE (PHYSICS)

BY

ABUBAKAR Muazu
(Adm. No. 15210305002)

DEPARTMENT OF PHYSICS

MARCH, 2019

Dedication

This work is dedicated to my parents.

Certification

This Dissertation by ABUBKAR, Muazu (Adm. No. 15210305002) has met the requirement for the award of the Degree of Master of Science (MSc. Physics) of the Usmanu Danfodiyo University, Sokoto, and is approved for its contribution to knowledge.

_____   _____

Dr. G. M. Argungu   **DATE**
Major Supervisor

_____   _____

Dr. Y. A. Sanusi   **DATE**
Co-Supervisor I

_____   _____

Dr. Abubakar Roko   **DATE**
Co-Supervisor II

_____   _____

Dr. Y. A. Sanusi   **DATE**
Head of Department

_____   _____

External Examinar   **DATE**

Acknowledgements

TABLE OF CONTENTS

List of Figures

List of Tables

Nomenclature

Symbol	Meaning
$a, b, c, .. u$	Regression Coefficients
H	Monthly Average Daily Global Solar Radiation on Horizontal Surface
H_o	Monthly Average Daily Extraterrestrial Radiation on Horizontal Surface
I_{sc}	Solar Constant = 1367 W m^{-2}
K_d	Diffuse Fraction or Cloudiness Index
K_{dd}	Diffuse Coefficient
K_t	Clearness Index
n	The nth day of the year (Jan 1=1; Dec 31=365)
PS	Ratio between Mean Sea Level Pressure and Mean Daily Vapor Pressure
RH	Relative Humidity
RH_{max}	Maximum Relative Humidity
S	Monthly Average Daily Bright Sunshine Duration
S_o	Monthly Average Maximum Possible Daily Sunshine Duration
T	Mean Air Temperature
T_{min}	Mean Minimum Daily Temperature in ^{o}C
T_{max}	Mean Maximum Daily Temperature in ^{o}C
ΔT_m	Monthly Mean Temperature difference
$h_\propto$	The Noon Solar Altitude Angle of the Sun
w_s	Sunset Hour Angle
θ_{max}	Mean Maximum Daily Temperature in Kelvin
θ_{min}	Mean Minimum Daily Temperature in Kelvin
$\tau_{f,max}$	Proportion of $\tau_{t,max}$ Observed on a given Day (Cloud Correction)
$\tau_{t,max}$	Maximum (Cloud-Free) Daily Total Transmittance at a Location
ΔT	Temperature difference
L	Latitude of the Location in (rad)
esT	Saturation Vapor Pressure at the Air Temperature T
γ	Longitude of the Location
δ	Solar Declination
θ	Solar Zenith Angle
τ	Atmospheric Transmittance
φ	Latitude of the Location

ABSTRACT

Accurate solar energy data is essential pre-requisite for designing, sizing and performance evaluation of any solar energy system in any part of the world, even though solar radiation data are not available in many localities of many developing countries such as Nigeria. Empirical models were studied for the estimation of global solar radiation in this study. The performance evaluation of six models for estimation of global solar radiation was carried for three locations (Kano, Katsina and Sokoto) from North West Zone of Nigeria. The models were formed from different combinations of some meteorological parameters (sunshine hours, relative humidity, maximum relative humidity, maximum and minimum temperatures). Monthly average extraterrestrial global solar radiation was evaluated for the three locations. Meteorological data for ten years (2006-2015) for all the variables was obtained from Nigeria Meteorological Agency (NIMET). The data was analyzed to find the empirical constants for all the selected models in all the locations. Estimated values of global solar radiation were obtained from the models. The estimated values were then compared using some statistical parameters (mean bias error (MBE), mean percentage error (MPE), root mean square error (RMSE), coefficient of regression (R), coefficient of determinant (R^2) and t-stat). Then the models that fit the measured data most at each of the selected locations based on various statistical parameters were   identified.

CHAPTER ONE

INTRODUCTION

1.1   INTRODUCTION

Energy is a prime requirement for progress and development of any Society. It is vital for all living beings on earth. The availability of cheap and abundant supply of energy is an index of standard of living of any nation. Industrialization and increase in population cause the demand for energy to increase both in developed and developing countries. The progress of a nation is sometimes compared in terms of per capita consumption of energy i.e. the amount of energy consumed per person per year (Innocent *et al.,* 2015).

Energy comes from many sources and most of the energy sources are substitutable to each other due to the fact that some form of energy can be converted to other- such as: Coal to electricity, Use of photo-electricity to derive a chemical reaction, Wind energy to pump and store water that could be used to produce electricity when required, Solid biomass to produce liquid or gaseous fuels of higher calorific value, etc (Sen, 2008).

Energy comes from the physical environment and ultimately returns there. Humans harness energy conversion processes to provide energy services. It comes from many sources and in many forms such as: chemical energy (oil, natural gas, coal, and biomass), mechanical energy (wind, falling water), thermal energy (geothermal deposits), radiation (sunlight, infrared radiation), electrical energy (electricity), nuclear (uranium, plutonium) (Innocent *et al.,* 2015).

The earth has a diameter of $12.7 \times 10^3 \ km$ while the sun diameter is $13.9 \times 10^5 \ km$, the earth maintains an eccentric orbit around the Sun in elliptical orbit around the sun every 365 days, the average earth–sun distance is $149.7 \times 10^6 km$ and is defined as the astronomical unit (AU) (Duffie and Beckman, 2013).

The sun subtends an angle of 32° on the earth at a 1AU distance which is used for calculating distances within the solar system, due to the eccentricity of the earth's orbit the distance varies by 1.7%. The point closest to the Sun on the Earth's orbital path is called the **perihelion**, while the point farthest away from the Sun is called the **aphelion** (Foster *et al.,* 2010)**.**

The Earth's orbit's eccentricity is very small, about 0.0167 which causes the elliptical path to be nearly circular, the earth is about 4% closer to the sun at the perihelion than the aphelion. Spencer in 1971 as cited in (Sen, 2008).

There are some forms of energy resources that are delectable and finite in nature, and for all practical purposes they are irreplaceable because it takes very long time to re-accumulate again. These energy sources are called non-renewable and examples are: fossil fuels, coal, oil and gas, and nuclear fission. Their rate of utilization far exceeds the rate at which they are formed. They have a cycling time greater than million years. They can be divided into: primary energy sources, secondary energy sources, and finite energy sources (Abdulrahim *et al.,* 2011).

Some other forms of energy are considered as renewable. They comprise of all energy sources which are in-exhaustible, at least in the sense that little change in their energy output is expected over a span of millions of years. Common examples of renewable resources are: water power /hydropower, wind power, tidal or lunar power, bio power or biomass, solar energy and nuclear fusion (Gairaa and Bakelli, 2011).

Any location on earth is described by three angles: latitude, longitude and altitude. The latitude corresponds to the elevation angle between a hypothetical line from the center of earth to any point on the surface and its projection on the equator plane, they circle the globe in an east-west direction, they measure how far north or south a point lies from the equator, latitude lines are also called parallels, as they are parallel to the equator, their values fall between -90° and +90° (Sen, 2008).

Longitudes are imaginary lines extended from pole to pole, they run from the north-pole to the south-pole, they are also called meridians, longitude measures how far east or west a point on earth lies from the prime meridian, longitude values to the east of the prime meridian can be specified by 0° to 180°E or by positive values 0° to +180°; while longitude values to the west of the prime meridian can be specified by 0° to 180°W or by negative values 0° to -180° (Sen, 2008).

Altitude is the angular height of the sun in the sky measured from the horizontal. It is zero degrees at sunrise and achieves its maximum value at solar noon, and it's measured from the horizontal.

Almost all the energy sources originate entirely from the sun. In general, the sun supplies the energy absorbed in the short term by the earth's atmosphere and oceans but in the long term by the lithosphere where the fossil fuels are embedded (Duffie and Beckman, 2013).

A small portion of solar energy appears in the form of kinetic energy of the winds which is derived from the uneven heating of the Earth's surface and due to more heat input at the equator with the accompanying transfer of water by evaporation and rain. In this sense, rivers and dams for hydro-energy are stored solar energy (Nwokoye and Ike, 2003).

Another aspect of solar energy is the interception of sunlight by plants and is transformed by photosynthesis into biomass. Solar energy can be tapped directly (solar thermal and solar photovoltaic) or indirectly as with wind biomass and hydropower; or as fossil fuels such as coal, oil and natural gas. Sunlight is by far the largest carbon-free energy source in the planet (Sen, 2008).

Solar radiation is the most important natural energy resource because it drives all environmental processes acting at the surface of the Earth. The sun is an internal energy generator and distributor responsible for most of our easily accessible energy resources including oil, coal, etc (Innocent *et al.,* 2015).

The diameter of the sun is about $1.39 \times 10^6 km$. It is estimated that 90% of the energy is generated in the region between 0 and 0.23% of its radius. The sun is by far the largest carbon-free energy source in the planet (Duffie and Beckman, 2013).

When the solar radiation reaches the outer atmosphere it is subjected to absorption, reflection and transmission processes through the atmosphere before reaching the earth's surface. It reaches the earth in three different ways: (Innocent *et al.,* 2015).

Global solar radiation consists of three components: direct or beam radiation, diffuse radiation and reflected radiation (Duffie and Beckman, 2013).

i.   Direct or Beam Radiation

It is the amount of solar radiation received at any place on the earth directly from the sun without suffering any atmospheric scattering or disturbance.

ii.   Diffuse Radiation

Some portion of solar radiation are scattered in many different directions by atmosphere before reaching the earth and it is called diffuse radiation. Some portion of diffuse radiation goes back to space (called reflected radiation) and a portion reaches the ground.

iii.   Reflected Radiation

Reflected sunlight bounces from trees, snow, landscapes, mirrors and other earthbound surfaces light tall building and mountains. Some beam radiation can be converted to reflected radiation before reaching the earth surface.

The sum of the beam and the diffuse components of solar radiation on a surface make "total (global) solar radiation" Solar energy is available and can be easily harnessed than other energy sources. Solar radiation data is necessary for quality study of the possible use of solar energy or design of some solar energy devices.

A knowledge of solar radiation characteristics is important for the design, construction and operation of many devices for converting solar radiation into other useful forms of energy. Solar energy is primarily transmitted to the earth by electromagnetic waves. The solar spectrum is roughly equivalent to a perfect black body at a temperature of $5800K$. The sun radiates in all regions: visible, ultraviolet and infrared radiations (Abdulrahim *et al.,* 2011).

1.2   STATEMENT OF THE PROBLEM

Solar radiation is a primary driver for many physical, chemical, and biological processes on the earth's surface. Solar energy engineers, architects, agriculturists, hydrologists, etc. often require a reasonable accurate knowledge of the availability of the solar resource for their relevant applications at their locality. In solar applications, one of the most important parameters needed is the long-term average daily global radiation for regions where no actual measured values are available. A common practice is to estimate the

average daily global solar radiation using appropriate empirical correlations models based on the measured relevant data at those locations. These correlations estimate the values of global solar radiation for a region of interest from more readily available meteorological, climatological, and geographical parameters.

1.3   AIM AND OBJECTIVES OF THE RESEARCH

The aim of this research is to evaluate and compare the performance of selected models for estimation of global solar radiation using various meteorological parameters for selected locations in Northwest, Nigeria.

The objectives for achieving the aim are:

i.   To evaluate extraterrestrial global solar radiation on horizontal surface, for the selected locations;

ii.   To evaluate the empirical constant of the selected models based on measured data solar radiation, sunshine hours, relative humidity, maximum relative humidity, maximum and minimum temperatures;

iii.   To use statistical methods to compare between the measured data and calculated values for all the selected models;

iv.   To identify, among the selected models, the one that best fit the measured data at each of the selected locations.

1.4   SIGNIFICANCE OF THE RESEARCH

Solar researchers have developed many empirical correlations which determine the relation between solar radiation and various meteorological parameters. In order to evaluate the performance of the models, the results obtained from the models are compared with measured data using some statistical parameters such as root mean square error (RMSE), Coefficient of determination (R^2), T-statistical values etc. different models show different degree of fitness with the measured data. In this research some selected models for estimating global solar radiation using sunshine hours, relative humidity, maximum and minimum temperature ware selected for some locations in north-west Nigeria. The models that fit the measured data most will be selected for each among the selected locations and recommended for used by researchers, governmental and non-

governmental agencies. The models will be compared using statistical variables for recommendation of the best model among them.

1.5 SCOPE AND LIMITATION OF THE STUDY

This study will cover three locations in Northwestern Nigeria (Kano, Katsina and Sokoto).

Daily average solar radiation data for ten (10) years only will be used for each of the selected locations.

Only three models from linear and three from non-linear models will be used for the analysis.

CHAPTER TWO

LITERATURE REVIEW

2.1   SOLAR RADIATION

Solar energy is renewable radiation energy of the sun and it is fast becoming an alternative to other conventional sources of energy (Nwokoye and Ike, 2003). It has been identified as the largest renewable resources of energy on earth. The energy source is more evenly distributed in the Sunbelt of the world than wind or biomass. The maximum intensity of solar radiation at the earth surface is about 1.2 kW/m^2.

Solar energy is not available continuously because of day/night cycle and clouds cover; its intensity varies according to time of the year (season), geographical locations and position of the collector (Abdulrahim *et al.,* 2011).

The world-wide quest for renewable and sustainable energy has provide the spur for increased research in the assessment and harnessing of available solar energy in any given locality due to problems arising from oil crisis, global warming and other environmental issues (Gairaa and Bakelli, 2011).

Solar radiation was historically monitored by measuring the sunshine duration with Cambell-Stokes sunshine recorders. Later pyranometers were introduced, but sunshine duration is still an essential climatological parameter that is still monitored in many meteorological stations (Duffie and Beckman, 2013; Journee *et al.,* 2013).

In the earth atmosphere, the solar radiation received directly from the sun is called direct or beam solar radiation. However, as radiation from the sun hits our atmosphere, some is scattered in all directions, some of this radiation is scattered towards the earth as shown in Figure 2.1.The solar radiation received from the sun after its direction has been changed by scattering in the atmosphere is called diffuse solar radiation (Mertens, 2014).

Global radiation is the sum of the reflected radiation, direct irradiation and the diffuse solar radiation on any plane, values of global and diffuse radiations for individual hours are essential for research and engineering applications (Vecan, 2011).
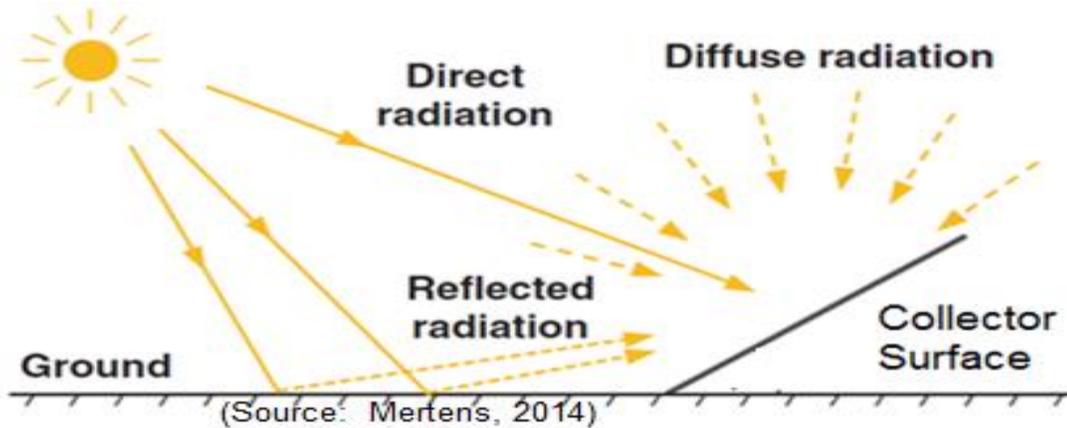
Figure 2.1. Direct, diffuse and reflected solar radiation

The total radiation on a horizontal surface is recorded at a large number of locations, while diffuse radiation, needed in many solar energy applications, is measured in comparatively few locations.

Knowledge of global solar radiation is essential in the prediction, study and design of the economic viability of systems which use solar energy. Information on global solar radiation received at any site (preferably gained over a long period) should be useful not only to the locality where the radiation data is collected but also for the wider world community, a global study of the world distribution of global solar radiation requires knowledge of the radiation data in various countries and for the purpose of world-wide marketing, the designers and manufacturers of solar equipment will need to know the average global solar radiation available in different and specific regions Ibrahim 1985 cited by (Akpabio and Etuk, 2003).

2.2   ESTIMATION OF GLOBAL SOLAR RADIATION TECHNIQUES

The first correlation proposed for estimating the monthly average daily global radiation is based on the method of Angstrom. The original Angstrom-Prescott type regression equation-related monthly average daily radiation to clear day radiation in a given location and average fraction of possible sunshine hours is given by (Duffie and Beckman, 2013; Gana and Akpootu, 2013):

$$\frac{H}{H_o} = a + b\left(\frac{S}{S_o}\right) \tag{2.1}$$

where: H is the monthly average daily global radiation on a horizontal surface on

	the earth's surface;
H_o	monthly average daily extraterrestrial radiation on a horizontal surface;
S	monthly average daily hours of bright sunshine;
S_o	monthly average day length;
a, b	are known as Angstrom constants and they are empirical.

The diffuse fraction under clear-sky conditions may be calculated theoretically, however, it is common practice for the large number data to be condensed and presented in simple useable form obtained from the measurements for various types of users.

Correlation used for predicting monthly average daily values of diffuse radiation may be classified in four groups (Vecan, 2011):

(i)   The clearness index$\left(K_t = \frac{H}{H_o}\right)$

(ii)   The relative sunshine duration or sunshine fraction$\left(\frac{S}{S_o}\right)$

(iii)   The diffuse coefficient$(k_{dd} = H_d/H_o)$

(iv)   The diffuse fraction or cloudiness index$(k_d = H_d/H)$.

2.3   THEORETICAL CONSIDERATION

Solar researchers have developed many empirical correlations which determine the relation between solar radiation and various meteorological parameters. The parameters used as the input of radiation model are the most important key to choose the proper radiation model at any location (Nwokoye and Ike, 2003).

Empirical models can be mainly classified into four categories based on the employed meteorological parameters:

i.   Sunshine-based models.

ii. Cloud-based models.

iii. Temperature-based models.

iv. Other meteorological parameter-based models.

Among all such meteorological parameters, bright sunshine hours, relative humidity and temperature are the most widely and commonly used ones to predict global solar radiation and its components at any location of interest (Korachagaon *et al.,* 2008).

Solar radiation models can also be classified as: Linear Models and Non-linear Models; depending on the type of relationships between the parameters.

2.3.1   Linear Models

For linear models, clearness index (H/H_o) is related to the meteorological parameters in the form of linear relationship. Most of the models relate the clearness index with sunshine duration; as sunshine duration can be easily and reliably measured, and data are widely available at the weather stations. The most widely used and simplest among them is Angstrom-Prescott Model.

Some models are temperature-based which assume that the difference in maximum and minimum temperature is directly related to the fraction of extraterrestrial radiation received at the ground level (Sen, 2008). Some also include relative humidity among the variables. Some widely used models are cited by Besharat *et al.,* (2013) as shown in Table 2.1:

Table 2.1: The linear regression models and their sources

S/N	Model Equation	Source.
1	$\dfrac{H}{H_o} = a + b\left(\dfrac{S}{S_o}\right)$	(Angstrom-Prescott, 1940)
2	$\dfrac{H}{H_o} = a + b\left(\dfrac{S}{S_o}\right) + c\left(\dfrac{T_{min}}{T_{max}}\right) + d\left(\dfrac{RH}{RH_{max}}\right)$	(Ojosu and Komolafe, 1987)
3	$\dfrac{H}{H_o} = a + b\left(\dfrac{S}{S_o}\right) + c(RH)$	(Swartman and Ogunlade, 1967)
4	$\dfrac{H}{H_o} = a + b\left(\dfrac{S}{S_o}\right) + c(T) + d(RH)$	(Abdallah, 1994)
5	$\dfrac{H}{H_o} = a + b\left(\dfrac{S}{S_o}\right) + c(T) + d(RH) + e(PS)$	(Abdallah, 1994)

2.3.2   Non-Linear Models

Some models relate the refractive index with sunshine duration, temperatures and relative humidity at non-linear relationships. Some of them are as shown in Table 2.2 as cited by Besharat *et al.*, (2013):

Table 2.2: Non-linear regression models and their sources

S/N	Model Equation	Source
1	$\dfrac{H}{H_o} = a + b\left(\dfrac{S}{S_o}\right) + c\left(\dfrac{S}{S_o}\right)^2$	(Ogelman *et al.*, 1984)
2	$\dfrac{H}{H_o} = a\left(\dfrac{S}{S_o}\right)^b$	(Bakirci, 2008)
3	$\dfrac{H}{H_o} = a^{\left[1/\frac{S}{S_o}\right]}$	(El-Metawally, 2004)
4	$\dfrac{H}{H_o} = a + b\left(\dfrac{S}{S_o}\right)^c$	(Sen, 2007)
5	$\dfrac{H}{H_o} = a + b\left(\dfrac{S}{S_o}\right) + c\,exp\left(\dfrac{S}{S_o}\right)$	(Bakirci and Pandey, 2010)
6	$\dfrac{H}{H_o} = e^a\left(\dfrac{S}{S_o}\right)^b$	(Coppolino, 1994)
7	$\dfrac{H}{H_o} = a + b\left(\dfrac{S}{S_o}\right) + c\left(\dfrac{S}{S_o}\right)^2 + d\left(\dfrac{S}{S_o}\right)^3$	(Samuel, 1991)
8	$\dfrac{H}{H_o} = e^a\left(\dfrac{S}{S_o}\right)^b (\sin h_\alpha)^c$	(Coppolino, 1994)
9	$\dfrac{H}{H_o} = a\cos\theta + b\left(\dfrac{S}{S_o}\right)$	(Glover and McGulluch, 1958)
10	$\dfrac{H}{H_o} a + b\left(\dfrac{S}{S_o}\right) + c\log\left(\dfrac{S}{S_o}\right)$	(Newland, 1988)
11	$\dfrac{H}{H_o} = a + b\log\left(\dfrac{S}{S_o}\right)$	(Ampratwum and Dorvlo, 1999)
12	$\dfrac{H}{H_o} = a\,exp\left[b\left(\dfrac{S}{S_o}\right)\right]$	(Elagib and Mansell, 2000)
13	$\dfrac{H}{H_o} = a + b\,exp\left(\dfrac{S}{S_o}\right)$	(Almorox and Hontoria, 2004)
14	$\dfrac{H}{H_o} = a[1 - exp(-b\Delta T^c)]$	(Bristow and Campbell, 1984)
15	$\dfrac{H}{H_o} = a[1 - exp\{-bf(T_{avg})\Delta T^c\}]$	(Donatelli and Campbell, 1998)
16	$\dfrac{H}{H_o} = a\left[1 - exp\left\{-b\left(\dfrac{\Delta T^c}{H_o}\right)\right\}\right]$	(Goodin *et al.*, 1996)
17	$\dfrac{H}{H_o} = \tau Dl\left[1 - a\dfrac{e_s T_{min}}{e_s T_{max}}\right]$	(Winslow *et al.*, 2001)
18	$\dfrac{H}{H_o} = a\ln(T_{max} - T_{min}) + b$	(Chen *et al.*, 2004)
19	$\dfrac{H}{H_o} = \tau_{t.max}\tau_{f.max}$	(Thorton and Running, 1999)
20	$\dfrac{H}{H_o} = a + b\cos\varphi + cZ + d\left(\dfrac{S}{S_o}\right) + eT + fRH$	(Gopinathan, 1988)

21	$\dfrac{H}{H_o} = Kr(T_{max} - T_{min})^{0.5}$	(Allen, 1997)
22	$\dfrac{H}{H_o} = a(T_{max} - T_{min})^{0.5}$	(Hargreaves and Samani, 1982)
23	$H = a(T_{max} - T_{min})^{0.5} H_o + b$	(Hunt $et\ al.$, 1998)
24	$\dfrac{H}{H_o} = a\left[1 - exp\left(-b\dfrac{\Delta T^c}{\Delta T_m}\right)\right]$	(Donatelli and Campbell, 1998)
25	$\dfrac{H}{H_o} = a(T_{max} - T_{min})^{0.5} + b$	(Chen $et\ al.$, 2004)
26	$H = a\left(\dfrac{S}{S_o}\right)^b RH^c$	(Swartman and Ogunlade, 1967)
27	$\dfrac{H}{H_o} = a\left(\dfrac{S}{S_o}\right)^b T_{max}{}^c RH^d$	(Ododo $et\ al.$, 1995)
28	$H = a(T_{max} - T_{min})^{0.5} H_o + bT_{max} + cP + dP^2 + e$	(Hunt $et\ al.$, 1998)
29	$\dfrac{H}{H_o} = a(T_{max} - T_{min})^b (1 + cP + dP^2)$	(De-Jong and Stewart, 1993)

2.4   EXTRATERRESTRIAL SOLAR RADIATION

Some variation in the extraterrestrial solar radiation above the atmosphere are not due to solar changes but rather to the earth sun distance throughout the year, the monthly average extraterrestrial radiation on a horizontal surface (H_o)can be computed from the following equation (Duffie and Beckman, 2013):

$$H_o = I_{sc}\left(\frac{24}{\pi}\right) E_o \left[\left(\frac{2\pi\omega_s}{360}\right)\sin\Phi\sin\delta + \cos\Phi\cos\delta\sin\omega_s\right] \qquad (2.2)$$

where, H_o is the extraterrestrial solar radiation on horizontal surface
$\quad\quad\quad\ I_{sc}$ is the solar constant
$\quad\quad\quad\ n$ is the nth day of the year (Jan 1=1; Dec 31=365)
$\quad\quad\quad\ E_o$ is the Earth's Eccentricity Factor
$\quad\quad\quad\ \Phi$ Latitude of the location
$\quad\quad\quad\ \delta$ Declination
$\quad\quad\quad\ w_s$ is sunset hour angle in degrees

2.4.1   Solar Constant

The solar radiation intensity received above the earth's atmosphere at mean earths-sun distance (one astronomical unit) is called solar constant, I_{sc}. The world Metrological Organization (WHO) promotes a value which is the commonly accepted value as: $I_{sc} = 1367 Wm^{-2}$ (Akpabio and Etuk, 2003).

2.4.2 Earth's Orbit Eccentricity Factor

The Earth maintains an eccentric orbit around the Sun in elliptical orbit every 365 days. The Earth's orbit's eccentricity is very small, about 0.0167 which causes the elliptical path to be nearly circular. The point closest to the Sun on the Earth's orbital path is called the Perihelion, while the point farthest away from the Sun is called the Aphelion (Goswami, 2015).

Perihelion is $147.2 \times 10^6 km$ and occurs at nearly January.

Aphelion is $152.2 \times 10^6 km$ and occurs at nearly June.

The average sun-earth distance is $149.7 \times 10^6 km$ and is defined as the Astronomical Unit (AU), the sun subtends an angle of 0.533° or 32′ on the earth at 1AU distance as shown in Figure 2.2
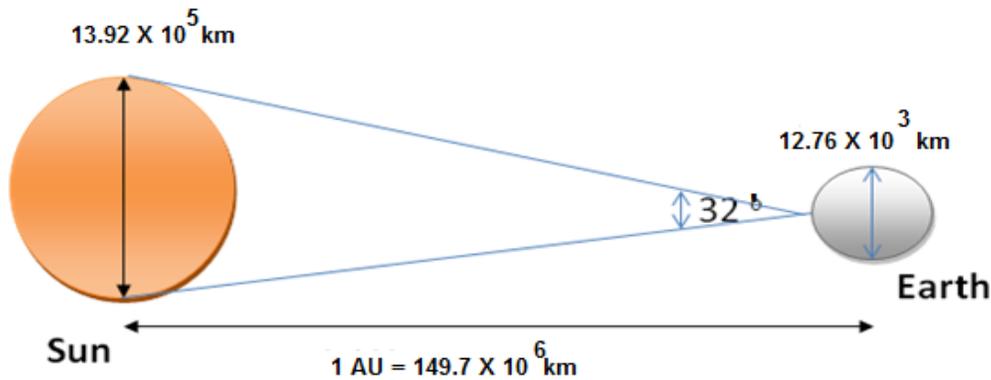
Figure 2.2: Sun-Earth Geometry

The earth's orbit eccentricity factor (E_o) is given by:

$$E_o = 1 + 0.033 \cos\left(\frac{360n}{365}\right)$$
(2.3)

where, n The nth day of the year (Jan 1=1; Dec 31=365)

2.4.3 Solar Latitude Angle (ϕ)

The latitude corresponds to the elevation angle between a hypothetical line from the center of earth to any point on the surface and its projection on the equator plane. They circle the globe in an east-west direction. They measures how far north or south a point lies from the equator, latitude lines are also called parallels, as they are parallel to the equator. Their values fall between -90° and +90°.

13

Some boundary latitudes are: (Goswami, 2015): Low latitude, Mid latitude and High latitude.

i.   **Low Latitude:** This is a region between tropic of cancer (latitude $23\frac{1}{2}°N$) and tropic of Capricorn (latitude $23\frac{1}{2}°N$). Because of the latitudes that form its boundaries, this zone is called the Tropics.

ii. **Mid Latitude:** This is a region between tropic of cancer (latitude $23\frac{1}{2}°N$) and Arctic circle (latitude $66\frac{1}{2}°N$) in the northern hemisphere and a region between tropic of Capricorn (latitude $23\frac{1}{2}°S$) and Antarctic circle (latitude $66\frac{1}{2}°S$) in the southern hemisphere

iii. **High Latitude:** The earth's polar areas are called high latitudes. This is a region between Arctic circle (latitude $66\frac{1}{2}°N$) and the North pole in the northern hemisphere and region between Antarctic circle (latitude $66\frac{1}{2}°S$) and the South pole in the southern hemisphere. This region experiences continues day light and continues darkness for at least a day in a year depending on the location, the North Pole experiences continues day light or twilight in days with positive declination angle (Mar 21 to Sep 20) and continues night for the other days with negative declination angle (Sep 21 to Mar 20), the same effect but reversed is experienced for South Pole.

2.4.4   Solar Declination Angle (δ)

The angle between the earth-sun line and equatorial plane is called the declination angle, δ, which changes with the date and it is independent of the location. It may also be defined as the angular position of the sun at noon with respect to equatorial plane. Declination angle is the same everywhere on earth at a given time and it changes with seasons, it varies in the range $-23.5° \leq \delta \geq 23.5°$, the maximum values of $\mp23.5°$ were on the summer/winter solstice and it is $0°$ on the equinoxes.

If the Earth's orbit is assumed circular then declination can be expressed as: (Okonkwo and Nkoye, 2014).

$$\delta = 23.45 \sin\left(360\,\frac{284+n}{365}\right) \tag{2.4}$$

where, n The nth day of the year (Jan 1=1; Dec 31=365

2.4.5 Sunset Hour Angle

The zenith angle equation is given as:

$$\cos \theta_z = \sin \delta \sin \emptyset + \cos \delta \cos \emptyset \cos \omega_s \tag{2.5}$$

At solar noon on horizontal surface, =0 at the sunset, the sunset hour angle is donated by ω_s and $\theta_z = 90^\circ$

Therefore,

$$\cos 90^\circ = 0 = \sin \delta \sin \emptyset + \cos \delta \cos \emptyset \cos \omega_s \tag{2.6}$$

Or

$$\cos \omega_s = -\frac{\sin \delta \sin \emptyset}{\cos \delta \cos \emptyset} = -\tan \delta \tan \emptyset \tag{2.7}$$

Therefore the sunset hour angle is given by:

$$\omega_s = \cos^{-1}(-\tan \delta \tan \emptyset) \tag{2.8}$$

Apparent time for sunset T_{ss} is given as

$$T_{ss} = 12 + \frac{\omega_s}{15} \tag{2.9}$$

There is exceptional case: if $(-\tan \emptyset \tan \delta) \leq -1$, then no sunset on that day *i.e* totally day (Grewel and Grewel, 2004).

2.4.6 Day Length

Sunshine duration is the length of time that the ground surface is irradiated by direct solar radiation (i.e. sunlight reaching the earth's surface directly from the sun). It is the period during which direct solar irradiance exceeds a threshold value of $120W/m^2$ (a value that is equivalent to the level of solar irradiance shortly after sunrise or shortly before sunset in cloud-free conditions) (Goswami, 2015).

From equation 2.8, $\omega_s = \cos^{-1}(-\tan \delta \tan \emptyset)$

Sunrise occurs at ω_s hour angles before solar noon; while sunset occurs at ω_s hour angles after solar noon, therefore, hour angle from sunrise to sunset ω_D is twice the hour angle from solar noon to sunset, i.e.

$$\omega_D = 2\omega_s = 2 \cos^{-1}(-\tan \delta \tan \emptyset) \tag{2.10}$$

But it takes the earth 1 hour for each 15° revolution, therefore, day length in hours, N_D can be expressed as:

$$N_D = \frac{2}{15}\omega_s = \frac{2}{15}\cos^{-1}(-\tan \emptyset \tan \delta) \tag{2.11}$$

where, N_D The day length in hours

           ω_D Angular day length

           ω_s Sunset hour angle

           $\emptyset$ Latitude of the location

           δ Declination

2.5   STATISTICAL TEST

The statistical test involves two processes:

i.   Use the data form a relationship (Regression Analysis).

ii. Investigate the accuracy of the regression equation formed.

2.5.1   Regression Analysis

Regression analysis is the form predicting modeling technique which investigates the relationship between a dependent (target) and independent variables (predictor). This technique is used for forecasting, time series modeling, and finding the causal effect relationship between the variables. It is important tool for modeling and analyzing data wire curve / line is fitted to the data points, in such a manner that the difference between the distances of data points from the curve or line is minimized (Foster *et al.,* 2010).

There are many benefits using regression analysis, they are as follows:

i.   It indicates the significant relationship between dependent variable and independent variables.

ii. It indicates the strength of impact of multiple independent variables on dependent variables.

Many techniques for carrying out regression analysis have been developed. The most popular method is the Least Square Method (Grewel and Grewel, 2004).

Linear models can be processed directly using the method while non-linear models can be transformed into linear and then processed. In the method, parametric equations are formed depending whether it is to be in the form of straight line or parabola.

2.5.1.1 To Fit in the Form of Straight Line

To fit the straight line $y = a + bx$

The parametric equations are:

$$\sum y = na + b \sum x_i$$
$$\sum xy = a \sum x + b \sum x^2$$

The parametric equations are then solved simultaneously to obtained the constant values; then the constant values "a" and "b" are substituted in the straight line equation $y = a + bx$, which is the required line of the best fit.

2.5.1.2 To Fit in the Form of Parabola

To fit the data in the form of parabola $y = a + bx + cx^2$

The parametric equations are:

$$\sum y = na + b \sum x + c \sum x^2$$
$$\sum xy = a \sum x + b \sum x^2 + c \sum x^3$$
$$\sum x^2 y = a \sum x^2 + b \sum x^3 + c \sum x^4$$

The parametric equations are then solved simultaneously to obtained the constant values; then the constant values a, b and c are substituted in the equation $y = a + bx + cx^2$ which is the required line of the best fit.

In general, the curve $y = a + bx + cx^2 + \cdots + kx^{m-1}$ can be fitted to a given data by writing m normal equation (Grewel and Grewel, 2004).

2.5.2   Statistical Test Parameters

The results obtained from various models (linear and non-linear) will be compared with measured values through the following statistical test:

2.5.2.1 Mean Bias Error (MBE)

The mean bias error (MBE) provides information on the long-term performance of the correlations by allowing a comparison of the actual deviation between calculated and measured values term by term, the ideal value of the MBE is zero, the MBE is given by:

$$MBE = \frac{1}{K} \sum_{i=1}^{k} (y_i - x_i) \qquad (2.12)$$

Where, y_i is the ith calculated values; x_i is the ith measured value, and n is the total number of observations.

2.5.2.2 Root Means Square Error (RMSE)

The root mean square error (RMSE) is a frequently used measure of the differences between values predicted by a model or an estimator and the values actually observed from the thing being modeled or estimated. RMSE is a good measure of precision. The value of RMSE is always positive, representing zero in the ideal case. The RMSE may be computed from the following equation.

$$RMSE = \left[\frac{1}{K}\sum_{i=1}^{k}(y_i - x_i)^2\right]^{\frac{1}{2}} \qquad (2.13)$$

2.5.2.3 Mean Percentage Error (MPE %)

The mean percentage error (MPE) is the computed average of percentage errors by which forecasts of a model differ from actual values of the quantity being forecasted.

$$MPE\% = \frac{1}{K}\sum_{i=1}^{k}(y_i - x_i) \times 100 \qquad (2.14)$$

where y_i is the actual value of the quantity being forecast, x_i is the forecasted, and k is the number of different times for which the variables is forecasted.

2.5.2.4 Mean Relative Error (MRE)

The MRE can be used to test for determining the linear relationship between measured and estimated values.

$$MRE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{y_i - x_i}{x_i}\right| \qquad (2.15)$$

The models with values of R and R^2 close to 1, and least values of RMSE and MPE will be said to be a better fit to the measured data at each of the selected location.

2.5.2.5 Correlation coefficient (r)

The Pearson correlation coefficient often referred to as the Pearson r test, is a statistical formula that measures the strength between variables and relationships, to determine how strong the relationship is between two variables, you need to find the coefficient value which can range between -1.00 and 1.00.

$$r = \frac{\sum_{i=1}^{k}(y_i - \bar{y})(x_i - \bar{x})}{\left[\sum_{i=1}^{k}(y_i - \bar{y})^2 \sum_{i=1}^{k}(x_i - \bar{x})^2\right]^{\frac{1}{2}}} \qquad (2.16)$$

2.5.2.6 Coefficient of Determinant (R^2)

The coefficient of determinant (R^2) is a key output of regression analysis. It is interpreted as the proportion of the variance in the dependent variable that is predictable from the independent variable.

$$R^2 = 1 - \frac{\sum_{i=1}^{k}(x_i - y_i)^2}{\sum_{i=1}^{k}(x_i - \bar{x})} \tag{2.17}$$

The coefficient of determination is the square of the correlation (r) between the predicted y values and actual y values. Thus it ranges from 0 to 1.

2.5.2.7 T-statistical Value

$$t = \left[\frac{(n-1)(MBE)^2}{(RMSE)^2 - MBE^2}\right]^{\frac{1}{2}} \tag{2.18}$$

After an estimation of a coefficient, the t-statistic for that coefficient is the ratio of the coefficient to its standard error. In the literature, Stone (1993) demonstrated that MBE and RMSE separately do not represent a reliable assessment of the model's performance and can lead to the false selection of the best model from a set of candidates. To determine whether or not the equation estimates are statistically significant, Stone (1993) proposed t-stat.

The models with values of R and R^2 close to 1, and least value of RMSE and MPE will be said to be better fit to the measured data at each of the selected location.

2.6   SUBJECT OF THE STUDY IN THE LITERATURE

Comparison of estimated daily global solar radiation using different empirical models was carried out in Ranchi Malaysia using one year data (2007-2008) in which Angstrom-Presscott model was compared with some other different empirical models (Namrata *et al.,* 2012).

The monthly specific daily global solar radiation estimate based on sunshine hours was carried out by WA Ghana for two years data (2010-2012) were used to perform the calculation using selected models by (Sarsah and Ubah, 2013).

The hourly global solar radiation estimates on a horizontal plane was carried out using four years data (2004-2008) in eastern cost of Malaysia using six empirical models, (Muzathik *et al.,* 2010)

The daily global solar radiation estimate based on sunshine hours was carried out in Malaysia using three years data (2004-2007) were used to calculate the monthly mean values of radiation on a horizontal surface by (Muzathik *et al.,* 2011).

Precise estimation of total solar radiation on tilted surface was carried out using 15 years measured data in Delhi, India. The estimated values of hourly solar radiation have also been compared to establish the accuracy of the results; the study reveals that the hourly and total solar radiation can be estimated using correction factor without applying any meteorological parameters for the locations having longitude range of $\pm$ 70 to $\pm$ 125 (Aggarwal, 2012).

Prediction of monthly average global solar radiation based on statistical distribution of clearness index was carried out in Ibadan, Nigeria (Ayodele and Ogunjuyigba, 2015) used eight years data (2000-2007) to predict values using four statistical tests.

The estimation of global solar radiation from temperature data in Minna location was carried out using thirteen years data (2000-2012) to established the Angstrom-type regression equation model. It was observed that the models used gave very good results in predicting the global solar radiation, considering their MBE, RMSE and MPE values, but they did not carry out further research for sunshine hours, relative humidity in the area, and the area of their research differs from this work (Okonkwo and Nwokoye, 2014).

The estimation of the global solar radiation in Gusau was carried out using six years data (1995-2000) daily sunshine duration were used, using Angstrom-Prescott model. The result obtained from the work clearly show that the level of global solar radiation reaching Gusau is adequate for supporting solar energy technology and can therefore be utilized by energy experts in the design and performance of solar energy systems to provide electricity for the communities within the location, (Innocent *et al.,* 2015).

The estimation of the global solar radiation using four sunshine based models in Kebbi, Nigeria, was carried out using 4 years data (2005-2009) and compared with the Angstrom-Prescott Model with some other four sunshine based models (Gana and Akpootu 2013).

Measurements of the global solar radiation and the sunshine duration was carried out using 15 years data from (1984-1999) at Onne, within the rainforest climatic zone of southern Nigeria, were used to establish an Angstrom-type correlation equation. Five other commonly used correlations between the global solar radiation and the sunshine duration were also used to the estimate global solar irradiation for Onne and their results are compared with our model (Louis *et al.,* 2002).

The estimation of the global solar radiation for Kano State Nigeria, based on meteorological data was carried out using two new models which were developed for estimating the monthly-average daily global solar radiation (Auwal and Darma, 2016).

Assessing the performance of the global solar radiation empirical equation in Sokoto, Nigeria, using the meteorological parameters was carried out using the period of ten years data (2005 - 2014) from NIMET, Gunn-Bellani solar radiation, sunshine hour's duration, maximum and minimum temperature which were analyzed using the modified Angstrom models to estimate the monthly mean global solar radiation in Sokoto (Garba *et al.,* 2018).

The evaluation of some global solar radiation models in selected locations in northwest, Nigeria was carried out using twenty two years data (1984 – 2005) from NIMET, global solar radiation estimation from the newly developed model was compared with the values obtained from Garcia, Hargreaves Samani and Angstrom-Prescott models, (Olomiyesan *et al.,* 2017).

CHAPTER THREE

MATERIALS AND METHODS

3.1   MATERIALS

The materials/data required for this research include:

- Global Solar Irradiance for the Selected Location;
- Measured meteorological data to be used for the modeling;
- Laptop Computer with Excel Software Installed.

3.1.1   Selected Locations

The study area for this research is Sokoto, Katsina, and Kano, North Western Nigeria. The zone comprises of seven states namely: Sokoto, Kebbi, Zamfara, Niger, Katsina, Kaduna, Kano and Jigawa.

Three locations in the area were selected. Their geographical co-ordinates are as shown in Table 3.1

Table 3.1: Geographical Co-ordinates of the locations

S/N	Location	Latitude	Longitude	Altitude
1	Sokoto	12.9374^{o}N	5.2267^{o}E	305m
2	Katsina	12.5139^{o}N	7.6114^{o}E	513m
3	Kano	11.7574^{o}N	8.6601^{o}E	488m

3.1.2   Extraterrestrial Solar Radiation of the Locations

Daily extraterrestrial solar radiation can be evaluated using the following parameters: solar constant, I_{sc}; day number, n; Solar eccentricity factor, E_o; the latitude of the location, Φ; solar declination angle, δ; and sunset hour angle, ω_s.

The daily extraterrestrial solar radiation at horizontal surface, H_o can be calculated using equation 2.2.

The eccentricity factor can be evaluated using equation (2.3).

The solar declination, δ; and the mean sunset hour angle, ω_s can be calculated by using equation (2.4) and (2.8) respectively.

For obtaining the monthly average value, recommended average days suggested by Klein (1976) as cited in Duffie and Beckman, (2013) was adopted for this work.

3.1.3 Selected Models to be Investigated

Global solar radiation on a horizontal surface will be evaluated using the six selected models (3 linear and 3 non-linear models) for the locations.

The selected linear models are:

Model 1: Angstrom-Prescott model

$$\frac{H}{H_o} = a + b\left(\frac{S}{S_o}\right) \tag{3.1}$$

Model 2: Sunshine Hour, Temperature and Relative Humidity Linear Model

$$\frac{H}{H_o} = c + d\left(\frac{S}{S_o}\right) + e\left(\frac{T_{min}}{T_{max}}\right) + f\left(\frac{RH}{RH_{max}}\right) \tag{3.2}$$

Model 3: Sunshine Hour and Relative Humidity Linear Model

$$\frac{H}{H_o} = g + h\left(\frac{S}{S_o}\right) + j(RH) \tag{3.3}$$

Model 4: Sunshine Hour Non-Linear Model

$$\frac{H}{H_o} = k\left(\frac{S}{S_o}\right)^l \tag{3.4}$$

Model 5: Multi-Sunshine Hour Non-Linear Model

$$\frac{H}{H_o} = m + p\left(\frac{S}{S_o}\right) + q\ exp\left(\frac{S}{S_o}\right) \tag{3.5}$$

Model 6: Sunshine Hour and Relative Humidity Non-Linear Model

$$\frac{H}{H_o} = r\left(\frac{S}{S_o}\right)^s T_{max}{}^t RH^u \tag{3.6}$$

where,
H	is the monthly average daily global radiation on horizontal surface
H_o	Monthly average daily extraterrestrial radiation on horizontal surface
S	Monthly average daily bright sunshine duration
S_o	Monthly average maximum possible daily sunshine duration
T_{min}	Mean minimum daily temperature
T_{max}	Mean maximum daily temperature
RH	Mean relative humidity
RH_{max}	Maximum relative humidity
$a - u$	are regression coefficients

3.1.4 Measured Meteorological Data for the Locations

Based on the models selected, meteorological data required include:

- Measured global solar Radiation, H;

- Sunshine hours S;

- Relative Humidity RH;

- Maximum relative humidity RH_{max};

- Maximum Temperatures T_{max};

- Minimum Temperatures T_{min}.

3.1.5 Statistical Package for the Analysis

The work involves a lot of statistical analysis. To carry it out efficiently, a personal computer system is required with at least two of the following statistical packages:

i. Microsoft excel;

ii. Minitab;

iii. Statistical Package for Social Sciences (SPSS).

3.2 METHODOLOGY

The methodology to be used for this work is as follows:

i.   Determination of Extraterrestrial Solar radiation for all the locations;

ii. Relevant Meteorological Data to be obtained for all the locations;

iii. Formation of Parametric equations for all the models;

iv. Evaluation of Parametric constants for all the models;

v.   Estimation of Solar Radiation using all the models for all the locations;

vi. Using Statistical Parameters to evaluate and compare the performance of the models.

3.2.1 Determination of Extraterrestrial Solar Radiation

The monthly average daily solar radiation can be determined using the following methods:

Method 1:

- Calculate the solar radiation for each day.
- Use the daily radiation and calculation the daily average for the month.

Method 2:

- Calculate the solar radiation for each day.
- Use the daily radiation and calculate the daily average for the month.
- Then pick the day with average value closet to the monthly average. The value for that day represent the monthly average day.

Method 3:

For reducing the amount of calculation short cut methods of using the middle day of each month is sometimes employed.

- ✓ Take the 16th day for all month with 31st days.
- ✓ 15th day for these with 30 days.
- ✓ 14th for February.

Method 1, is tedious and cumbersome, while method 3 is not very accurate. Klein (1976) as cited in (Duffie and Beckman, 2013) used the second method and recommended days for each month for latitude from 60°S to 60°N as shown in table 2.3

Table 3.2. Monthly average days and their day numbers

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
i^{th} Day	I	31+i	59+i	90+i	120+i	151+i	181+i	212+i	243+i	273+i	304+i	334+i
Ave Day	17	16	16	15	15	11	17	16	15	15	14	10
Day No	17	47	75	105	135	162	198	228	258	288	318	344

Source: Klein, 1977 as cited in Duffie and Beckman(2013)

The recommended monthly average days suggested was used to calculate the average monthly:

- Eccentricity factor E_o;
- Declination angle δ;
- Sunset hour angle w_s;

The values obtained were used to find the monthly average extraterrestrial solar radiation, H_o for all the three locations.

The results obtained are as shown in Table 4.1

3.2.2 Relevant Meteorological Data

Daily average data was obtained from the Nigeria Meteorological Agency (NIMET) for all the three locations (Kano, Katsina and Sokoto) for:

- Solar Radiation at Horizontal Surface in $MJ/m^2 - day$;
- Sunshine Hours in hours;
- Relative Humidity in percentage;
- Maximum Relative Humidity in percentage;
- Maximum Temperature in degree Celsius;
- Minimum Temperature in degree Celsius.

The data obtained is for ten years (2006 – 2015) and Microsoft excel was used to evaluate the monthly and yearly average for all the data obtained. The temperatures obtained were in degree Celsius, and then they were converted to Kelvin using the relationship:

$$T = \theta + 273 \tag{3.7}$$

The results obtained are as shown in Tables 4.2 to 4.19.

3.2.3 Formation of Parametric Equations

From the selected six models, Model 2 and Model 6 involves temperature, since the temperature is in degree Celsius is also converted to kelvin, additional two models were merged (Model 2b and Model 6b) to investigate whether the temperature is to be used in degree Celsius or in kelvin for better correlation.

The non-linear models were transformed to linear and then Method of Least square error was used to form the parametric equations for all the models.

3.2.3.1 Parametric Equations for Model 1

This model is the Angstrom-Prescott model involving only sunshine duration given as:

$$\frac{H}{H_o} = a + b\left(\frac{S}{S_o}\right)$$

Its parametric equations were formed as:

$$\Sigma\frac{H}{H_o} = an + b\,\Sigma\left(\frac{S}{S_o}\right)$$

$$\Sigma\frac{H}{H_o}\cdot\frac{S}{S_o} = a\,\Sigma\frac{S}{S_o} + b\,\Sigma\left(\frac{S}{S_o}\right)^2$$

3.2.3.2 Parametric Equations for Model 2

This model is a Linear Model involving Sunshine hour, temperature in degree Celsius and Relative humidity expressed as:

$$\frac{H}{H_o} = c + d\left(\frac{S}{S_o}\right) + e\left(\frac{T_{min}}{T_{max}}\right) + f\left(\frac{RH}{RH_{max}}\right)$$

Its parametric equations were formed as:

$$\Sigma\frac{H}{H_o} = cn + d\,\Sigma\left(\frac{S}{S_o}\right) + e\,\Sigma\left(\frac{T_{min}}{T_{max}}\right) + f\,\Sigma\left(\frac{RH}{RH_{max}}\right)$$

$$\Sigma\frac{H}{H_o}\cdot\frac{S}{S_o} = c\,\Sigma\left(\frac{S}{S_o}\right) + d\,\Sigma\left(\frac{S}{S_o}\right)^2 + e\,\Sigma\left(\frac{S}{S_o}\cdot\frac{T_{min}}{T_{max}}\right) + f\,\Sigma\left(\frac{RH}{RH_{max}}\cdot\frac{S}{S_o}\right)$$

$$\Sigma\left(\frac{H}{H_o}\cdot\frac{T_{min}}{T_{max}}\right) = c\,\Sigma\frac{T_{min}}{T_{max}} + d\,\Sigma\left(\frac{S}{S_o}\cdot\frac{T_{min}}{T_{max}}\right) + e\,\Sigma\left(\frac{T_{min}}{T_{max}}\right)^2 + f\,\Sigma\left(\frac{RH}{RH_{max}}\cdot\frac{T_{min}}{T_{max}}\right)$$

$$\Sigma\left(\frac{H}{H_o}\cdot\frac{RH}{RH_{max}}\right) = c\,\Sigma\left(\frac{RH}{RH_{max}}\right) + d\,\Sigma\left(\frac{S}{S_o}\cdot\frac{RH}{RH_{max}}\right) + e\,\Sigma\left(\frac{T_{min}}{T_{max}}\cdot\frac{RH}{RH_{max}}\right) + f\,\Sigma\left(\frac{RH}{RH_{max}}\right)^2$$

3.2.3.3 Parametric Equations for Model 2b

This model is a Linear Model involving Sunshine hour, temperature in kelvin and Relative humidity expressed as:

$$\frac{H}{H_o} = c_1 + d_1 \left(\frac{S}{S_o}\right) + e_1 \left(\frac{\theta_{min}}{\theta_{max}}\right) + f_1 \left(\frac{RH}{RH_{max}}\right)$$

Its parametric equations were formed as:

$$\sum \frac{H}{H_o} = c_1 n + d_1 \sum \left(\frac{S}{S_o}\right) + e_1 \sum \left(\frac{\theta_{min}}{\theta_{max}}\right) + f_1 \sum \left(\frac{RH}{RH_{max}}\right)$$

$$\sum \frac{H}{H_o} \cdot \frac{S}{S_o} = c_1 \sum \left(\frac{S}{S_o}\right) + d_1 \sum \left(\frac{S}{S_o}\right)^2 + e_1 \sum \left(\frac{S}{S_o} \cdot \frac{\theta_{min}}{\theta_{max}}\right) + f_1 \sum \left(\frac{RH}{RH_{max}} \cdot \frac{S}{S_o}\right)$$

$$\sum \left(\frac{H}{H_o} \cdot \frac{\theta_{min}}{\theta_{max}}\right) = c_1 \sum \frac{\theta_{min}}{\theta_{max}} + d_1 \sum \left(\frac{S}{S_o} \cdot \frac{\theta_{min}}{\theta_{max}}\right) + e_1 \sum \left(\frac{\theta_{min}}{\theta_{max}}\right)^2 + f_1 \sum \left(\frac{RH}{RH_{max}} \cdot \frac{\theta_{min}}{\theta_{max}}\right)$$

$$\sum \left(\frac{H}{H_o} \cdot \frac{RH}{RH_{max}}\right) = c_1 \sum \left(\frac{RH}{RH_{max}}\right) + d_1 \sum \left(\frac{S}{S_o} \cdot \frac{RH}{RH_{max}}\right) + e_1 \sum \left(\frac{\theta_{min}}{\theta_{max}} \cdot \frac{RH}{RH_{max}}\right) + f_1 \sum \left(\frac{RH}{RH_{max}}\right)^2$$

3.2.3.4 Parametric Equations for Model 3

This model is a linear model involving sunshine hours and relative humidity expressed as

$$\frac{H}{H_o} = g + h \left(\frac{S}{S_o}\right) + j(RH)$$

Its parametric equations were formed as:

$$\sum \frac{H}{H_o} = gn + h \sum \frac{S}{S_o} + j \sum (RH)$$

$$\sum \frac{H}{H_o} \cdot \frac{S}{S_o} = g \sum \left(\frac{S}{S_o}\right) + h \sum \left(\frac{S}{S_o}\right)^2 + j \sum (RH) \cdot \left(\frac{S}{S_o}\right)$$

$$\sum \frac{H}{H_o} \cdot (RH) = g \sum (RH) + h \sum \frac{S}{S_o} \cdot (RH) + j \sum (RH)^2$$

3.2.3.5 Parametric Equations for Model 4

This model is a non-linear model involving sunshine hour expressed as:

$$\frac{H}{H_o} = k \left(\frac{S}{S_o}\right)^l$$

Its parametric equations were formed as:

$$\sum \ln \frac{H}{H_o} = n \ln k + l \sum \ln \left(\frac{S}{S_o}\right)$$

$$\sum \ln \left(\frac{H}{H_o}\right) \cdot \ln \left(\frac{S}{S_o}\right) = \ln k \sum \ln \left(\frac{S}{S_o}\right) + l \sum \left(\ln \frac{S}{S_o}\right)^2$$

3.2.3.6 Parametric Equations for Model 5

This model is a non-linear model involving multi-sunshine hour expressed as:

$$\frac{H}{H_o} = m + p \left(\frac{S}{S_o}\right) + q \, exp \left(\frac{S}{S_o}\right)$$

Its parametric equations were formed as:

$$\sum \frac{H}{H_o} = mn + p \sum \left(\frac{S}{S_o}\right) + q \sum exp\left(\frac{S}{S_o}\right)$$

$$\sum \left(\frac{H}{H_o} \cdot \frac{S}{S_o}\right) = m \sum \left(\frac{S}{S_o}\right) + p \sum \left(\frac{S}{S_o}\right)^2 + q \sum \left(exp\left(\frac{S}{S_o}\right)\right)^2$$

$$\sum \left(\frac{H}{H_o}\right) \cdot exp\left(\frac{S}{S_o}\right) = m \sum exp\left(\frac{S}{S_o}\right) + p \sum \left(\frac{S}{S_o}\right) \cdot exp\left(\frac{S}{S_o}\right) + q \sum \left(exp\left(\frac{S}{S_o}\right)\right)^2$$

3.2.3.7 Parametric Equations for Model 6

This model is a non-linear model involving sunshine hour, temperature in degree Celsius and relative humidity expressed as:

$$\frac{H}{H_o} = r \left(\frac{S}{S_o}\right)^S T_{max}{}^t RH^u$$

Its parametric equations were formed as:

$$\sum \ln\left(\frac{H}{H_o}\right) = n \ln r + s \sum \ln\left(\frac{S}{S_o}\right) + t \sum \ln(T_{max}) + u \sum \ln(RH)$$

$$\sum \ln\left(\frac{H}{H_o}\right) \ln\left(\frac{S}{S_o}\right) = \ln r \sum \ln\frac{S}{S_o} + s \sum \left(\ln\left(\frac{S}{S_o}\right)\right)^2 + t \sum \ln(T_{max}) \ln\left(\frac{S}{S_o}\right) + u \sum \ln(RH) \ln\left(\frac{S}{S_o}\right)$$

$$\sum \ln\left(\frac{H}{H_o}\right) \ln(T_{max}) = \ln r \sum \ln(T_{max}) + s \sum \ln\left(\frac{S}{S_o}\right) \ln(T_{max}) + t \sum (\ln(T_{max}))^2 + u \sum \ln(RH) \ln(T_{max})$$

$$\sum \ln\left(\frac{H}{H_o}\right) \ln(RH) = \ln r \sum \ln(RH) + s \sum \ln\left(\frac{S}{S_o}\right) \ln(RH) + t \sum \ln(T_{max}) \ln(RH) + u \sum (\ln(RH))^2$$

3.2.3.8 Parametric Equations for Model 6b

This model is a non-linear model involving sunshine hour, temperature in kelvin and relative humidity expressed as:

$$\frac{H}{H_o} = r_1 \left(\frac{S}{S_o}\right)^{S_1} \theta_{max}{}^{t_1} RH^{u_1}$$

Its parametric equations were formed as:

$$\sum \ln\left(\frac{H}{H_o}\right) = n \ln r_1 + s_1 \sum \ln\left(\frac{S}{S_o}\right) + t_1 \sum \ln(\theta_{max}) + u_1 \sum \ln(RH)$$

$$\sum \ln\left(\frac{H}{H_o}\right) \ln\left(\frac{S}{S_o}\right) = \ln r_1 \sum \ln\frac{S}{S_o} + s_1 \sum \left(\ln\left(\frac{S}{S_o}\right)\right)^2 + t_1 \sum \ln(\theta_{max}) \ln\left(\frac{S}{S_o}\right) + u_1 \sum \ln(RH) \ln\left(\frac{S}{S_o}\right)$$

$$\sum \ln\left(\frac{H}{H_o}\right) \ln(\theta_{max}) = \ln r_1 \sum \ln(\theta_{max}) + s_1 \sum \ln\left(\frac{S}{S_o}\right) \ln(\theta_{max}) + t_1 \sum (\ln(\theta_{max}))^2 + u_1 \sum \ln(RH) \ln(\theta_{max})$$

$$\sum \ln\left(\frac{H}{H_o}\right) \ln(RH) = \ln r_1 \sum \ln(RH) + s_1 \sum \ln\left(\frac{S}{S_o}\right) \ln(RH) + t_1 \sum \ln(\theta_{max}) \ln(RH) + u_1 \sum (\ln(RH))^2$$

3.2.4 Evaluation of Parametric Constants

To evaluate the parametric constants, the parametric equations were solved simultaneously. There are many methods that can be used to solve the equations:

  i.   Substitution method;

ii.   Elimination method;

iii.   Cramer's rule;

iv.   Gausian Elimination Method;

v.   Gauss Jordan Method; etc.

From the parametric equations:

✓ Model 1 and model 4 involves two parametric equations;

✓ Model 3 and model 5 involves three parametric equations;

✓ Model 2 and model 6 involves four parametric equations.

Considering the task involved in solving all the equations, Cramer's rule was chosen.

To simplify the work further, a program was formed using Microsoft excel.

3.2.5   Estimation of Solar Radiation using the Models

After evaluating the parametric constants using the parametric equations, their values were replaced in the initial model equation.

The models formed were used to predict the solar radiation. The results obtained for all the locations are as shown in Table 4.23 to 4.25.

3.2.6   Statistical Analysis of the Models

To evaluate and compare the performance of the models, statistical analysis was conducted and evaluated as in Table 3.3.

Table 3.3 Statistical Parameters

S/N	Statistical Parameter	Relationship
1.	Mean Bias Error (MBE)	$MBE = \dfrac{1}{K}\sum\limits_{i=1}^{k}(y_i - x_i)$
2.	Root means square error	$RMSE = \left[\dfrac{1}{K}\sum_{i=1}^{k}(y_i - x_i)^2\right]^{\frac{1}{2}}$
3.	Mean percentage error (%)	$MPE\% = \dfrac{1}{K}\sum\limits_{i=1}^{k}(y_i - x_i) \times 100$
4.	Mean relative error	$MRE = \dfrac{1}{n}\sum_{i=1}^{n}\left|\dfrac{y_i - x_i}{x_i}\right|$
5.	Correlation coefficient (r)	$r = \dfrac{\sum_{i=1}^{k}(y_i - \bar{y})(x_i - \bar{x})}{\left[\sum_{i=1}^{k}(y_i - \bar{y})^2 \sum_{i=1}^{k}(x_i - \bar{x})^2\right]^{\frac{1}{2}}}$
6.	Coefficient of determinant (R^2)	$R^2 = 1 - \dfrac{\sum_{i=1}^{k}(x_i - y_i)^2}{\sum_{i=1}^{k}(x_i - \bar{x})}$
7.	T-statistical value	$t - stat = \left[\dfrac{(n-1)(MBE)^2}{(RMSE)^2 - MBE^2}\right]^{\frac{1}{2}}$

The results obstained for all the locations are as shown in Tables 4.23 to 4.25.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1   RESULTS

The extraterrestrial solar radiation calculated for the locations as shown in the Table 4.1.

Table 4.1. Extraterrestrial Solar Radiation in $MJ/m^2 - day$ for the Locations.

Months	Kano	Katsina	Sokoto
Jan	31.148	30.781	30.574
Feb	33.970	33.696	33.541
Mar	36.598	36.460	36.381
Apr	38.004	38.029	38.040
May	37.932	38.087	38.171
Jun	37.512	37.726	37.843
Jul	37.545	37.732	37.834
Aug	37.737	37.817	37.859
Sep	36.916	36.842	36.798
Oct	34.582	34.353	34.222
Nov	31.714	31.373	31.179
Dec	30.194	29.805	29.586
Average	**35.321**	**35.225**	**35.169**

The monthly average data for solar radiation for the three locations are as shown in Tables 4.2 to 4.4.

Table 4.2. Monthly Average Measured Values of Solar Radiation for Kano in $MJ/m^2 - day$

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	25.36	23.96	22.54	24.40	26.00	24.62	25.56	25.48	23.82	24.35	24.61
Feb	26.04	26.30	24.67	25.46	26.77	25.61	26.13	24.03	25.60	25.53	25.62
Mar	26.19	25.39	26.60	25.80	25.18	27.27	25.83	24.26	24.67	26.60	25.78
Apr	24.07	23.56	23.85	23.15	24.16	24.83	23.90	22.82	24.29	23.75	23.84
May	20.00	19.97	21.20	21.17	20.02	21.73	21.06	20.54	20.86	21.05	20.76
Jun	19.82	18.66	19.28	19.79	18.15	18.79	18.28	17.79	18.28	19.77	18.86
Jul	19.48	17.98	16.72	18.04	16.66	18.19	17.11	17.62	16.66	16.35	17.48
Aug	18.23	17.98	16.72	17.51	17.71	17.55	17.72	18.11	16.71	16.85	17.51
Sep	20.22	20.76	19.83	19.51	19.43	20.32	20.02	20.26	18.25	19.24	19.78
Oct	21.95	23.40	22.76	21.42	21.26	22.75	23.12	22.93	21.69	22.04	22.33
Nov	24.48	24.99	25.32	23.68	25.07	26.39	25.91	25.98	24.60	24.19	25.06
Dec	23.22	24.19	23.95	25.21	25.15	24.62	25.58	17.28	23.36	23.94	23.65

Table 4.3. Monthly Average Measured Value of Solar Radiation for Katsina in $MJ/m^2 - day$

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	25.31	24.06	22.72	23.20	25.32	23.78	25.03	24.47	27.31	25.15	24.64
Feb	26.49	26.76	26.28	25.30	26.14	25.98	27.26	26.58	28.33	23.80	26.29
Mar	26.53	25.28	26.07	25.35	24.74	28.63	25.80	26.76	27.47	23.48	26.01
Apr	25.83	24.61	23.64	22.72	22.93	25.20	23.68	23.27	26.74	22.69	24.13
May	20.28	20.05	20.55	20.06	19.97	21.71	19.94	22.05	23.41	20.04	20.80
Jun	18.73	19.69	18.82	19.43	18.29	19.17	17.94	19.96	20.78	18.66	19.15
Jul	18.93	17.49	17.32	19.00	16.35	20.10	17.22	18.46	21.00	17.42	18.33
Aug	17.32	16.24	17.77	17.70	17.64	19.26	18.46	18.17	20.64	18.25	18.14
Sep	19.24	20.03	19.77	20.21	19.73	22.01	20.64	20.21	22.69	18.12	20.27
Oct	22.26	22.98	22.75	21.59	20.68	23.83	23.69	23.36	25.52	22.59	22.93
Nov	24.97	24.99	25.03	23.19	24.90	25.89	24.66	25.89	26.74	24.84	25.11
Dec	24.40	24.79	23.37	24.01	24.38	24.64	24.10	24.64	26.48	23.91	24.47

Table 4.4. Monthly Average Measured Value of Solar Radiation for Sokoto in $MJ/m^2 - day$

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	24.56	24.00	23.07	24.56	25.58	23.59	25.05	23.94	25.15	22.94	24.24
Feb	25.71	26.10	25.16	25.70	27.71	24.11	25.18	25.46	25.03	25.60	25.38
Mar	25.89	26.23	26.42	25.47	24.41	25.21	25.38	25.25	26.28	24.79	25.53
Apr	24.76	22.82	23.75	25.05	22.63	23.53	23.29	21.37	22.61	22.22	23.00
May	20.79	20.24	20.61	20.45	19.66	20.14	19.62	19.88	19.37	20.52	20.13
Jun	18.31	19.68	18.36	18.45	17.63	17.35	17.05	18.98	17.78	18.42	18.20
Jul	17.85	18.42	15.82	17.42	16.03	17.17	15.57	17.51	17.00	17.24	17.00
Aug	17.05	17.63	17.14	17.38	16.60	17.87	16.46	16.49	17.03	17.40	17.10
Sep	18.60	21.10	18.89	19.02	18.73	20.88	19.67	19.87	19.51	19.54	19.58
Oct	21.63	22.62	23.22	21.36	20.84	23.45	22.01	23.45	23.16	21.68	22.34
Nov	24.23	25.17	25.74	22.61	23.73	25.09	25.09	25.97	24.73	24.72	24.80
Dec	24.07	23.84	24.29	24.35	24.63	23.94	24.66	23.94	24.58	24.69	24.30

The monthly average data for Sunshine Hours for the three locations are as shown in Tables 4.5 to 4.7.

Table 4.5. Monthly Average Measured Values of Sunshine Hours for Kano in Hours

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	8.74	8.85	7.50	7.24	8.03	9.14	8.43	6.92	8.33	7.54	8.07
Feb	8.20	7.06	8.30	7.60	6.85	9.33	6.42	7.99	8.19	7.68	7.76
Mar	7.56	7.72	7.33	7.86	4.77	6.88	7.21	7.17	6.73	5.59	6.88
Apr	9.11	7.28	7.70	7.01	6.18	8.19	8.07	7.45	7.10	7.44	7.55
May	8.81	7.87	9.24	7.65	8.06	8.08	8.63	7.83	6.29	7.83	8.03
Jun	7.98	7.80	7.45	8.40	7.37	9.06	8.01	7.26	8.40	8.58	8.03
Jul	7.40	7.37	7.29	6.92	6.25	6.98	7.53	6.41	6.83	7.34	7.03
Aug	8.13	7.09	7.57	8.41	7.97	7.71	8.34	6.43	6.38	6.20	7.42
Sep	7.94	7.33	7.82	6.63	7.58	8.16	7.07	7.41	8.88	7.32	7.61
Oct	8.37	8.47	6.66	6.45	6.89	8.71	9.26	8.55	9.07	9.27	8.17
Nov	7.86	8.23	9.35	8.74	8.99	8.37	9.44	9.23	8.21	8.16	8.66
Dec	9.11	8.06	8.84	6.59	7.82	8.61	8.44	7.63	8.18	8.49	8.18

Table 4.6. Monthly Average Measured Values of Sunshine Hours for Katsina in Hours

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	8.23	9.08	7.81	8.88	7.49	7.30	8.06	7.53	7.53	8.41	8.03
Feb	8.09	9.37	9.23	7.83	8.32	8.84	7.87	8.38	8.45	9.14	8.55
Mar	6.98	8.21	8.24	8.97	5.83	7.32	7.46	8.31	5.89	7.27	7.45
Apr	7.96	8.40	7.65	7.68	7.13	8.63	7.48	7.44	5.93	7.52	7.58
May	7.69	8.00	8.33	7.92	7.15	8.98	7.26	8.69	7.63	8.12	7.98
Jun	7.59	7.65	8.41	8.66	7.69	7.55	6.95	8.27	6.57	7.13	7.65
Jul	7.88	8.20	7.23	7.16	7.15	7.00	6.73	8.20	7.15	6.51	7.32
Aug	6.93	6.20	6.87	6.86	6.11	7.45	6.40	8.07	7.44	7.52	6.98
Sep	8.69	7.43	8.22	7.59	7.50	8.78	7.31	8.17	7.50	7.97	7.92
Oct	8.98	9.44	9.14	8.62	8.28	9.18	7.76	8.94	8.10	8.71	8.71
Nov	9.29	9.21	8.99	9.24	7.57	8.96	8.69	9.02	9.93	8.47	8.94
Dec	10.01	8.77	8.27	9.08	8.54	8.36	7.94	9.46	6.79	7.16	8.44

Table 4.7. Monthly Average Measured Values of Sunshine Hours for Sokoto in Hours

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	9.04	9.34	7.33	7.83	8.41	8.58	8.64	8.28	8.04	8.85	8.43
Feb	7.75	7.60	8.35	8.37	9.39	8.99	8.49	8.84	7.85	8.62	8.42
Mar	7.89	8.08	8.25	5.98	7.31	7.58	5.67	7.30	7.58	8.17	7.38
Apr	7.40	7.08	7.83	8.55	6.01	7.55	7.98	7.41	7.48	8.56	7.59
May	7.48	7.04	8.39	8.98	7.63	8.12	5.66	9.66	7.40	8.46	7.88
Jun	8.09	7.11	6.74	7.74	6.18	7.16	7.68	7.97	7.69	8.27	7.46
Jul	7.27	7.67	7.86	7.35	7.05	6.77	6.91	8.03	6.68	8.21	7.38
Aug	8.03	6.22	7.27	8.57	7.26	7.52	6.29	6.52	6.96	8.06	7.27
Sep	8.21	8.21	7.47	7.23	7.50	7.97	7.09	7.19	8.69	8.15	7.77
Oct	9.09	7.97	8.36	7.37	7.96	8.51	8.42	9.44	8.98	8.94	8.50
Nov	7.90	8.49	9.41	8.33	9.93	8.47	7.19	8.22	9.70	9.04	8.67
Dec	9.56	8.56	8.51	7.00	7.56	7.50	8.38	8.41	9.91	9.46	8.49

The monthly average data for Relative Humidity for the three locations are as shown in Tables 4.8 to 4.10.

Table 4.8. Monthly Average Measured Values of Relative Humidity for Kano in (%)

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	60.06	27.35	28.99	29.82	17.18	21.23	21.05	29.03	42.25	24.47	30.14
Feb	33.69	24.48	23.28	21.06	15.13	20.71	22.93	23.85	27.46	23.83	23.64
Mar	26.01	28.50	19.15	18.91	20.02	13.60	18.73	20.98	18.12	21.54	20.55
Apr	45.87	62.82	28.68	37.24	29.45	20.67	30.57	28.80	35.38	36.79	25.63
May	59.61	77.10	42.39	52.45	47.19	39.98	41.55	43.48	55.20	39.95	49.89
Jun	70.13	75.62	56.24	57.74	58.08	56.65	61.95	62.43	68.28	58.28	62.54
Jul	72.75	70.40	70.85	76.77	70.29	66.00	71.29	73.84	75.98	71.55	71.97
Aug	79.27	76.86	77.52	81.20	74.94	73.42	74.44	78.48	81.42	78.28	77.58
Sep	75.89	69.43	68.92	77.13	69.43	65.77	64.95	73.23	76.32	74.81	71.59
Oct	46.30	53.27	41.97	57.12	56.13	45.56	46.57	56.28	43.47	57.60	50.43
Nov	26.64	28.29	26.39	33.00	21.22	21.63	28.85	31.48	27.24	32.53	27.73
Dec	30.32	31.10	26.98	29.34	24.06	22.87	29.30	31.51	29.62	28.92	28.40

Table 4.9. Monthly Average Measured Values of Relative Humidity for Katsina in (%)

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	26.25	23.54	37.02	47.55	19.94	25.40	21.15	21.28	20.77	20.95	26.38
Feb	20.12	19.55	17.98	37.43	14.02	18.89	12.48	19.32	11.86	17.75	18.94
Mar	16.20	17.55	15.08	29.10	15.59	13.89	12.27	15.30	11.19	16.44	16.26
Apr	18.50	33.16	23.04	47.90	16.46	23.02	24.35	25.12	31.87	29.34	27.28
May	46.60	48.69	42.53	62.61	43.46	41.15	42.68	45.91	36.95	42.83	45.24
Jun	54.27	57.43	54.83	68.13	49.48	50.30	56.70	56.80	54.14	54.91	55.70
Jul	64.78	68.35	69.72	79.65	68.17	57.39	67.76	64.98	68.52	65.14	67.45
Aug	77.43	77.62	76.89	87.90	78.40	68.23	70.92	74.88	77.85	74.31	76.44
Sep	74.44	56.27	67.88	84.40	70.78	58.92	60.63	69.13	74.16	67.83	68.44
Oct	56.34	35.00	44.33	79.03	37.27	32.68	38.15	64.91	59.84	43.31	49.09
Nov	31.31	28.86	32.08	49.23	20.17	14.72	24.30	32.50	28.07	23.33	28.46
Dec	25.49	45.92	40.56	42.61	22.14	20.48	24.22	26.60	23.47	23.73	29.52

Table 4.10. Monthly Average Measured Values of Relative Humidity for Sokoto in (%)

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	26.42	27.05	26.44	14.58	18.75	17.37	15.84	21.74	20.58	15.10	20.39
Feb	22.63	18.91	19.83	14.50	10.80	18.34	16.79	18.51	15.96	58.37	21.46
Mar	19.11	22.89	17.21	14.13	15.20	10.84	9.13	16.77	40.86	64.00	23.01
Apr	20.48	34.88	24.05	23.90	30.27	20.72	30.59	36.13	57.04	65.48	33.36
May	47.31	46.24	45.60	39.69	44.55	41.74	46.82	47.56	68.83	65.67	49.40
Jun	53.95	57.08	55.73	51.11	51.73	52.45	56.07	54.87	75.80	59.18	56.80
Jul	64.90	69.52	71.26	64.97	71.81	58.87	69.04	68.05	69.66	65.97	67.40
Aug	79.23	78.90	76.55	72.47	79.49	67.89	74.14	79.74	31.34	76.87	71.66
Sep	75.56	73.02	71.68	68.27	73.16	59.17	68.02	67.52	19.99	68.50	64.49
Oct	61.91	48.60	50.44	38.89	56.41	41.35	46.36	53.17	24.80	38.39	46.03
Nov	27.50	28.77	26.73	18.34	23.11	15.03	23.31	19.60	18.68	16.23	21.73
Dec	33.33	24.63	28.35	18.31	16.95	16.84	21.95	18.11	12.72	18.87	21.01

The monthly average data for maximum relative humidity for the three locations are as shown in Tables 4.11 to 4.13.

Table 4.11. Monthly Average Measured Values of Maximum Relative Humidity for Kano in (%)

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	74.00	41.50	43.33	43.67	23.00	30.50	29.50	40.33	49.00	36.00	41.08
Feb	64.67	37.00	43.00	29.00	20.00	33.00	36.50	33.00	52.33	38.67	38.72
Mar	49.00	50.00	38.67	45.67	34.50	18.50	39.50	39.67	26.33	45.00	38.68
Apr	70.00	85.50	48.67	48.67	63.50	47.50	41.00	49.33	62.33	53.33	56.98
May	78.67	97.00	64.00	79.33	61.50	79.00	65.00	62.33	79.00	51.00	71.68
Jun	87.00	89.50	84.67	69.33	75.00	80.00	81.50	85.67	82.00	70.67	80.53
Jul	95.33	80.00	81.33	89.00	89.50	85.00	88.00	94.33	92.67	86.00	88.12
Aug	90.67	91.33	94.33	93.00	92.00	88.00	93.50	88.67	92.67	86.67	91.08
Sep	86.67	86.00	79.00	89.67	88.50	80.00	90.50	87.00	91.33	89.67	86.83
Oct	71.33	79.33	62.33	78.00	76.00	80.00	63.13	81.00	65.00	87.33	74.35
Nov	34.00	33.33	34.00	57.00	35.00	33.00	31.51	39.33	36.00	43.33	37.65
Dec	39.67	38.67	35.00	37.33	36.50	32.50	45.00	40.00	45.33	38.67	38.87

Table 4.12. Monthly Average Measured Values of Maximum Relative Humidity for Katsina in (%)

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	34.00	35.33	50.67	64.00	32.67	37.50	29.00	33.33	29.33	29.00	37.48
Feb	26.33	26.33	31.00	95.00	20.00	28.00	19.00	26.67	24.00	26.33	32.27
Mar	24.67	35.00	31.33	40.00	40.00	18.00	23.50	30.00	19.00	31.33	29.28
Apr	39.33	51.33	41.00	69.00	35.67	44.50	49.50	42.00	74.33	68.33	51.50
May	66.33	65.00	59.00	100.00	73.00	82.00	78.00	58.33	56.67	61.67	70.00
Jun	74.33	71.00	65.67	91.00	80.33	63.50	77.50	78.67	65.33	79.67	74.70
Jul	79.67	89.67	92.33	95.00	86.00	75.00	84.50	75.00	89.33	89.00	85.55
Aug	94.00	91.33	90.33	95.00	92.67	85.50	95.00	87.00	91.33	83.00	90.52
Sep	88.33	66.33	80.00	98.00	86.00	73.50	78.00	85.33	89.67	80.00	82.52
Oct	79.33	62.00	67.33	94.00	63.00	84.50	65.00	86.33	75.67	69.33	74.65
Nov	39.33	37.33	39.00	82.00	27.00	28.00	37.00	61.00	38.67	38.00	42.78
Dec	34.33	56.50	51.00	54.00	30.67	29.00	39.00	35.00	32.33	33.67	39.55

Table 4.13. Monthly Average Measured Values of Maximum Relative Humidity for Sokoto in (%)

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	39.00	45.00	34.50	20.33	28.33	25.00	23.00	34.33	49.00	46.00	34.35
Feb	34.50	25.50	26.50	29.00	19.00	50.00	27.00	33.33	30.00	73.67	34.85
Mar	28.00	36.00	37.00	37.00	35.67	17.00	16.00	36.67	70.33	79.00	23.01
Apr	43.00	55.50	48.50	44.67	44.00	45.50	39.38	56.33	83.67	78.33	53.89
May	65.00	57.00	73.00	49.33	63.00	71.50	53.91	58.00	85.50	83.67	65.99
Jun	74.50	75.00	80.50	65.33	64.67	84.50	61.74	71.33	90.33	82.67	75.06
Jul	80.00	84.50	91.50	81.33	83.33	82.00	74.55	81.00	84.00	86.00	82.82
Aug	90.33	92.50	94.00	84.33	90.00	86.00	76.70	95.00	64.33	94.00	71.66
Sep	89.00	91.00	92.00	86.33	84.00	79.50	73.57	82.00	27.33	90.00	79.47
Oct	78.33	62.50	72.50	59.67	82.33	73.00	62.50	67.33	37.33	70.00	66.55
Nov	31.33	39.50	36.50	28.67	59.33	24.00	28.28	36.67	24.00	22.00	33.03
Dec	39.67	35.00	35.00	27.00	25.50	24.50	23.37	22.67	22.00	24.00	27.87

The monthly average data for minimum temperature for the three locations are as shown in Tables 4.14 to 4.16.

Table 4.14. Monthly Average Measured Values of Minimum Temperature for Kano in ($^{\circ}$C)

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	13.53	14.17	12.79	15.66	13.67	11.38	11.67	14.03	12.70	12.17	13.19
Feb	18.97	16.55	14.09	18.21	17.99	18.51	17.38	16.62	17.62	17.19	17.31
Mar	20.00	20.06	20.99	20.49	21.53	19.91	18.97	21.74	20.80	20.88	20.45
Apr	23.87	25.17	23.60	25.89	24.63	23.08	25.44	25.83	24.05	21.42	24.30
May	24.87	25.68	25.28	25.04	26.82	25.33	25.25	25.50	25.78	26.08	25.56
Jun	22.53	23.34	24.27	24.27	24.50	23.69	22.83	23.79	24.68	25.07	23.90
Jul	21.19	22.39	21.99	22.41	22.74	22.15	21.78	21.73	21.50	23.55	22.14
Aug	21.19	21.23	21.93	22.37	22.20	21.46	20.96	19.69	20.57	22.33	21.39
Sep	21.50	22.13	22.20	22.67	22.06	21.72	21.99	19.86	20.36	22.45	21.70
Oct	21.97	20.97	20.98	23.29	22.84	20.95	22.59	21.20	21.65	21.74	21.82
Nov	17.03	17.93	16.52	17.98	18.02	14.70	16.93	18.28	17.49	14.59	16.95
Dec	14.58	14.55	15.62	14.09	12.99	12.07	12.75	15.15	15.72	11.93	13.95

Table 4.15. Monthly Average Measured Values of Minimum Temperature for Katsina in (^{o}C)

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	15.20	13.73	12.22	16.13	14.51	13.17	12.54	14.30	14.20	12.90	13.89
Feb	18.14	15.41	13.55	18.34	18.54	17.92	16.25	15.73	16.67	18.04	16.86
Mar	20.00	19.95	20.23	20.69	21.11	17.55	18.65	22.07	21.75	20.79	20.28
Apr	21.43	24.63	23.58	26.08	25.61	22.13	25.42	23.43	26.12	22.23	24.07
May	26.19	26.52	26.19	25.41	26.76	24.85	26.28	24.28	25.67	26.65	25.88
Jun	25.10	24.17	25.10	23.88	24.98	23.71	23.43	22.74	25.46	24.86	24.34
Jul	23.16	22.45	21.68	21.82	22.48	20.63	21.36	21.92	24.17	22.69	22.24
Aug	22.23	21.61	20.87	22.71	21.35	20.45	20.41	21.03	22.07	22.07	21.48
Sep	22.17	22.20	22.97	22.97	21.54	20.94	21.65	22.27	22.04	22.28	22.10
Oct	21.65	20.35	21.71	23.65	23.03	21.20	22.06	20.89	20.73	23.33	21.86
Nov	14.77	17.61	16.79	18.45	18.46	16.07	19.00	16.07	19.16	17.69	17.41
Dec	11.81	13.98	15.94	15.76	13.87	12.21	14.64	12.21	14.16	13.28	13.76

Table 4.16. Monthly Average Measured Values of Minimum Temperature for Sokoto in (^{o}C)

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	19.80	17.00	15.25	18.20	17.45	16.65	15.60	18.10	16.72	14.91	16.97
Feb	21.48	19.54	17.02	21.95	22.42	22.30	21.12	20.55	20.26	20.40	20.71
Mar	23.61	21.85	23.42	24.39	24.89	24.63	22.21	25.60	23.34	22.82	23.68
Apr	25.90	27.74	26.18	27.92	28.32	26.31	27.19	27.45	26.86	23.37	26.72
May	26.77	27.67	26.88	27.87	28.55	27.65	27.25	27.70	26.20	27.16	27.37
Jun	26.40	23.79	26.20	26.56	25.69	25.57	24.89	25.58	27.78	26.30	25.68
Jul	24.61	22.71	24.07	24.63	23.94	24.74	23.23	24.08	24.17	23.92	24.01
Aug	22.84	21.68	23.31	23.78	23.22	22.90	22.80	22.49	22.40	23.00	22.84
Sep	22.97	22.13	23.87	24.16	23.35	22.88	23.09	23.39	22.22	23.41	22.97
Oct	23.29	21.61	23.21	24.35	23.53	23.00	23.55	23.00	22.42	24.84	23.28
Nov	19.27	21.08	19.93	21.03	21.74	18.96	21.47	18.96	20.11	21.43	17.43
Dec	16.42	18.75	19.00	18.58	16.77	16.30	17.98	16.30	16.89	16.38	17.34

The monthly average data for maximum temperature for the three locations are as shown in Tables 4.17 to 4.19.

Table 4.17. Monthly Average Measured Values of Maximum Temperature for Kano in (^{o}C)

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	31.09	29.77	26.52	31.81	31.98	27.76	29.49	31.58	29.50	28.09	29.76
Feb	36.19	34.05	29.41	34.70	36.09	35.41	34.51	28.68	33.05	35.43	33.75
Mar	37.06	35.98	38.42	36.87	37.23	38.17	35.46	35.61	36.08	37.36	36.82
Apr	38.97	39.69	38.46	39.90	39.87	39.17	40.38	38.10	38.75	38.53	39.18
May	36.71	37.43	38.44	38.18	38.57	39.10	38.26	37.00	36.31	41.07	38.11
Jun	35.00	34.53	36.04	36.64	35.06	34.88	33.45	34.33	35.63	37.45	35.30
Jul	32.90	32.45	30.70	32.45	31.34	32.32	30.82	32.52	32.32	33.92	32.17
Aug	30.48	30.23	29.78	30.98	30.94	30.07	29.73	31.52	30.05	31.19	30.49
Sep	31.87	33.13	32.22	32.34	31.70	32.23	32.23	32.90	31.42	32.14	32.22
Oct	34.15	34.88	34.27	34.92	34.31	34.17	36.12	35.97	33.55	35.06	34.74
Nov	33.08	34.64	33.64	32.97	34.79	33.29	34.82	35.40	34.13	32.96	33.97
Dec	29.63	30.93	31.68	31.75	30.57	28.98	30.95	30.48	30.32	26.26	30.15

Table 4.18. Monthly Average Measured Values of Maximum Temperature for Katsina in (^{o}C)

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	32.77	29.52	26.36	30.87	32.03	28.76	29.65	30.63	30.78	28.22	29.96
Feb	35.89	33.71	31.08	34.71	35.92	35.14	35.13	33.89	32.15	35.16	34.28
Mar	37.45	35.85	37.05	36.64	36.36	37.84	35.15	39.80	37.56	36.11	36.98
Apr	39.00	40.60	38.32	39.64	39.48	38.88	40.14	37.84	39.71	37.48	39.12
May	38.35	38.38	38.65	37.33	38.54	38.82	38.04	38.75	37.60	40.26	38.47
Jun	36.33	36.51	36.39	36.02	35.68	35.45	33.71	35.57	36.62	37.48	35.98
Jul	34.29	32.03	31.13	33.15	30.99	33.15	30.74	32.45	33.39	33.72	32.51
Aug	30.71	29.00	29.91	31.58	30.13	30.86	30.07	30.25	30.66	30.68	30.39
Sep	31.77	32.50	33.01	33.42	31.60	33.39	32.59	32.78	32.13	32.52	32.57
Oct	34.42	33.94	34.98	35.60	34.01	35.79	36.39	34.95	35.88	35.87	35.18
Nov	31.67	34.47	33.65	32.96	35.19	34.15	35.36	34.15	36.15	33.34	24.12
Dec	28.61	31.30	31.34	31.95	30.61	29.30	30.93	29.30	30.51	25.89	29.97

Table 4.19. Monthly Average Measured Values of Maximum Temperature for Sokoto in (^{o}C)

Months	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Jan	36.16	32.74	39.77	34.72	35.23	31.97	32.75	33.64	32.81	30.83	33.06
Feb	38.32	36.86	32.93	38.75	39.31	37.19	37.25	37.11	34.87	38.00	37.06
Mar	40.23	38.89	40.70	40.43	39.70	40.41	38.13	41.55	39.28	38.29	39.76
Apr	42.00	41.47	41.01	41.89	41.87	40.92	41.45	39.52	40.45	40.49	41.12
May	39.52	39.81	39.40	40.20	39.95	39.61	38.64	39.40	37.50	41.09	39.51
Jun	37.07	36.14	37.07	34.44	35.64	35.53	34.29	37.14	36.85	37.74	36.49
Jul	34.48	33.36	31.98	34.14	32.01	33.98	30.93	33.67	33.99	34.03	33.29
Aug	31.07	30.55	31.57	32.29	30.98	31.82	30.51	30.17	30.93	31.93	31.18
Sep	31.90	33.53	33.03	33.42	32.37	34.02	33.00	33.47	32.30	33.00	33.01
Oct	35.36	34.74	37.04	35.95	34.61	37.06	35.88	37.06	36.28	37.02	36.10
Nov	35.10	38.18	37.75	34.81	36.91	37.09	38.39	37.09	37.29	36.58	36.91
Dec	32.68	34.70	35.55	35.17	33.81	32.37	35.01	32.37	33.91	39.70	33.53

The annual average data for solar radiation, sunshine hours, relative humidity, maximum relative humidity, maximum and minimum temperature for all the locations is as shown in Tables 4.20 to 4.22.

Table 4.20. The Annual Average Data Values for Kano

Months	S (hrs)	H (MJ/m² − day)	RH (%)	RH$_{max}$(%)	T$_{min}$(°C)	T$_{max}$(°C)
Jan	8.07	24.61	30.14	41.08	13.19	29.76
Feb	7.76	25.62	23.64	38.72	17.31	33.75
Mar	6.88	25.78	20.55	38.68	20.45	36.82
Apr	7.55	23.84	25.63	56.98	24.30	39.18
May	8.03	20.76	49.89	71.68	25.56	38.11
Jun	8.03	18.86	62.54	80.53	23.90	35.30
Jul	7.03	17.48	71.97	88.12	22.14	32.17
Aug	7.42	17.51	77.58	91.08	21.39	30.49
Sep	7.61	19.78	71.59	86.83	21.70	32.22
Oct	8.17	22.33	50.43	74.35	21.82	34.74
Nov	8.66	25.06	27.73	37.65	16.95	33.97
Dec	8.18	23.65	28.40	38.87	13.95	30.15
Average	**7.78**	**22.11**	**45.01**	**62.05**	**20.22**	**33.89**

Table 4.21. The Annual Average Data Values for Katsina

Months	S (hrs)	H (MJ/m² − day)	RH (%)	RH$_{max}$(%)	T$_{min}$(°C)	T$_{max}$(°C)
Jan	8.03	24.64	26.38	37.48	13.89	29.96
Feb	8.55	26.29	18.94	32.27	16.86	34.28
Mar	7.45	26.01	16.26	29.28	20.28	36.98
Apr	7.58	24.13	27.28	51.50	24.07	39.12
May	7.98	20.80	45.24	70.00	25.88	38.47
Jun	7.65	19.15	55.70	74.70	24.34	35.98
Jul	7.32	18.33	67.45	85.55	22.24	32.51
Aug	6.98	18.14	76.44	90.52	21.48	30.39
Sep	7.92	20.27	68.44	82.52	22.10	32.57
Oct	8.71	22.93	49.09	74.65	21.86	35.18
Nov	8.94	25.11	28.46	42.78	17.41	24.12
Dec	8.44	24.47	29.52	39.55	13.76	29.97
Average	**7.96**	**22.52**	**42.43**	**59.23**	**20.35**	**33.29**

Table 4.22. The Annual Average Data Values for Sokoto

Months	S (hrs)	H $(MJ/m^2 - day)$	RH (%)	RH_{max}(%)	$T_{min}(^oC)$	$T_{max}(^oC)$
Jan	8.43	24.24	20.39	34.35	16.97	33.06
Feb	8.42	25.38	21.46	34.85	20.71	37.06
Mar	7.38	25.53	23.01	23.01	23.68	39.76
Apr	7.59	23.00	33.36	53.89	26.72	41.12
May	7.88	20.13	49.40	65.99	27.37	39.51
Jun	7.46	18.20	56.80	75.06	25.68	36.49
Jul	7.38	17.00	67.40	82.82	24.01	33.29
Aug	7.27	17.10	71.66	71.66	22.84	31.18
Sep	7.77	19.58	64.49	79.47	22.97	33.01
Oct	8.50	22.34	46.03	66.55	23.28	36.10
Nov	8.67	24.80	21.73	33.03	17.43	36.91
Dec	8.49	24.30	21.01	27.87	17.34	33.53
Average	**7.94**	**21.80**	**41.40**	**54.05**	**22.42**	**35.92**

The empirical constants evaluated by solving the parametric equations were obtained and the results for all the models for each location were substituted in the equation as follows:

Kano Locations:

Model 1: $$\frac{H}{H_o} = -0.24 + 1.34\left(\frac{S}{S_o}\right) \tag{4.1}$$

Model 2: $$\frac{H}{H_o} = 0.847 + 0.792\left(\frac{S}{S_o}\right) + (-0.828)\left(\frac{T_{min}}{T_{max}}\right) + (-0.328)\left(\frac{RH}{RH_{max}}\right) \tag{4.2}$$

Model 2b: $$\frac{H}{H_o} = 0.508 + 1.356\left(\frac{S}{S_o}\right) + (-0.281)\left(\frac{\theta_{min}}{\theta_{max}}\right) + (-0.676)\left(\frac{RH}{RH_{max}}\right) \tag{4.2b}$$

Model 3: $$\frac{H}{H_o} = 0.376 + 0.722\left(\frac{S}{S_o}\right) + (-0.005)(RH) \tag{4.3}$$

Model 4: $$\frac{H}{H_o} = 1.23\left(\frac{S}{S_o}\right)^{1.571} \tag{4.4}$$

Model 5: $$\frac{H}{H_o} = -0.269 + 1.393\left(\frac{S}{S_o}\right) + (-0.001)\,exp\left(\frac{S}{S_o}\right) \tag{4.5}$$

Model 6: $$\frac{H}{H_o} = 3.597\left(\frac{S}{S_o}\right)^{0.860} T_{max}^{-0.056} RH^{-0.318} \tag{4.6}$$

Model 6b: $$\frac{H}{H_o} = 2.748\left(\frac{S}{S_o}\right)^{0.298} \theta_{max}^{0.001} RH^{-0.365} \tag{4.6b}$$

Katsina Location:

Model 1: $$\frac{H}{H_o} = -0.24 + 1.331\left(\frac{S}{S_o}\right) \tag{4.7}$$

Model 2: $\quad \dfrac{H}{H_o} = 0.566 + 1.013\left(\dfrac{S}{S_o}\right) + (-0.650)\left(\dfrac{T_{min}}{T_{max}}\right) + (-0.280)\left(\dfrac{RH}{RH_{max}}\right)$ (4.8)

Model 2b: $\quad \dfrac{H}{H_o} = 0.451 + 1.223\left(\dfrac{S}{S_o}\right) + (-0.316)\left(\dfrac{\theta_{min}}{\theta_{max}}\right) + (-0.453)\left(\dfrac{RH}{RH_{max}}\right)$ (4.8b)

Model 3: $\quad \dfrac{H}{H_o} = 0.264 + 0.820\left(\dfrac{S}{S_o}\right) + (-0.004)(RH)$ (4.9)

Model 4: $\quad \dfrac{H}{H_o} = 1.178\left(\dfrac{S}{S_o}\right)^{1.495}$ (4.10)

Model 5: $\quad \dfrac{H}{H_o} = -0.281 + 1.402\left(\dfrac{S}{S_o}\right) + (-0.002)\,exp\left(\dfrac{S}{S_o}\right)$ (4.11)

Model 6: $\quad \dfrac{H}{H_o} = 6.456\left(\dfrac{S}{S_o}\right)^{0.795} T_{max}^{-0.308} RH^{-0.251}$ (4.12)

Model 6b: $\quad \dfrac{H}{H_o} = 0.557\left(\dfrac{S}{S_o}\right)^{1.153} \theta_{max}^{0.241} RH^{-0.213}$ (4.12b)

Sokoto Location:

Model 1: $\quad \dfrac{H}{H_o} = -0.57 + 1.807\left(\dfrac{S}{S_o}\right)$ (4.13)

Model 2: $\quad \dfrac{H}{H_o} = 0.906 + 0.610\left(\dfrac{S}{S_o}\right) + (-1.162)\left(\dfrac{T_{min}}{T_{max}}\right) + (-0.061)\left(\dfrac{RH}{RH_{max}}\right)$ (4.14)

Model 2b: $\quad \dfrac{H}{H_o} = -5.383 + 2.250\left(\dfrac{S}{S_o}\right) + 4.678\left(\dfrac{\theta_{min}}{\theta_{max}}\right) + (0.059)\left(\dfrac{RH}{RH_{max}}\right)$ (4.14b)

Model 3: $\quad \dfrac{H}{H_o} = 0.802 + 0.154\left(\dfrac{S}{S_o}\right) + (-0.007)(RH)$ (4.15)

Model 4: $\quad \dfrac{H}{H_o} = 1.309\left(\dfrac{S}{S_o}\right)^{1.820}$ (4.16)

Model 5: $\quad \dfrac{H}{H_o} = -0.518 + 1.726\left(\dfrac{S}{S_o}\right) + 0.001\,exp\left(\dfrac{S}{S_o}\right)$ (4.17)

Model 6: $\quad \dfrac{H}{H_o} = 0.322\left(\dfrac{S}{S_o}\right)^{1.227} T_{max}^{0.522} RH^{-0.196}$ (4.18)

Model 6b: $\quad \dfrac{H}{H_o} = 28.531\left(\dfrac{S}{S_o}\right)^{0.510} \theta_{max}^{-0.411} RH^{-0.351}$ (4.18b)

Graphical representation of the measured and estimated values for solar radiations in Kano, Katsina and Sokoto locations using the models obtained are as shown in Figures 4.1 to 4.3 for the three locations respectively (the numerical values can be seen in appendix 1 to 3).
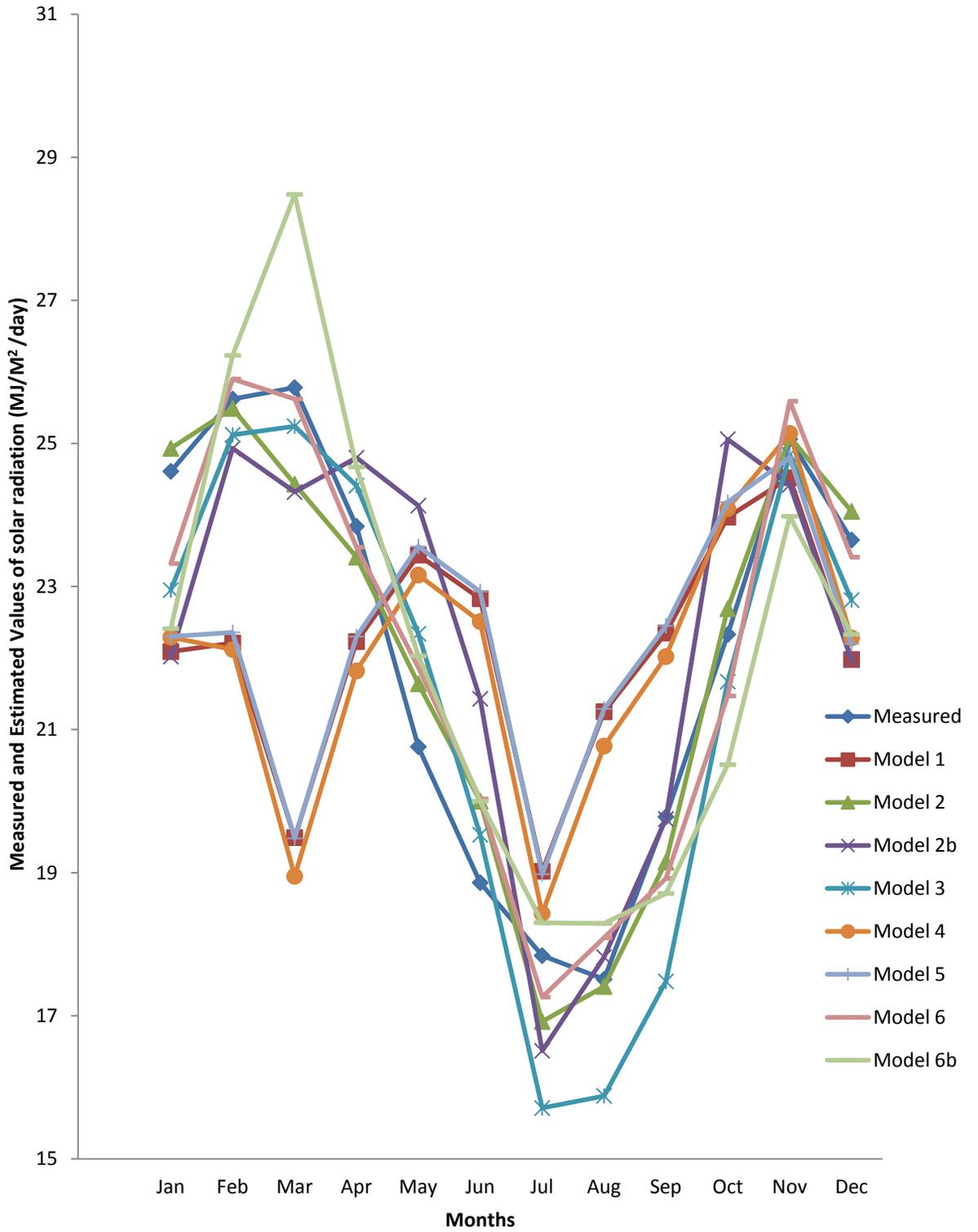
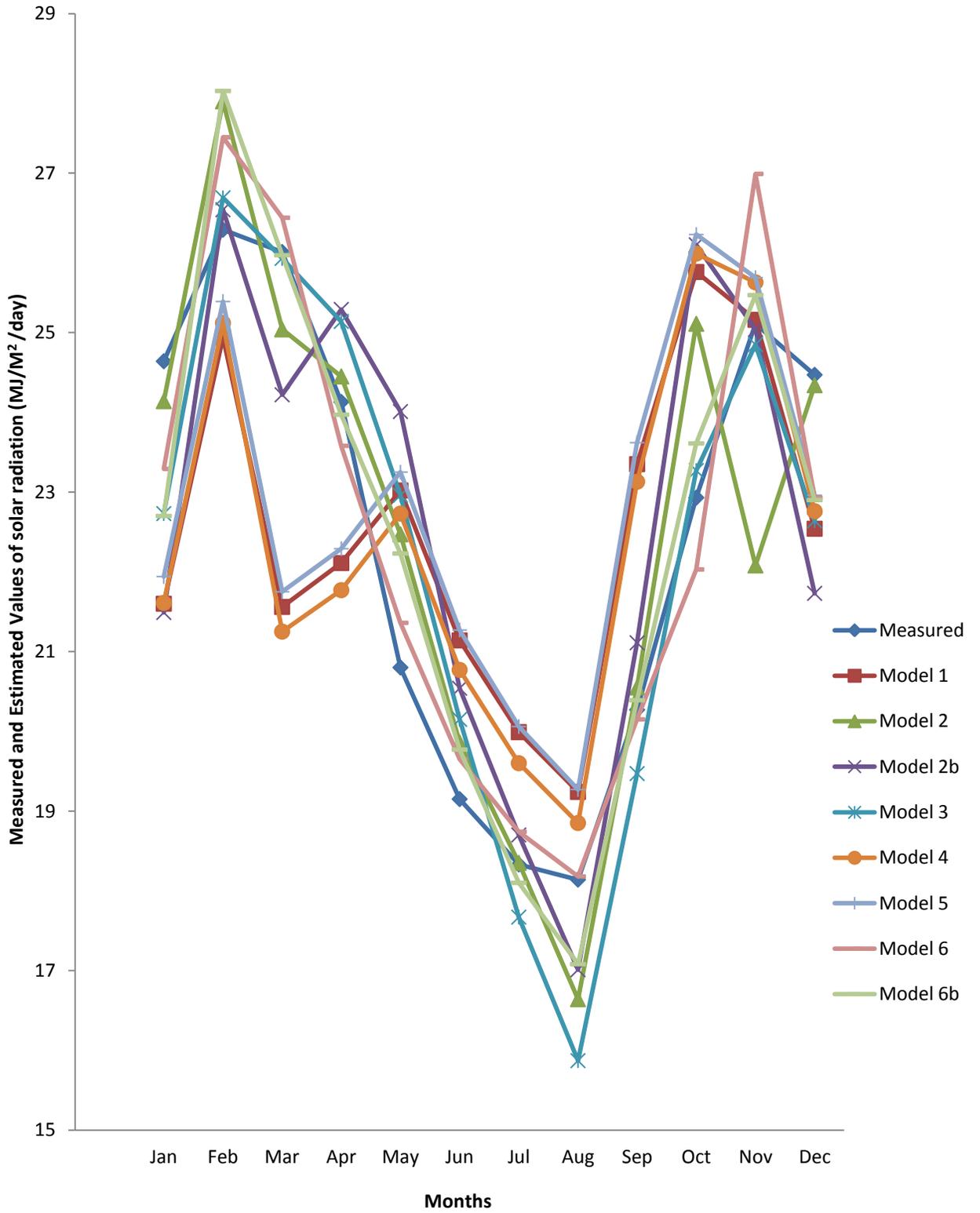Figure 4.1. Measured and Estimated Values of Solar Radiation of Kano for Model 1to 6b

Figure 4.2. Measured and Estimated Values of Solar Radiation of Katsina Model 1 to 6b
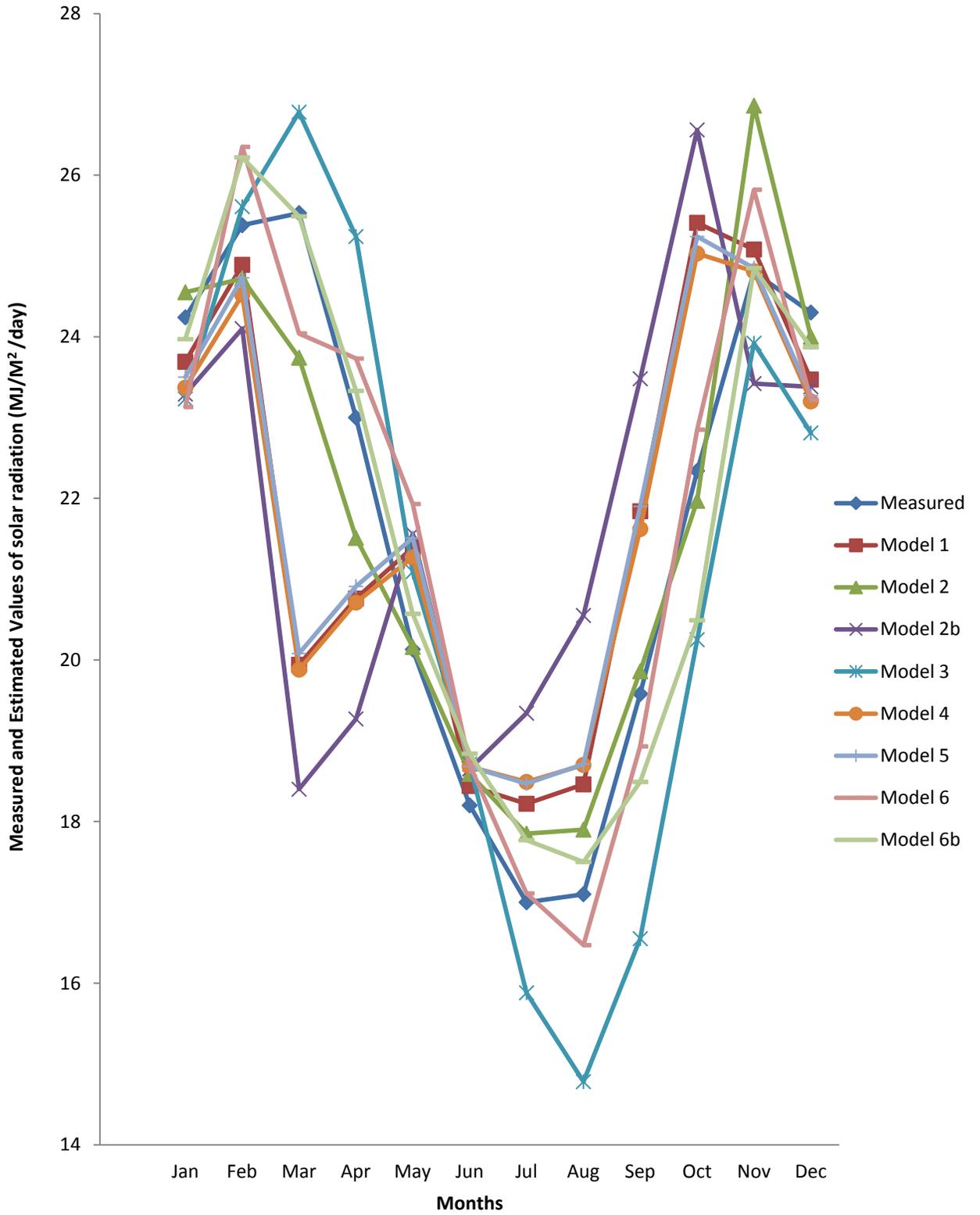
Figure 4.3. Measured and Estimated Values of Solar Radiation of Sokoto Model 1 to 6b

The accuracy of all the models was compared using the statistical parameters of Table 3.3.

The measured values were compared with the estimated values obtained from the models; the results obtained are summarized as shown in Tables 4.23 to 4.25.

Table 4.23. Statistical Analysis of the Models for Kano Location

Statistical parameters	Model 1	Model 2	Model 2b	Model 3	Model 4	Model 5	Model 6	Model 6b
MBE	-0.0205	-0.03699	0.125214	-0.63886	-0.17151	0.097635	-0.05012	0.02541
RMSE	3.03923	0.693367	1.842097	1.29789	3.006419	3.03668	0.76141	1.42209
MPE%	-2.0559	-3.6986	12.5214	-63.8861	-17.1507	9.7635	-5.0115	2.54123
MRE	0.01535	-0.00126	0.00972	-0.03127	0.00710	0.02047	-0.0012	0.00264
R	0.1953	0.9720	0.7952	0.9451	0.2724	0.2144	0.9994	0.9980
R^2	0.0381	0.9448	0.6324	0.8932	0.0742	0.0460	0.9988	0.9960
t-stat	0.0090	0.1730	0.1875	1.5024	0.0799	0.0429	0.2125	0.0535

Table 4.24. Statistical Analysis of the Models for Katsina Location

Statistical parameters	Model 1	Model 2	Model 2b	Model 3	Model 4	Model 5	Model 6	Model 6b
MBE	0.0109	0.0557	0.1268	-0.2407	-0.0867	0.2881	0.0453	-0.0038
RMSE	2.3980	1.3997	1.9674	1.2994	2.3789	2.4004	0.9633	1.0593
MPE%	1.0945	5.5670	12.6809	-24.0686	-8.6682	28.8077	4.5314	-0.3817
MRE	0.0109	0.0030	0.0093	-0.0115	0.0053	0.0227	0.0024	-0.0004
R	0.5680	0.8928	0.7696	0.9180	0.5915	0.5828	0.9991	0.9989
R^2	0.3226	0.7971	0.5923	0.8427	0.3499	0.3397	0.9982	0.9978
t-stat	0.0105	0.1196	0.1721	0.5652	0.0842	0.2747	0.1493	0.0113

Table 4.25. Statistical Analysis of the Models for Sokoto Location

Statistical parameters	Model 1	Model 2	Model 2b	Model 3	Model 4	Model 5	Model 6	Model 6b
MBE	0.00025	0.01000	0.032204	-0.56076	-0.11065	0.021341	0.05741	-0.0170
RMSE	2.17963	1.001715	3.19671	1.63347	2.189993	2.17618	0.98734	0.76552
MPE%	0.02525	1.0000	3.2204	-56.0755	-11.0646	2.1341	5.74133	-1.7029
MRE	0.00828	0.00338	0.01650	-0.02968	0.00441	0.01028	0.00326	0.00055
R	0.7200	0.9468	0.3604	0.9261	0.7108	0.7150	0.9503	0.9692
R^2	0.5184	0.8964	0.1299	0.8577	0.5053	0.5113	0.9031	0.9393
t-stat	0.0003	0.0316	0.0089	0.9909	0.1258	0.0245	0.1841	0.0718

4.2   DISCUSSIONS

From Table 4.1, the yearly average values of extraterrestrial solar radiation for Kano, Katsina and Sokoto are: 35.321, 35.225 and 35.169 $MJ/m^2 - day$ respectively. This indicates that the result for Kano is the highest, followed by Katsina. The difference in extraterrestrial radiation followed the same order with respect to closeness with the equator with location farthest away from the equator having the least extraterrestrial solar radiation.

Monthly average solar radiations for the three locations (Tables 4.2 to 4.4) indicate that there are little differences among the years for all the three locations; but the maximum solar radiations are mostly obtained between the months of March and April while minimum values fall between July and August. The maximum values can be attributed to the absence of cloud cover and lower relative humidity; and vice versa for months with minimum values. The ranges of monthly average radiation for Kano, Katsina and Sokoto are obtained as: $27.27 - 16.55$; $28.63 - 16.24$ and $27.71 - 15.57 \ MJ/m^2 - day$ respectively.

The range of monthly average sunshine hours for Kano, Katsina and Sokoto (Tables 4.5 to 4.7) are: $9.44 - 5.59$; $10.01 - 5.83$ and $9.93 - 5.66 \ hours$ respectively. It can be seen that monthly average sunshine hours follow the same pattern with monthly average solar radiation.

The range of monthly average relative humidity for Kano, Katsina and Sokoto (Tables 4.8 to 4.10) are: $81.42 - 13.6$; $87.9 - 11.19$ and $79.74 - 9.13 \ percent$ respectively; while the range of monthly average maximum relative humidity for Kano, Katsina and Sokoto (Table 4.11 to Table 4.13) are: $97 - 18.5$; $99 - 18$ and $95 - 16 \ percent$ respectively. It can be seen that highest value of both relative humidity and maximum relative humidity is obtained in Katsina then followed by Kano while least value of both relative humidity and maximum relative humidity is obtained in Sokoto then followed by Katsina.

This result has good agreements with results found by Olomiyesan *et al.,* (2017), Garba *et al.,* (2018) and Auwal and Darma (2016), but there are no researches on my locations for better comparison of the results.

The range of monthly average minimum temperature for Kano, Katsina and Sokoto (Tables 4.14 to 4.16) are: $26.82 - 11.38$; $26.76 - 11.81$ and $28.55 - 14.91^oC$ respectively; while the range of monthly average maximum temperature for Kano, Katsina and Sokoto (Tables 4.17 to 4.19) are: $41.07 - 26.26$; $40.60 - 25.89$ and $42.00 - 30.17^oC$ respectively. It can be seen that highest value of both minimum temperature and maximum temperature are obtained in Sokoto then followed by Kano while highest value minimum temperature is obtained in Sokoto then followed by Katsina; and maximum temperature is obtained also in Sokoto then followed by Kano.

The measured and estimated solar radiation using the models formed for Kano, Katsina and Sokoto are as shown as in Figures 4.1, 4.2 and 4.3 respectively. Looking at the Figures, accuracy and comparison between the models cannot be easily inferred. To compare the correlations between estimated results obtained from the models by the measured values, the results are represented graphically for each location as shown in Figures 4.1 to 4.3. From the graphs, it can be seen that some models overestimated the result while others are under estimated with some very close to the measured values in some months.

To make stronger inference, seven statistical parameters were used. The results for Kano, Katsina and Sokoto are as shown in Tables 4.23, 4.24 and 4.25 respectively.

From Table 4.23, results for **Kano** can be deduced as follows:
Models No. 1, 2, 3, 4 and 6 have negative values of MBE which indicates under estimation; while models No. 2b, 5 and 6b have positive values of MBE which indicates overestimation of the calculated values compared to the measured values. The lower the value of MBE, the better the model; Model No. 1 has the least value, then followed by Model 6b then Model No. 2 then Model No. 6, etc.

The root mean square error (RMSE) indicates the differences between values predicted by the models and the values obtained from the actual measurement. RMSE is a good

measure of precision. The value of RMSE is always positive, a value of zero in the ideal case. Model No. 2 has the least value, then No. 6, then No. 3, etc.

The mean percentage error (MPE) is the computed average of percentage errors by which forecast of a model differ from actual values measured. The smaller the value, the better the Model. From the analysis, Model No. 1 has the least value, and then followed by Model 6b then Model No. 2 then Model No. 6, etc.

Mean Relative Error (MRE) can be used for determining the linear relationship between measured and estimated values. Smaller value of MRE indicates better model. From the results, Model No 6 is the best, then No. 2, followed by No. 6b, etc.

The Pearson correlation coefficient measures the strength between variables and relationships. Its value range between -1.00 and 1.00; positive value indicates positive correlation while negative value indicates negative correlation. From the analysis all the values are positive.

The coefficient of determination (R^2) is interpreted as the proportion of the variance in the dependent variable that is predictable from the independent variable. Its value ranges from 0 to 1 with 1 indicating perfect correlation. From the results, Model No 6 is the best then followed by No 6b, etc.

MBE and RMSE separately do not represent a reliable assessment of the model's performance and can lead to the false selection of the best model from a set of candidates. To be sure that the estimates are statistically significant, t-stat is used. But for t-stat, the value obtained has to be compared with standard values from the t-table.

The same analysis was carried out on the other two locations. The results for Kano, Katsina and Sokoto are summarized as shown in Tables 4.26 to 4.28 respectively.

Table 4.26. Ranking based on Statistical Analysis for Kano Location

Statistical parameters	Model 1	Model 2	Model 2b	Model 3	Model 4	Model 5	Model 6	Model 6b
MBE	1st	3rd	6th	7th	8th	5th	4th	2nd
RMSE	8th	1st	7th	3rd	5th	6th	2nd	5th
MPE%	1st	3rd	6th	7th	8th	5th	4th	2nd
MRE	6th	2nd	5th	8th	4th	7th	1st	3rd
R	8th	3rd	5th	4th	6th	7th	1st	2nd
R^2	8th	3rd	5th	4th	6th	7th	1st	2nd
t-stat	1st	5th	6th	8th	4th	2nd	7th	3rd

Table 4.27. Ranking based on Statistical Analysis for Katsina Location

Statistical parameters	Model 1	Model 2	Model 2b	Model 3	Model 4	Model 5	Model 6	Model 6b
MBE	2nd	4th	6th	7th	5th	8th	3rd	1st
RMSE	7th	4th	5th	3rd	6th	8th	1st	2nd
MPE%	2nd	4th	6th	7th	5th	8th	3rd	1st
MRE	4th	3rd	5th	6th	4th	8th	2nd	1st
R	8th	4th	5th	3rd	6th	7th	1st	2nd
R^2	8th	4th	5th	3rd	6th	7th	1st	2nd
t-stat	1st	4th	6th	8th	3rd	7th	5th	2nd

Table 4.28. Ranking based on Statistical Analysis for Sokoto Location

Statistical parameters	Model 1	Model 2	Model 2b	Model 3	Model 4	Model 5	Model 6	Model 6b
MBE	1st	2nd	5th	8th	7th	4th	6th	3rd
RMSE	6th	3rd	8th	4th	7th	5th	2nd	1st
MPE%	1st	2nd	5th	8th	7th	4th	6th	3rd
MRE	5th	3rd	7th	8th	4th	6th	2nd	1st
R	5th	3rd	8th	4th	7th	6th	2nd	1st
R^2	5th	3rd	8th	4th	7th	6th	2nd	1st
t-stat	1st	4th	2nd	8th	6th	3rd	7th	5th

Comparison of Table 4.20 to 4.22, the results can be summarized as:

- Annual average solar radiation is highest in Katsina (22.52), then Kano (22.11) and lastly Sokoto (21.80 $MJ/m^2 - day$);

- Annual average sunshine hours is highest in Katsina (7.96), then Sokoto (7.94) and lastly Kano (7.78 $hours$);

- Annual average relative humidity is highest in Kano (45.01%), then Katsina (42.43%) and lastly Sokoto (41.40%);

- Annual average maximum relative humidity is highest in Kano (62.05%), then Katsina (59.23%) and lastly Sokoto (54.05%);

- Annual average minimum temperature is highest in Sokoto (22.42^oC), then Katsina (20.35^oC) and lastly Kano (20.22^oC);

Annual average maximum temperature is highest in Sokoto (35.92^oC), then Kano (33.89^oC) and lastly Katsina (33.29^oC).

CHAPTER FIVE

SUMMARY CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY

Solar radiation data is among the major requirements for design and performance evaluation of solar energy systems, but the data is not easily accessible in many localities; as such many researchers developed various models in order to estimate the solar radiation from available data of some meteorological variables (temperatures, sunshine hours, relative humidity etc.). In this work, some of such models were reviewed and six models were selected for performance investigation in three selected locations in Northwest region of Nigeria (Kano, Katsina and Sokoto).

Ten years data (2006-2015) of daily average global solar radiation were obtained from Nigerian Meteorological Agency (NIMET). The data was analyzed to obtain monthly average values. Also corresponding meteorological data for sunshine hours, minimum & maximum temperatures, and maximum & minimum relative humidity were also obtained and analyzed accordingly.

Empirical values of the constants from the models were evaluated for all the three locations; from which global solar radiation was estimated using the models. Statistical analysis was carried out to determine the variation of the estimated values compared with the measured data. The statistical parameters used were: Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), Mean Relative Error (MRE), Correlation Coefficient (r), Coefficient of determinant (R^2) and T-statistical value.

The models were finally compared based on the statistical parameters results obtained.

5.2 CONCLUSION

Based on the analysis conducted the following conclusions can be drawn:

- The result shows that location closest to equator (those with lower value of degree of latitude) has the highest average extraterrestrial solar radiations; i.e. Kano has the highest, followed by Katsina then Sokoto.

- For the period under consideration, the highest values of solar radiation are generally observed in the months at April and May for all locations and least values in the months of July and August.

- All the models agreed to a similar pattern with measured data for all locations and all the months of the year.

- From the statistical comparison between the estimated results obtained from the models with that of measured values, none of the models is best in all the parameters for all the locations; but it can be concluded that for most of the statistical parameters evaluated, the Non-linear models involving sunshine hour, temperatures (in degree Celsius and Kelvin) and relative humidity (Model No. 6 and model No. 6b) have better performances then followed by the Linear Model involving Sunshine hour, temperature in degree Celsius and Relative humidity (Model No. 2).

- Model 6b is the best for all the three locations followed by model 6a and model 2, while model 4 is the least in performance for all the locations.

5.3   RECOMMENDATIONS

The following are recommended to be considered for feature work:

   i.   Data obtained from Nigerian Meteorological Agency (NIMET) need to be compared with data from another sources such as NASA, PVGIS etc. and if possible to be validated with data obtained from field measurements and

   ii.   Other more models apart from the six used in this research need to be explored.

REFERENCES

Abdallah, Y.A.G. (1994). New Correlation of Global Solar Radiation with Meteorological Parameters for Bahrain. *International Journal of Solar Energy,* **16**(1) 111-120.

Abdulrahim, A.T., Diso, I.S., and El-jummah A.M. (2011). A Simple Correlation to Estimate Global Solar Irradiation on a Horizontal Surface using Meteosat Satellite Images. *Constant Journal of Engineering Science,* **6**(3) 30-37.

Aggarwal, R.K. (2012). Precise Estimation of Total Solar Radiation on Tilt Surface. *African Journal of Environmental Science and Technology,* **6**(9), 365-370.

Akpabio, L.E., and Etuk, S.E. (2003). Relationship between Global Solar Radiation and Sunshine Duration for Onne, Nigeria. *International Journal of Physics,* **27**(1) 161-167.

Allen, R.G. (1997). Self-calibrating Method for Estimating Solar Radiation from Air Temperature. *Journal of Hydrologic Engineering,* **2**(2) 56-67.

Almorax, J., and Hontoria. C. (2004). Global Solar Radiation Estimation using Sunshine Duration in Spain. *Energy Conversion and Management,* **45**(1) 1529-1535.

Ampratwum, D.B. and Dorvlo, A.S.S. (1999). Estimation of Solar Radiation from the Number of Sunshine Hours. *Applied Energy.* **63**(1) 161-170.

Auwal, M., and Darma, T. H. (2016). Estimation of Global Solar Radiation for Kano State Nigeria Based on Meteorological Data. *IOSR Journal of Applied Physics,* **6**(6) 19-23.

Ayodele, T.R., and Ogunjuyigba, A.S. (2015). Prediction of Monthly Average Global Solar Radiation Based on Statistical Distribution of Clearness Index. *Journal Energy,* **90**(1), 1733-1742.

Bakirci, K. (2008). Correlation for Estimating of Solar Radiation on Horizontal Surface. *Journal of Energy Engeering,* ISSN: **134**(4), 130-4.

Bakirci, K., and Pandey, C.K. (2010). Simple Correlation for Estimating the Global Solar Radiation on Horizontal Surface in India. *Journal of Thermal Science and Technology in india*, **3**(1) 60-71.

Besharat, F., Dehghan, A.A., and Faghih, A.R. (2013). Empirical Models for Estimating Global Solar Radiation in Yazd City, Iran, *Proceedings of the "International Conference on Solar Energy for MENA region (INCOSOL)" Amman, Jordan, 22-23 October Paper Number:* **2**(1).

Bristow, K.L., and Campbell, G.S. (1984). On the Relationship between Incoming Solar Radiations and Daily Maximum and Minimum Temperature. *Agricultural Forum of Meteorology,* **31**(1) 159-166.

Chen, R., Ersi, K., Yang, J., Lu, S., and Zhao, W. (2004). Validation of Five Global Radiation Models with Measured Daily Data in China. *Theoretical and Applied Climatology,* **89**(1) 83-94.

Coppolino, S.A. (1994). New Correlation Between Clearness Index and Relative Sunshine. *Renewable Energy,* **4**(4) 23-417.

De Jong, R., and Stewart, D.W. (1993). Estimating Global Solar Radiation from Common Meteorological Observations in West Canada. *Canadian Journal of Plant Science,* **73**(1) 509-518.

Donatelli, M., and Campbell, G.S. (1998). Simple Model to Estimate Global Solar Radiation in Nitra, Slovak Republic. *Proceeding of the Fifth European Society of Agronomy Congress,* **4**(1) 4-133.

Duffie, J.A. and Beckman, W.A. (2013). *Solar Engineering of Thermal Processing,* 4th Ed. Madison: John Wiley & Sons, Inc.

Elagib, N. and Mansell, M.G. (2000). New Approaches for Estimating Global Solar Radiation Across Sudan. *Energy Conversion and Management,* **41**(1) 419-434.

El-Metwally, M. (2004). Sunshine and Global Solar Radiation Estimation at Different Sites in Egypt. *Journal of Atmospheric and Solar-Terrestrial Physics,* **67**(1) 1331-1342.

Foster, R., Ghassemi, M., and Cota, A. (2010). Determination of the Optimal Tilt Angle for Solar Photovoltaic Panel in Ilorin, Nigeria. *Solar Energy Renewable Energy and the Environment*, 1st Ed. Boca Raton: Taylor & Francis Group. Inc.

Gairaa, K., and Bakelli, Y. (2011). an Overview of Global Solar Radiation Measurement in Ghardaia Area, South Algeria. *International Journal of Energy and Environment,* **2**(2) 255-260.

Gana, N.N. and Akpootu, D.O. (2013). Estimation of Global Solar Radiation using Four Sunshine Based Models in North-western Nigeria, *Journal Advance in Applied Science Research,* **4**(5): 409-421.

Garba, M. B., Muhammad, A., Musa, M., and Muhammad, A. G. (2018). Assessing the Performance of Global Solar Radiation Empirical Equations in Sokoto, Nigeria using Meteorological Parameters. *Nigerian Journal of Technology,* (NIJOTECH) **37**(2) 358-364.

Glover, j., and McGulloch, J.S.C., (1958). The Empirical Relation between Solar Radiation and Hours of Sunshine. *Quarterly Journal of the Royal Meteorological Society,* **84**(1) 172-175.

Goodin, D.G., Hutchinson, J.M.S., Vanderlip, R.L., and Knapp, M.C. (1999). Estimating Solar Irradiance for Crop Modeling using Daily Air Temperature Data. *Agronomy Journal,* **91**(1) 845-851.

Gopinathan, K.K. (1988). Simple Method for Predicting Global Solar Radiation on a Horizontal Surface. *Solar and Wind Technology,* **5**(1) 581-583.

Goswami, D.Y. (2015). *Principles of Solar Engineering,* 3rd Ed. Parkway NW: Taylor & Francis Group. Inc.

Grewal, B.S. and Grewal, J.S. (2004). *Higher Engineering Mathematics*. 38th Ed. Nai Sarak Delhi, India: Romesh Chander Khanna. **4**(1) 733-749.

Hargrreaves, G.H., and Samani, Z.A. (1982). Estimating Potential Evapotranspiration. *Journal of Irrigation and Drainage Engineering,* **108**(3) 223-230.

Hunt, L.A., Kucharb L., and Swanton C.J. (1998). Estimation of Solar Radiation for use in Crop Modeling, Ghana. *Journal of Agricultural and Forest Meteorology,* **91**(1) 293-300.

Innocent, A.J., Jacob, O.B., Chibuzo, G.C., James, I. and Odeh, O. (2015). Estimation of Global Solar Radiation in Gusau, Nigeria. *International Journal of Research in Engineering and Technology,* ISSN: 2347-4599.

Journee, M., Damain, C., and Bertrand, C. (2013). Advance in Science and Research Open Access Proceedings. *International Journal of Energy and Environmental*, **10**(1) 15-19.

Korachagaon, I.B., Bapat, V.N., and Anjum, M.I. (2008). Predicting Global Solar Radiation for South America. *International Journal of Mechanical Meter Eng,* ISSN: **2**(3), 139.

Louis, E., Akpabio, A., Sunday, E., and Etuk, A. (2002). Relationship between Global Solar Radiation and Sunshine Duration for Onne, Nigeria. *Turkey Journal Physics* **27**(1) 161-167.

Medugu, D.W., Adisa, A.B., Burari, F.W., and Abdul'Azeez, M.A. (2013). Solar Rdaiation Correlation between Measured and Pridicted Values in Mubi, Nigeria. *International Journal of Physics Sciences,* **4**(1) 11-17.

Mertens, K. (2014). Photovoltaic Fundamentals Technology and Practice. John Wiley & Sons. Ltd., Hoboken, New Jersey, USA.

Muzathik, A.M., Nik, W.M., Ibrahim, M.Z., Samo, K.B., Sopian, K., and Alghoul, M.A. (2011). Daily Global Solar Radiation Estimation Based on Sunshine Hours using

Different Models over Terengganu State, Malaysia. *International Journal of Mechanical and Material Engineering (IJMME),* **6**(1) 75-80.

Namrata, K., Sharma, S., and Seksena, S.B. (2012). Estimation and Comparison of Diffuse Solar Radiation on Horizontal Surface using Different Models over Jharkhand, India. *International Journal of Science and Advance Technology,* **2**(2) ISSN: 2221-8386.

Newland, F.J. (1988). A Study of Solar Radiation Models for the Coastal Region of South China. *Solar Energy,* **41**(1) 499-502.

Nwokoye, A.O., and Ike, C.U. (2003). Measurement of Global Radiation Constant "Intensity"Awka, using Pyranometer, Nigeria. *Journal on Renewable Energy,* **11** (1&2) 1-8.

Ododo, J.C., Sulaiman, A.T., Aidan, J., and Yuguda, M.M. (1995). The Importance of Maximum Air Temperature in the Parameterisation of Solar Radiation in Nigeria. *Renewable Energy,* **6**(1) 751-763.

Ogelman, H., Ecevit, A., and Tasdemiroglu E. (1984). A new Method for Estimating Solar Radiation from Bright Sunshine Data. *Solar Energy,* **33**(1) 25-619.

Ojasu, J.O., and Komolafe, L.K. (1987). Solar Radiation Energy of Nigeria. *Nigerian Journal of Solar Energy,* ISSN **4**(1) 16-69.

Okonkwo, G.N., and Nwokoye, A.O.C. (2014). Estimation of Global Solar Radiation from Temperature Data in Minna Location. *European Scientific Journal May 2014 Ed.* **10**(5) ISSN: 1857-7881.

Olomiyesan, B. M., Oyedum, O, D., Ugwuoke, P, E., and Abolarim, M. S. (2017). Evaluation of some Global Solar Radiation Models in Selected Locations in Northwest, Nigeria. *Open Access Journal of Photo energy.* **1**(1) 10-154.

Samuel, T.D.M.A. (1991). Estimation of Global Solar Radiation for Sri Lanka. *Solar Energy Journal,* **47**(1) 333-337.

Sarsah, E.A., and Uba, F.A. (2013). Monthly-Specific Daily Global Solar Radiation Estimates Based on Sunshine Hours in Wa, Ghana, *International Journal of Science and Technology,* **4**(1) 1943-2429.

Sen, Z. (2008). *Solar Energy Fundamental and Modeling Technique, Atmosphere, Environment, Climate Change and Renewable Energy, Istanbul, Turkey,* Springer Verlag, London, 34469.

Stone, R.J. (1993). Improved Statistical Procedure for the Evaluation of Solar Radiation Estimation Models. *Solar Energy Journal,* **4**(1) 51-289.

Swartman, R.K., and Ogunlade, O. (1967). Solar Relation Estimates from Common Parameters. *Journal of Solar Radiation,* **3687**(1) 11-34.

Thornton, P.E., and Running, S.W. (1999). An Important Algorithm for Estimating Incident Daily Solar Radiation from Measurement of Temperature, Humidity and Precipitation. *Agricultural and Forest Meteorology,* **93**(1) 211-228.

Vecan, D. (2011). Measurement and Comparison of Solar Radiation estimation Models for Izmir, Turkey.*International Journal of Science and Technology,* **4**(1) 1943-2429.

Winslow, J.C., Hunt, E.R., Piper, S.C. (2001). Globally Applicable Model of Daily Solar Irradiance Estimation from Air Temperature and Precipitation Data. *Ecological Modeling*, **143**(1) 227-243.

APPENDICES

Appendix 1. Measured and Estimated Solar Radiation for Kano in $MJ/m^2 - day$

Months	Measured	Estimated Solar Radiation using:							
		Model 1	Model 2	Model 2b	Model 3	Model 4	Model 5	Model 6	Model 6b
Jan	24.61	22.09	24.93	22.02	22.95	22.29	22.30	23.32	22.41
Feb	25.62	22.21	25.49	24.93	25.12	22.12	22.36	25.90	26.23
Mar	25.78	19.49	24.43	24.32	25.24	18.95	19.48	25.62	28.48
Apr	23.84	22.23	23.41	24.80	24.41	21.82	22.30	23.55	24.67
May	20.76	23.44	21.64	24.13	22.34	23.16	23.56	21.87	22.03
Jun	18.86	22.83	20.00	21.43	19.53	22.51	22.93	20.03	20.00
Jul	17.84	19.02	16.92	16.51	15.71	18.43	18.98	17.26	18.30
Aug	17.51	21.25	17.41	17.82	15.88	20.77	21.29	18.09	18.29
Sep	19.78	22.35	19.15	19.75	17.48	22.02	22.45	18.92	18.71
Oct	22.33	23.97	22.69	25.06	21.67	24.09	24.18	21.47	20.51
Nov	25.06	24.52	25.09	24.42	24.84	25.14	24.80	25.59	23.98
Dec	23.65	21.98	24.05	21.97	22.81	22.28	22.20	23.41	22.33

Appendix 2. Measured and Estimated Solar Radiation for Katsina in $MJ/m^2 - day$

Months	Measured	Estimated Solar Radiation using:							
		Model 1	Model 2	Model 2b	Model 3	Model 4	Model 5	Model 6	Model 6b
Jan	24.64	21.60	24.14	21.49	22.73	21.61	21.94	23.29	22.70
Feb	26.29	24.94	27.90	26.54	26.69	25.12	25.39	27.45	28.03
Mar	26.01	21.56	25.04	24.22	25.93	21.25	21.75	26.44	25.97
Apr	24.13	22.11	24.45	25.29	25.14	21.77	22.29	23.58	23.97
May	20.8	23.02	22.47	24.01	22.96	22.73	23.25	21.36	22.23
Jun	19.15	21.14	19.86	20.54	20.15	20.77	21.27	19.65	19.77
Jul	18.33	19.99	18.35	18.70	17.67	19.60	20.06	18.74	18.10
Aug	18.14	19.24	16.64	17.01	15.87	18.85	19.27	18.18	17.08
Sep	20.27	23.35	20.55	21.11	19.47	23.13	23.62	20.15	20.39
Oct	22.93	25.76	25.11	26.10	23.27	25.99	26.23	22.03	23.61
Nov	25.11	25.16	22.08	25.04	24.85	25.63	25.69	26.99	25.47
Dec	24.47	22.54	24.34	21.73	22.64	22.76	22.96	22.93	22.90

Appendix 3. Measured and Estimated Solar Radiation for Sokoto in $MJ/m^2 - day$

Months	Measured	Estimated Solar Radiation using:							
		Model 1	Model 2	Model 2b	Model 3	Model 4	Model 5	Model 6	Model 6b
Jan	24.24	23.69	24.55	23.29	23.23	23.37	23.50	23.13	23.97
Feb	25.38	24.89	24.72	24.10	25.61	24.52	24.73	26.35	26.22
Mar	25.53	19.94	23.74	18.40	26.78	19.88	20.08	24.04	25.49
Apr	23.00	20.76	21.51	19.27	25.24	20.71	20.91	23.73	23.33
May	20.13	21.39	20.16	21.56	21.09	21.27	21.51	21.93	20.57
Jun	18.20	18.44	18.59	18.65	18.71	18.68	18.68	18.70	18.84
Jul	17.00	18.22	17.85	19.34	15.88	18.49	18.47	17.11	17.77
Aug	17.10	18.46	17.90	20.55	14.78	18.70	18.71	16.47	17.50
Sep	19.58	21.84	19.86	23.48	16.55	21.62	21.90	18.93	18.49
Oct	22.34	25.41	21.97	26.56	20.25	25.03	25.24	22.85	20.49
Nov	24.80	25.08	26.86	23.42	23.92	24.81	24.85	25.82	24.85
Dec	24.30	23.47	24.00	23.38	22.81	23.20	23.27	23.22	23.87