ESTIMATION AND ANALYSIS OF TOTAL SOLAR RADIATION FOR SELECTED EIGHTEEN NIGERIAN CITIES USING MEASURED METEOROLOGICAL DATA (2000 – 2010)

BY

ELEKALACHI CHUKWUEMEKA INNOCENT

REG N0: 2009536010P

DEPARTMENT OF PHYSICS AND INDUSTRIAL PHYSICS

FACULTY OF PHYSICAL SCIENCES

NNAMDI AZIKIWE UNIVERSITY AWKA

AUGUST, 2018

ESTIMATION AND ANALYSIS OF TOTAL SOLAR RADIATION FOR SELECTED EIGHTEEN NIGERIAN CITIES USING MEASURED METEOROLOGICAL DATA (2000 – 2010)

BY

ELEKALACHI CHUKWUEMEKA INNOCENT

REG N0: 2009536010P

A THESIS PRESENTED TO THE DEPARTMENT OF PHYSICS AND INDUSTRIAL PHYSICS FACULTY OF PHYSICAL SCIENCES NNAMDI AZIKIWE UNIVERSITY, AWKA

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (M.Sc) DEGREE IN PHYSICS AND INDUSTRIAL PHYSICS (SOLAR ENERGY OPTION)

PROJECT SUPERVISOR: A.O.C NWOKOYE

AUGUST, 2018

DECLARATION

I, Elekalachi Chukwuemeka Innocent with registration number 2009536010P hereby state that this thesis is original and was written by me. It is a record of my research. To the best of my knowledge no part thereof has been submitted elsewhere for the award of any degree. The works of others have been duly referenced and acknowledged.

Elekalachi Chukwuemeka Innocent

Author

CERTIFICATION

This is to certify that Elekalachi Chukwuemeka Innocent carried out the research work and produced this report under our supervision in partial fulfillment of the requirement for the award of Masters of Science (Solar Energy Option).

--	------------------------------------
PROF. A.O.C. NWOKOYE Project Supervisor	Date
--	------------------------------------
PROF. A.O.C. NWOKOYE Head of Department	Date
---	------------------------------------
PROF. S. O. ANIGBOGU Dean, Faculty of Physical Sciences	Date
--	------------------------------------
External Examiner	Date
--	-------------------------------------
PROF. I. H. ODIMEGWU Dean, School of Postgraduate Studies	Date

DEDICATION

This research work is dedicated to my wife and children.

ACKNOWLEDGEMENTS

I am very much indebted to my supervisor Prof. A.O.C. Nwokoye, the former Dean Faculty of Physical Sciences, Nnamdi Azikiwe University Awka, for the close surveillance, expertise guidance and constructive criticisms he made which contributed immensely to the successful completion of this work.

My profound gratitude goes to Prof. A. J. Ekpunobi, Prof. G. Anene, Dr. C. U. Ike, Dr. D. N. Okoli, Head of Department; Dr. T. N. Obiekezie and other lecturers in the Department of Physics and Industrial Physics for their assistance and critical evaluation of this work.

My gratitude also goes to Mr. Okoli N. L. and all other persons who in one way or the other made useful contributions, by way of logistics and other support that motivated me to execute this project.

My thanks go to my wife and children for making me comfortable throughout the duration of this project.

Finally, I thank God the Almighty for His abundant love and protection and for granting me His grace to successfully carry out this project.

ABSTRACT

Global solar radiation is an important parameter necessary for most ecological models and serves as input for different photovoltaic conversion systems. Hence it is of economic importance to renewable energy alternative. In this study, we have employed the linear regression model of Angstrom (1924) and Page (1964) for these analyses to correlate the global solar radiation data with relative sunshine duration, relative humidity and maximum temperature for 3 cities (sites) in each of the six geopolitical zones in Nigeria, which gives a total of 18 sites. Other multiple linear regression models were obtained to check the correlation of global solar radiation with sunshine duration combined with other meteorological parameters which include maximum temperature and relative humidity. These meteorological parameters used for this work were obtained from the archives of National Aeronautics and Space Administration (NASA) for the time period of 11 years from 2000 to 2010. The results obtained were statistically tested using four statistical error indicators; Mean Bias Error (MBE), Root Mean Square Error, (RMSE), Mean Percentage Error (MPE) and t-stat to establish the validity of the results. The analyses show that there is close correlation between the calculated mean global solar radiation and the estimated global solar radiation using our established models, though some models correlate better than others. The best empirical equation for each of the sites was evaluated based on the values of the t – stat. H_3 is the best model for Awka with t – stat value of 0.050. H_1 is the best model for Enugu with t – stat value of 0.045. H_5 is the best model for Owerri with t – stat value of 4.692. H_3 is the best model for Calabar with t – stat value of 0.0327. H_3 is the best model for Port – Harcourt with t – stat value of 0.0830. H_1 is the best model for Asaba with t – stat value of 0.0126. H_5 is the best models for Lagos with t – stat value of 0.00259. H_5 is the best model for Akure with t – stat value of 0.0232. H_5 is the best model for Ado – Ekiti with t – stat value of 01.166. H_5 is the best model for Gombe with t – stat value of 0.0361, H_1 is the best model for Yola with t – stat value of 0.056. H_3 is the best model for Maiduguri with t – stat value of 0.0359. H_1 is the best model for Abuja with t – stat value of 0.0882. H_1 is the best model for Minna with t – stat value of 0.281. H_3 is the best model for Ilorin with t – stat value of 0.00148. H_3 is the best model for Gusau with t – stat value of 0.0184. H_2 is the best model for Kano with t – stat value of 0.0112. H_5 is the best model for Birnin – Kebbi with t – stat value of 0.0338.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Solar energy is vital for life on our planet because all other forms of energy depend on it. Solar radiation arriving on earth is the most fundamental renewable energy source in nature. Solar energy which is the radiant light and heat from the sun, has been harnessed by humans since ancient times using a range of ever evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture and artificial photosynthesis. The energy from the sun could play a key role in decarbonizing the global economy alongside improvements in energy efficiency and imposing costs on greenhouse gas emitters (International Energy Agency, 2015).

This energy determines the surface temperature of the earth as well as supplying almost all the energy for natural processes both on its surface and in the atmosphere. It heats up homes and provides energy to grow crops through the process of photosynthesis. Sunshine has traditionally been used for drying all types of things: clothes, agricultural produce, cash crops, and bricks. Profitable use of this energy from the sun has been made in the production of salt. The energy we derive from wood, petroleum, paraffin and hydroelectricity originates indirectly from the sun. Solar energy is captured and stored in plants. We use this energy when we burn firewood or eat food.

The sun also powers the rainfall cycles that fill the rivers from which we extract hydroelectricity. Petroleum is made up of fossil remains of plants and animals that collected energy from the sun thousands of years ago (Hankins, 1995).

Solar energy arrives at the edge of the earth's atmosphere at the rate of about 1367 watts per square metre. This is fairly constant throughout the year and is referred to as the solar constant (Iqbal, 1983). However, not all of this energy reaches the earth's surface. When the solar radiation enters the earth's atmosphere, a part of the incident energy is removed by scattering or by absorption by air molecules, clouds and particulate matter usually referred to as aerosols.

The amount of solar radiation to the earth can be direct, diffuse or reflected radiation. Direct radiation is sometimes called beam radiation or direct beam radiation, it describes solar radiation travelling on a straight line from the sun down to the surface of the earth daily. On the other hand, diffuse solar radiation describes the solar radiation that has been scattered by molecules and particles in the atmosphere but has still made it down to the surface of the earth. The third radiation known as global radiation describes the sum of direct radiation and diffuse radiation incident on the earth surface.

For a country like Nigeria, the economical and efficient application of solar energy seems inevitable because of abundant sunshine available throughout the year. It has been found that there is an estimated 3,000 hours of annual sunshine (Augustine and Nnabuchi, 2010) and average solar radiation received in Nigeria per day is as high as 20 MJ/m^2 depending on the time of the year and location (Olayinka, 2011).

In energy terms, Osuji (2003) estimates that Nigeria receives on her land area an annual insolation that is four thousand times the annual production of crude oil. However, only a negligible part of this abundant solar energy potential has been tapped by Nigeria. Harnessing solar energy presents several problems. One of the main problems is the collection of solar power. Information on the amount of global solar radiation is one of the primary variables for determining solar energy production in a region. Despite the importance of such solar radiation data, there are very few locations in Nigeria where solar radiation is continuously and accurately measured. The problem of lack of data is further compounded by the high cost of solar radiation measuring equipment. However, the operation and maintenance of these instruments are not within the budget estimations of many local meteorological stations. It is therefore necessary to employ solar radiation estimation methods, which use as inputs certain meteorological parameters, such as ambient temperatures, sunshine and relative humidity that are much more readily measured than the solar radiation components.

Global solar radiation is of economic importance as a renewable energy alternative. Recently, global solar radiation has being studied due to its importance in providing energy for Earth's climate system. The solar radiation reaching the Earth's surface depends upon climatic conditions of a location, which is essential to the prediction, and design of solar energy systems (Burari and Sambo, 2001).

Nwokoye (2009) defined insolation as, "a measure of solar radiation energy received on a surface area in a given time. It is commonly expressed as average irradiance in Watts per square meter (W/m^2) or kilowatt hours per square meter per day ($KWhr/m^2/day$). The insolation unto a surface is largest when the surface faces the sun perpendicularly. The earth receives 174 Petawatts (174×10^{15} Watts) of incoming solar radiation (insolation) at the upper atmosphere and about 30% is reflected back to space while the rest is absorbed by clouds, oceans, and land masses. However, the spectrum of solar light at the earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet.

Martin (2005) was of the view that, total solar energy absorbed by earth's atmosphere, oceans and land masses is 3,850,000 exajoules per year ($3{,}850{,}000 \times 10^{15}$ Joules per year). The amount of solar energy reaching the surface of the planet is so vast that in one year alone, the amount is twice compared to the one obtained from all of the earth's non-renewable energy resources of coal, oil, natural gas and mined Uranium.

Nwokoye (2003) in his work stated that, solar energy in effect is the light radiant heat from the sun. It therefore drives the earth's climate, plant, marine and terrestrial life and cycles. Since ancient times, man has tried to harness solar energy using various evolving technologies. Solar radiation and other secondary resources of energy such as wind and tidal power accounts for most of the available renewable energy on earth. The energy is in turn captured in form of heat or electricity and like any other source of energy can be put to various uses. Solar energy is fast becoming an alternative to other renewable sources of energy.

In Nigeria, only few stations have been measuring daily solar radiation on a consistent basis. Therefore, it is rather important to develop method to estimate the global solar radiation using climatological parameters such as sunshine hours, relative humidity, maxi mum and minimum temperature, cloud cover and geographical location. Several empirical formulae have been developed to calculate the global solar radiation using various parameters. These statistical relationships between daily global solar irradiation and other climatic variables provide a practical way to calculate daily global irradiation (Barr *et al.*, 1996). For this reason, there are in existence many techniques for estimating daily global solar radiation. These empirical formulae could be categorized according to the time scale of the estimated insolation, that is, hourly, daily, weekly, monthly or yearly (Kizu, 1998). They vary in sophistication, according to (Gooding *et a1.*, 1999), from the simple empirical formulations based on common weather or climate data to the complex radiative transfer schemes that explicitly model the absorption and scattering of the solar beam as it passes through the atmosphere. Whichever of these is the most accurate is not known but it is known that different empirical formulae give different results, even when applied to an identical climate data set. The complex models are said to be capable of highly accurate estimations but they tend to be too complex and data intensive and are therefore not really suitable for use in a developing country like Nigeria that has little or no equipment for such intensive data acquisition

These statistical models and parameters used include: The sunshine hours (Angstrom, 1924; Black *et al*, 1954); the relative humidity and sunshine hours (Gopinathan, 1988); the declination angle and the latitude (Liu and Jordan, 1960); sunshine duration, relative humidity, maximum temperature, latitude, altitude and location (Sabbagh et al, 1977) and the total precipitation, turbidity and surface albedo (Hoyt, 1978).

1.2 Statement of Problem

The scarcity of hourly solar radiation data which is available in few locations in Nigeria is due to lack of existing solar radiation measuring instruments such as pyranometers and pyrheliometers which presents difficulties in assessing the potential of solar energy applications. The present worldwide economic recession with its effects in all spheres of life contributes to the lack of some of these instruments in some areas, particularly in developing countries like Nigeria. In some stations, the available instruments are degrading and lack adequate maintenance culture. This leads to incorrect reading of some meteorological data which are highly unreliable and unsuitable for analytical purpose.

Scientists have therefore thought it wise to develop mathematical tools (models) that can be employed to calculate or predict the availability of solar radiation within a given location on the earth surface. Meteorological parameters such as sunshine duration, latitude and cloud cover are the most widely and commonly used data to predict daily global solar radiation and its components at any location of study. The other input parameters such as minimum, maximum and average temperature, relative humidity and altitude of any location can also be employed in predicting daily global solar radiation.

1.3 Aim and Objectives of the Study

The aim of this study is to estimate and analyze total solar radiation received on a surface of unit cross-sectional area at a given location within the selected eighteen Nigeria cities using measured meteorological data.

The specific objectives of the study include;

1. Calculation of global solar radiation H_{cal} using different climatic parameters such as ratio of sunshine hour, relative humidity, maximum temperature.
2. Correlation between calculated global solar radiation H_{cal} and measured global solar radiation H_m for each location under study.
3. Determination of empirical equations for the estimation of global solar radiation in the cities under study.
4. The selection of the best performed empirical equation for each of the cities.

1.4 Significance of Study

The present system of energy production is heavily dependent on the use of conventional energy sources which is highly damaging to the environment and human health and causes air pollution, and the depletion of ozone layer. These negative effects to the human existence can be reduced or totally eradicated if solar energy systems are introduced such as the photovoltaics and photo thermal systems.

From this study therefore, we can accomplish the following.

(i) Accurate prediction of the availability of solar energy and the effective designs of solar energy conversion systems.

(ii) Adequate conversion of solar energy to electricity in any part of Nigeria so as to meet the domestic energy needs of typical households in the country.

(iii) A reliable source of reference material for other researchers in this field of study.

(iv) A veritable tool for policy makers on solar energy matters.

1.5 Scope of Study

The study is limited to 3 cities in each of the six geopolitical zones of Nigeria. Cities involve in this research are presented in the Nigeria map of figure 1.1

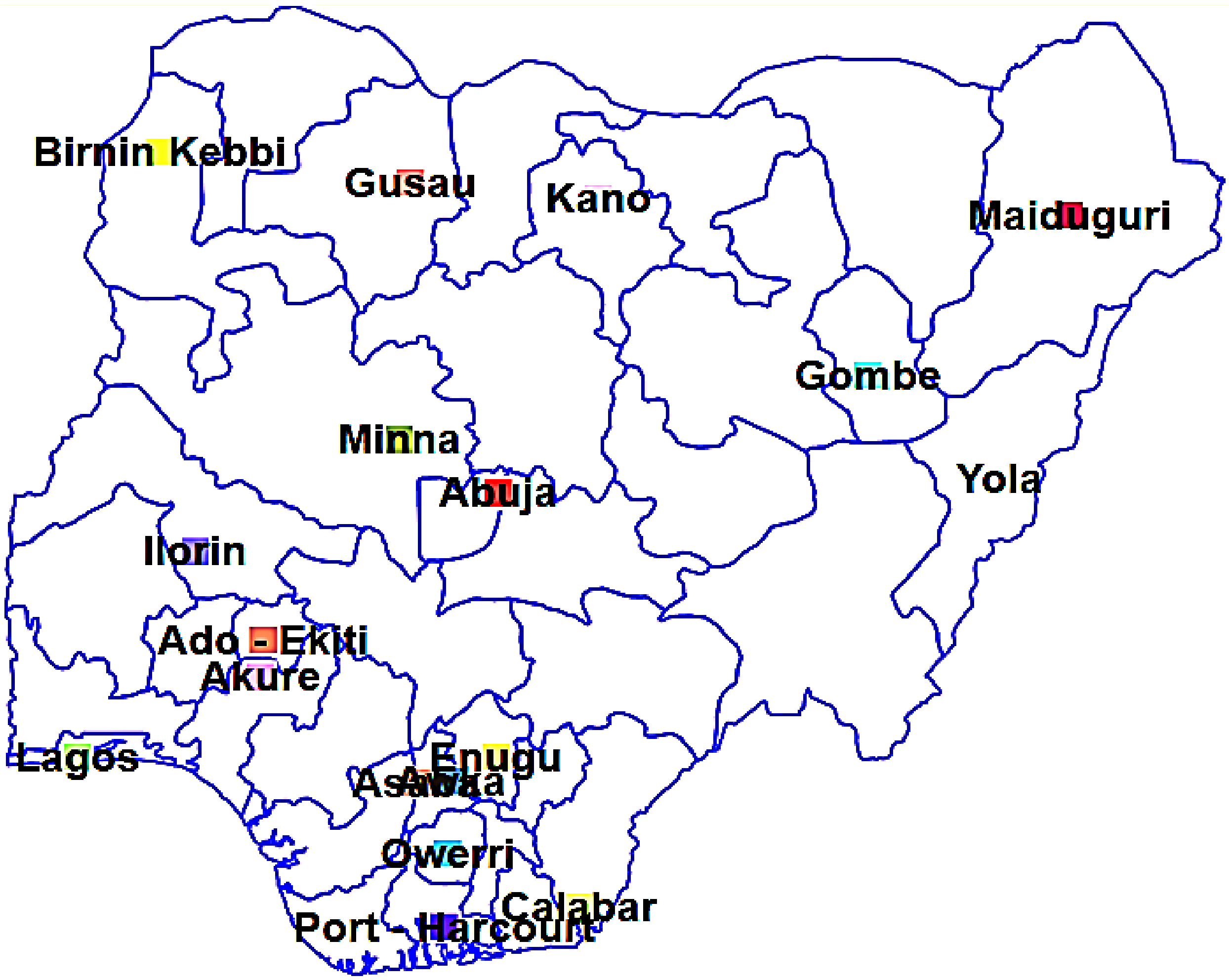

Figure 1.1: Map of Nigeria showing the cities under study

Cities covered within the South Eastern zone are Awka, Enugu and Owerri. Cities covered in the South Southern Zone are Port Harcourt, Calabar and Asaba. Cities in the South Western Zone include Lagos, Ado – Ekiti and Akure. Cities studied within the North Central Zone are Abuja, Minna and Ilorin. Cities studied within the North Eastern Zone are Gombe, Yola and Maiduguri. Cities studied within the North Western Zone Gusau, Kano and Birinin – Kebbi. The data for these sites such as sunshine hour, humidity, temperature, rainfall, wind speed, longitude and latitude, and the daily insolation for the locations concerned were obtained from NASA’s website. The daily data were analyzed into monthly mean values. These data analyzed were used to develop empirical equations for each city. Statistical error indicators such MBE, RMSE, MPE and t – stat were used to evaluated the performance of all the developed equations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Estimation of Global Solar Radiation

According to Chegaar and Chibani (2000) solar energy occupies one of the most important places among the various possible alternative energy sources for both urban and rural areas. An accurate knowledge of the solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices and for estimation of their performance.

Garba *et al.*, (2018) in their study, used the meteorological parameters measured in Sokoto ($12.55\ °N$, $5.15\ °E$) for a period of 10 years (2005 – 2014) obtained from the Nigerian Meteorological Agency Sultan Abubakar III International Airport, Sokoto state. The data used include Gunn-Bellani solar radiation, sunshine hour duration, maximum and minimum temperatures, which were analyzed using modified Angstrom models to estimate the monthly mean global solar radiation in Sokoto. Four statistical methods have been used in order to evaluate the results namely; Mean Bias Error (MBE), Mean Percentage Error (MPE), Root Mean Square Error (RMSE) and T-statistic. The standard error (SE) and coefficient of determination (R^2) were also obtained for each model. Based on the result obtained models 4 and 5 gave lower RMSE values, and R^2 values close unity, which indicates that there is a good agreement between measured and estimated global solar radiation.

Muhammad et al., (2018) reviewed the global solar radiation models available in the literature. according to their study, there are several formulae which relate global radiation to other climatic parameters such as sunshine hours, relative humidity and maximum temperature. They classified the reviewed models into three categories viz: models based on ratio (H/H_o), non-linear models and models based on empirical coefficients 'a' and 'b'. they concluded that (i) Most of solar radiation models given to estimate the monthly average daily global solar radiation are of the modified Angstrom-type equation. (ii It may be concluded that the models presented in this study may be used reasonably well for estimating the solar radiation at a given location and possibly in anyplace with similar climatic conditions. (iii) Solar radiation models are to measure amount of solar radiation hourly or daily. (iv) Solar radiation can be affected due to some parameters such as atmospheric layer, distance between the Earth and Sun, incident angle of solar radiation, length of the day and rotation of Earth, e.t.c. (v) The regression constants of some collected solar models have been generally presented to calculate the global solar radiation with high accuracy in a given location.

Adejumo et al., (2017) analyzed readings of solar radiation received at three meteorological sites in Nigeria. Analysis of Variance (ANOVA) statistical test was carried out on the data set to observe the significant differences on radiations for each quarter of the specified years. The data were obtained in raw form from Nigerian Meteorological Agency (NIMET), Oshodi, Lagos. In order to get a clear description and visualization of the fluctuations of the radiation data, each year were considered independently, where it was discovered that for the 3rd quarter of each year, there is a great fall in the intensity of the solar radiation to as low as 73.27 (W/m^2), 101.66 (W/m^2), 158.51 (W/m^2) for Ibadan, Port-Harcourt and Sokoto respectively. they concluded that the data can provide insights on the health implications of exposure to solar radiation and the effect of solar radiation on climate change, food production, rainfall and flood patterns.\

Okundamiya et al., (2016) assessed the performance of six solar radiation models. The objective was to determine the most accurate model for estimating global solar radiation on a horizontal surface in Nigeria. Twenty-two years meteorological data sets collected from the Nigerian Meteorological agency and the National Aeronautics and Space Administration for the three regions, covering the entire climatic zones in Nigeria were utilized for calibrating and validating the selected models for Nigeria. The accuracy and applicability of various models were determined for three locations (Abuja, Benin City, and Sokoto), which spread across Nigeria using seven viable statistical indices. This study found that the estimation results of considered models are statistically significant at the 95% confidence level, but their accuracy varies from one location to another. However, the multivariable regression relationship deduced in terms of sunshine ratio, air temperature ratio, maximum air temperature, and cloudiness performs better than other relationships. The multivariable relationship has the least root mean square error and mean absolute bias error, not exceeding 1.0854 and 0.8160 MJ m^{-2} day^{-1}, respectively, and monthly relative percentage error in the range of ± 12% for the study areas.

Pandey *et al.,* (2018) developed sunshine based Angstrom meteorological parameter (relative sunshine hours, maximum and minimum temperature, minimum relative humidity) to predict the monthly average global solar radiation for the year 2011 of Jumla in Nepal. The estimated solar radiation from these models were compared with the measured solar radiation which were found to be in close agreement with each other. The statistical test like mean bias error (MBE), mean percentage error (MPE), root mean square error (RMSE) and coefficient of determination (R^2) were performed to evaluate the model. The multiple linear regression model has a higher value of R^2 (0.95) and lower value of RMSE (0.3614) which indicate a better agreement between measured and estimated global solar radiation. It is suggested that the multiple linear model can be employed for the estimation of monthly global solar radiation on horizontal surface for Jumla and other region with similar climatic condition where radiation data are inaccessible.

Augustine and Nnabuchi, (2010) opined that solar radiation data may be considered as an essential requirement to conduct feasibility studies for solar energy systems. The knowledge of solar energy preferably gained over a long period should be useful not only to the locality where the radiation data is collected but for the wider world community.

Several empirical formulas have been developed to calculate the global solar radiation using various parameters. These parameters include: the sunshine hours (Angstrom, 1924; Black et al, 1954); the relative humidity and sunshine hours (Gopinathan, 1988); the declination angle and the latitude (Liu and Jordan, 1960); sunshine duration, relative humidity, maximum temperature, latitude, altitude and location (Sabbagh et al, 1977) and the total precipitation, turbidity and surface albedo (Hoyt, 1978).

In Nigeria, a number of correlations involving global solar radiation and sunshine duration maximum and minimum temperatures, relative humidity and other climate parameters for different locations have been studied by different researchers.

Gana and Akpootu, (2013) used the measured data of global solar radiation on a horizontal surface and number of bright sunshine hours for Kebbi to evaluate global solar radiation. Regression constants for the first order Angstrom-type correlations for Kebbi was calculated and developed using the method of regression analysis. The monthly calculated clearness index and monthly sunshine duration were correlated and modeled using four sunshine-based models. Linear model: $\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right)$, quadratic model: $\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2$, exponential model: $\frac{H}{H_0} = a^{\left(\frac{1}{\frac{S}{S_0}}\right)}$ and $\frac{H}{H_0} = a + \left(\frac{S}{S_0}\right)^b$. The model that performed well is the quadratic model which according to them has a 100% clearness index.

Musa et al. (2012) used the daily sunshine duration to estimate average global solar radiation for Maiduguri, Nigeria. The daily sunshine hour were measured for five years (2004 to 2007) from which the monthly mean values were determined. The Angstrom model; $\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right)$ was used to estimate the global solar radiation. According to their findings, the values of solar radiation for Maiduguri town vary from the range of $16.80403 MJm^{-2}day^{-1}$ to $25.03763 MJm^{-2}day^{-1}$ under the period of study with the mean value of $23.20437 MJm^{-2}day^{-1}$. In their own opinion, the results of their research clearly indicate the main significance of developing empirical models for estimating global solar radiation.

Ituen et al (2012) used the Angstrom model as the basis to develop other regression equations by modifying Angstrom equation to include maximum temperature and relative humidity which they used to estimate global solar for Uyo in Niger Delta region of Nigeria. The developed equations are as follow; $\frac{\bar{H}_p}{\bar{H}_0} = 0.239 + 0.585\left(\frac{\bar{S}}{\bar{S}_0}\right)$, $\frac{\bar{H}_p}{\bar{H}_0} = -0.229 + 0.02(\bar{T}_m)$, $\frac{\bar{H}_p}{\bar{H}_0} = -0.589 - 0.280\left(\frac{\bar{R}}{100}\right)$, $\frac{\bar{H}_p}{\bar{H}_0} = -1.395 - 0.046(\bar{T}_m) + 1.591\left(\frac{\bar{S}}{\bar{S}_0}\right)$, $\frac{\bar{H}_p}{\bar{H}_0} = 0.056 + 0.833\left(\frac{\bar{S}}{\bar{S}_0}\right) + 0.170\left(\frac{\bar{R}}{100}\right)$, $\frac{\bar{H}_p}{\bar{H}_0} = 0.138 + 0.011(\bar{T}_m) - 0.136\left(\frac{\bar{R}}{100}\right)$ and $\frac{\bar{H}_p}{\bar{H}_0} = 1.387 + 1.592\left(\frac{\bar{S}}{\bar{S}_0}\right) - 0.045(\bar{T}_m) + 0.004\left(\frac{\bar{R}}{100}\right)$. The results obtained show a remarkable agreement between the measured and the predicted values using different models.

Innocent et al., (2015) applied Angstrom-Prescott model $\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right)$ to estimate the global solar radiation based on the monthly mean sunshine hours. The values of global solar radiation obtained for Gusau within the period of study (1995 – 2000) ranged from 16.168 - 21.654 $MJm^{-2}day^{-1}$ with mean value of 18.8015 $MJm^{-2}day^{-1}$. The results obtained in this research work clearly indicate the importance of developing empirical models for estimating global solar radiation reaching a given geographical location.

Akpabio et al. (2005) presented a quadratic form of the Angstrom-Prescott model to estimate global solar radiation at Onne. They employed Ogelman et al. model: $K_T = 0.195 + 0.675S_R – 0.142S_R^2$, Akinoglu and Ecevit model: $K_T = 0.145 + 0.845S_R – 0.280S_R^2$ and Fagbenle's model: $K_T = 0.375 + 0.128S_R + 0.660S_R^2$ which were compared with the ones developed for the Nigerian environment $K_T = 0.147 + 1.125S_R – 1.416S_R^2$, $K_T = 0.181 + 0.781S_R – 0.626S_R^2$ and $K_T = 2.014 + 9.445S_R + 13.412S_R^2$. These results showed that the relationship between clearness index and relative sunshine in quadratic form is to some extent locality dependent.

Okundamiya and Nzeako (2010) developed empirical model for estimating global solar radiation on horizontal surfaces for selected cities of Abuja, Benin City, Kastina, Lagos, Nsukka and Yola in the six geopolitical zones of Nigeria. Their study proposes a temperature-based model of monthly mean daily global solar radiation on horizontal surfaces for each site, representing the six geopolitical zones in Nigeria. Their modeling was based on linear regression theory and was computed using monthly mean daily data set for minimum and maximum ambient temperatures. Their developed model has a general form as $\bar{H} = \bar{H}_0(m_0 + m_1\bar{R}_T + m_2\bar{T}_{max})$, where $R_T = \frac{\bar{T}_{min}}{\bar{T}_{max}}$, m_0, m_1 and m_2 are regression constants. The results of their analysis suggest that a significant statistical relationship (with coefficient of correlation (CC) of 89.9– 97.6%) exists between the clearness index, ambient temperature ratio, and maximum ambient temperature.

Agbo et al (2010) developed empirical models for the correlation of monthly average global solar radiation with sunshine hours at Minna, Nigeria. Using monthly average daily values of global solar radiation and relative sunshine hours over a period of five years (1987-1991). Using multi-linear polynomial form of the Angstrom-Prescott based models were developed to estimate global solar radiation at Minna Nigeria. They expanded the Angstrom - Prescott based models to the fourth order polynomials. It was found that the fourth order polynomial utilizing relative sunshine hours gave the best overall estimate of the total solar radiation in Minna. The correlation coefficient of 0.932 was found in the fourth order polynomials and was the highest value compared to order models.

Medugu and Yakubu (2011), used angstrom model to estimate mean monthly global solar radiation in Yola, Nigeria with latitude $9° \, 12' \, N$. The daily sunshine hour were measured for four years (2004 to 2007) using sunshine recorder. The monthly mean values were determined. The Angstrom model was then used to estimate the global solar radiation based on the available climatic parameters of sunshine hour. From the results obtained, the values of the radiation varies from the range of 13.75 $MJm^{-2}day^{-1}$ to 25.16 $MJm^{-2}day^{-1}$ with the mean value of 21.54 ± 0.46 $MJm^{-2}day^{-1}$.

Okonkwo and Nwokoye (2014) analyzed solar energy parameters in Bida, Nigeria. The monthly daily average solar energy parameters measured in Bida (9.1°N, 6.02°E) for a period of thirteen years (2000 – 2012) were obtained from the Nigerian Meteorological Agency Bida, Niger State. These data which include Gunn-Bellani solar radiation, sunshine hour duration, relative humidity, rainfall, wind speed, maximum and minimum temperatures were analysed using both single-variable and multi-variable regression techniques of the Angstrom type to generate 12 regression equations (models) that were used to estimate the total solar radiation reaching a horizontal surface in Bida. Based on the highest values of correlation coefficient (R) and coefficient of determination (R^2) and least RMSE value, the empirical equation below performed better than the other model,

$$\frac{\bar{H}}{\bar{H}_o} = -0.568 + 0.699\left(\frac{\bar{n}}{\bar{N}}\right) + 0.033(\bar{T}_{max}) - 0.020(\bar{T}_{min}) + 0.022(\bar{R}).$$

They recommended this model for designers and engineers of solar energy and other renewable energy devices in this area.

Falayi et al (2008) developed numbers of multi-linear regression equations to predict the relationship between global solar radiations with one or more combinations of the following weather parameters: clearness index, mean daily temperature, ratio of maximum and minimum daily temperature, relative humidity and relative sunshine duration for Iseyin, Nigeria for five years (1995 - 1999). Using the Angstrom model as the base, other regression equations were developed by modifying Angstrom equation. The value of correlation coefficient (R) and value of Root Mean Square Error (RMSE), Mean Bias Error (MBE) and Mean Percentage Error (MPE) were determined for each equation. The equation with the highest value of correlation coefficient (R) and least values of RMSE, MPE and MBE is given as $\frac{\bar{H}}{\bar{H}_o} = 1.3467 + 0.5305\left(\frac{S}{S_0}\right) - 1.567(\theta) + 0.0033(RH) - 0.00806(\bar{T})$. Other empirical equations developed are $\frac{H}{H_0} = 1.1203 + 0.4690\left(\frac{S}{S_0}\right) - 1.595(T_R) - 0.0041(RH)$, $\frac{H}{H_0} = 0.8559 + 0.6758\left(\frac{S}{S_0}\right) - 0.01049(T_{mean}) - 0.0043(RH)$. Where $\frac{\bar{H}}{\bar{H}_o}$ is the cleanness index, RH is the relative humidity, $\frac{S}{S_0}$ is the relative sunshine duration, θ is ratio of minimum and maximum daily temperature, T is the monthly average daily temperature. The developed model can be used for estimating global solar radiation on horizontal surfaces.

Akpabio and Etuk (2003) developed a relationship between global solar radiation and sunshine duration for Onne. Global solar radiation and sunshine duration data during the period from 1984 to 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 global solar radiation and sunshine duration were also used to estimate global solar irradiation for Onne and their results are compared with our model. A good agreement (greater than 90% in most cases) was observed between the measured and the predicted values of our model. They obtained an empirical equation for Onne with regression coefficients a = 0.23 and b = 0.38.

Olayinka (2011) used Angstrom model to estimate the global and diffuse solar radiation for selected cities of Abeokuta, Ilorin, Port – Harcourt, Sokoto in Nigeria. From the estimated values it was found that solar energy can be utilized very efficiently throughout the year in Sokoto and Ilorin. The clearness index which is availability of global solar radiation varies with geographical location and period of the year. Clearness index in the cities studied varies from 0.303 to 0.683. The least clearness index is in Port- Harcourt (0.303) in the month of July and the highest value is 0.683 in Sokoto in the month of March. The developed model equations are; $\frac{H}{H_0} = -0.423 + 0.301\left(\frac{S}{S_0}\right) + 0.0256(T_{max}) + 0.0725\left(\frac{RH}{100}\right)$ for Ilorin, $\frac{H}{H_0} = 1.164 + 0.294\left(\frac{S}{S_0}\right) + 0.0346(T_{max}) - 2.0997\left(\frac{RH}{100}\right)$ for Port – Harcourt, $\frac{H}{H_0} = -0.834 + 0.248\left(\frac{S}{S_0}\right) + 0.0438(T_{max}) - 0.00131\left(\frac{RH}{100}\right)$ for Abeokuta, $\frac{H}{H_0} = 0.376 + 0.0129\left(\frac{S}{S_0}\right) + 0.00842(T_{max}) - 0.1001\left(\frac{RH}{100}\right)$ for Sokoto.

Augustine and Nnabuchi (2010) used monthly mean daily global solar radiation, sunshine duration hours, maximum temperature, Cloudiness index and relative humidity data for some selected cities in the Eastern and Southern zone of Nigeria covering a period of seventeen years (1990 - 2007) were used to generate several linear and multi-linear regression equations. The values of the solar radiation estimated by the equations and the measured solar radiation were tested using the mean bias error (MBE), root mean square error (RMSE) and mean percentage error (MPE) statistical techniques. The values of the correlation coefficient (R) and coefficient of determination (R^2) were also determined for each equation. The equations with the highest values of R, R^2 and least values of MBE, RMSE and MPE are suitable for predicting global solar radiation in the Eastern and Southern parts of Nigeria. They suggested that the developed empirical equations can be used for estimating solar radiation in other locations with similar geographical information. Mfon *et al.*, (2013) developed a model on the estimation of global solar radiation on horizontal surface from sunshine hours and other meteorological parameters for Calabar. Multiple linear regression models were developed by them to estimate the monthly daily Sunshine Hours using four parameters during a period of eleven years (1997 – 2007) for Calabar, Nigeria (Latitude 5o16'07.6''N); The parameters include Relative Humidity, Maximum and Minimum temperatures, Rainfall and Wind Speed. The result of the correlations shows that the four variable correlations with the highest value of R gives the best result when considering the error term Root Mean Square Error (RMSE). The model is given as $\frac{\bar{H}}{\bar{H}_o} = -11.049 - 6.540RF - 0.534W + 0.142RH + 1.127T$. Where RH is Relative humidity, T is the Difference in maximum and minimum temperature, RF is Rainfall, and W is wind speed. The developed model can be used in estimating Global solar radiation for Calabar and other locations with similar climatic conditions.

Ogolo (2014) developed model equations for estimation of global solar radiation for Port – Harcourt, Benin, Lagos, Akure, Ibadan, Osogbe, Lokoja, Yola, Minna, Jos, Maiduguri an Sokoto stations in Nigeria. The equations are given as; $\frac{H}{H_0} = 0.439 + 0.119\left(\frac{S}{S_0}\right) + 0.0346(T_{mean}) - 0.00689(RH)$ for Port – Harcourt, $\frac{H}{H_0} = 0.728 + 0.116\left(\frac{S}{S_0}\right) - 0.00642(T_{mean}) - 0.00218(RH)$ for Benin, $\frac{H}{H_0} = 2.459 - 0.549\left(\frac{S}{S_0}\right) - 0.0881(T_{mean}) + 0.00779(RH)$ for Lagos, $\frac{H}{H_0} = 0.333 + 0.233\left(\frac{S}{S_0}\right) - 0.000537(T_{mean}) - 0.00017(RH)$ for Akure, $\frac{H}{H_0} = 0.291 - 0.0029\left(\frac{S}{S_0}\right) - 0.0205(T_{mean}) - 0.00603(RH)$ for Ibadan, $\frac{H}{H_0} = 0.743 + 0.266\left(\frac{S}{S_0}\right) + 0.0187(T_{Mean}) - 0.0138(RH)$ for Osogbo, $\frac{H}{H_0} = 2.873 - 0.453\left(\frac{S}{S_0}\right) - 0.0908(T_{mean}) - 0.0379(RH)$ for Lokoja, $\frac{H}{H_0} = -0.65 - 0.033\left(\frac{S}{S_0}\right) + 0.0459(T_{mean}) - 0.000926(RH)$ for Yola, $\frac{H}{H_0} = 0.777 + 0.128\left(\frac{S}{S_0}\right) - 0.0104(T_{mean}) - 0.000342(RH)$ for Minna, $\frac{H}{H_0} = 0.875 + 0.214\left(\frac{S}{S_0}\right) - 0.036(T_{mean}) - 0.00684(RH)$ for Jos, $\frac{H}{H_0} = 2.166 - 0.819\left(\frac{S}{S_0}\right) + 0.00294(T_{mean}) - 0.032(RH)$ for Maiduguri and $\frac{H}{H_0} = 0.382 - 0.0712\left(\frac{S}{S_0}\right) + 0.0062(T_{mean}) - 0.00157(RH)$ for Sokoto.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Research Method

The data for this work were collected from the Archives of National Aeronautics and Space Administration (NASA). The climate parameter data collected were; measured daily global radiation (H_m), the daily extra-terrestrial solar radiation on a horizontal surface (H_o), the daily maximum temperature (T_{max}), the daily maximum number of hours of possible sunshine (N), the daily number of hours of bright sunshine (n) and daily relative humidity (RH) values of each site.

3.2 Procedure for Data Collection and Analysis

The daily data for the sunshine duration, global solar radiation, extra – terrestrial global solar radiation on a horizontal surface, minimum temperature, maximum temperature, average temperature and relative humidity were obtained from the archives of National Aeronautics and Space Administration (NASA). The duration of record is from 2000 to 2010. The daily data were analyzed to obtain monthly mean values for each of the parameters for the years from 2000 to 2010. The cities under study with their latitude and longitude in degrees are listed in table 3.1. The mean values of the meteorological parameters for each of the eighteen cities studied are presented in table 3.2 to table 3.19 below.

3.3 Models used for the Estimation

Many researchers have proposed correlation that should be used to estimate global solar radiation in different locations around the world. Angstrom (1924) proposed the first correlation for estimating the monthly mean daily global solar radiation (H) on a horizontal surface using the sunshine duration and clear sky radiation (H_c) data. The developed equation according Angstrom is given as

$$\frac{H}{H_c} = a + b\left(\frac{n}{N}\right) \tag{3.1}$$

Because there may be problems in calculating clear sky radiation accurately, by replacing clear sky radiation with extraterrestrial radiation (H_o), the Angstrom correlation was put in more convenient form by Prescott (Prescott, 1940). Page (1961) and others have modified the method using the value of the extraterrestrial radiation H_0 on a horizontal surface rather than the clear day radiation H_c (Duffie and Beckman, 1991).

$$\frac{\bar{H}}{\bar{H}_0} = a + b\left(\frac{\bar{n}}{\bar{N}}\right) \tag{3.2}$$

Where $\bar{H}$ is the monthly average daily global radiation on a horizontal surface ($mJ.m^{-2}.day^{-1}$). $\bar{H}_0$ is the daily extraterrestrial solar radiation on a horizontal surface $mJ.m^{-2}.day^{-1}$, $\bar{n}$ is the monthly average daily hours of bright sunshine, $\bar{N}$ is the monthly average day length, (a and b) values are known as angstrom empirical constant or regression coefficients. Their values have been obtained from the relationship given by (Tiwari and Sangetta, 1977) and also confirmed by (Frere et al., 1980) as

$$a = -0.110 + 0.235 \cos \emptyset + 0.323 \left(\frac{n}{N}\right) \tag{3.3}$$

$$b = 1.449 - 0.553 \cos \emptyset - 0.694 \left(\frac{n}{N}\right) \tag{3.4}$$

$\overline{H}_0$ is the monthly mean extra – terrestrial solar radiation on horizontal surface given by Iqbal (1983) as;

$$\overline{H}_0 = \frac{24}{\pi} I_{sc} \epsilon_o \left[\frac{\pi}{180} \omega \sin \emptyset \sin \delta + \cos \emptyset \cos \delta \sin \omega_s\right] \tag{3.5}$$

Where

I_{sc} – the solar constant,

ϵ_0– the eccentricity correction factor of the earth's orbit,

$\emptyset$ – the latitude

δ - the solar declination angle

ω_s – the sunset hour angle

The expressions for I_{sc}, ϵ_0, δ, and ω are given by same Iqbal as:

$$I_{sc} = \frac{1367 \times 3600}{1000000} \text{ mJm}^{-2}\text{day}^{-1} \tag{3.6}$$

$$\epsilon_0 = 1 + 0.033 \, cos \left(\frac{360 d_n}{365}\right) \tag{3.7}$$

Equations for the solar declination angle (δ) and the sunset hour angle (ω_s) are given as

$$\delta = 23.45 \sin \left[\frac{360(284 + d_n)}{365}\right] [°] \tag{3.8}$$

$$\omega_s = \cos^{-1}(-\tan \emptyset \tan \delta) \tag{3.9}$$

Other regression models were obtained through the modification of the Angstrom – Page model by various researchers. Multiple linear regression and correlation analysis of different parameters for example, $\frac{\bar{H}_m}{\bar{H}_{cal}}$,$\frac{\bar{n}}{\bar{N}}$,$\bar{T}_{max}$ and $\overline{RH}$ were employed to estimate the global solar radiation in this work. Where $\frac{H_m}{H_{cal}}$ is the clearness index, $\frac{\bar{n}}{\bar{N}}$ is monthly mean fraction of sunshine radiation, $\bar{T}_{max}$ is the monthly mean maximum temperature,

Equation (3.2) has been found to be very convenient in estimation of global solar radiation of a number of locations around the world. In this work, simple linear and multiple linear regression analysis of different climatic parameters such as $\frac{\bar{H}_m}{\bar{H}_{cal}}$,$\frac{\bar{n}}{\bar{N}}$,$\bar{T}_{max}$ and $\overline{RH}$ were used to develop model equations which were used to estimate global solar radiation in the sites under study.

3.4 Linear Regression Equation

The general equation of simple linear regression of first order with two variables, one dependent and one independent is given as

$$Y = a_1 + b_1X. \tag{3.10}$$

Where a_1 and b_1 are regression constants which can be determined. Y is the dependent variable and X is the independent variable (Nnabuchi *et al.*, 2013). Other first order linear regression containing one dependent variable and two or more independent variables known as multiple linear regression equation can be given as

$$Y = a_2 + b_2X_1 + cX_2 + dX_3 \tag{3.11}$$

Where X_1, X_2 and X_3 are independent variables. a_2, b_2, c and d are the regression constants. Equation (3.10) and (3.11) are used in this work to develop our empirical equation.

In developing our model equations, climatic parameters such as fraction of sunshine hours, maximum temperature and relative humidity are substituted in equation (3.10) and (3.11) which give rise to the following equations.

$$\frac{\bar{H}_1}{\bar{H}_0} = a_1 + b_1\left(\frac{\bar{n}}{\bar{N}}\right) \tag{3.12}$$

$$\frac{\bar{H}_2}{\bar{H}_0} = a_2 + b_2\left(\frac{\bar{n}}{\bar{N}}\right) + c_2(\bar{T}_{max}) \tag{3.13}$$

$$\frac{\bar{H}_3}{\bar{H}_0} = a_3 + b_3\left(\frac{\bar{n}}{\bar{N}}\right) + c_3\left(\frac{\overline{RH}}{100}\right) \tag{3.14}$$

$$\frac{\bar{H}_4}{\bar{H}_0} = a_4 + b_4\left(\frac{\bar{n}}{\bar{N}}\right) + c_4(\bar{T}_{max}) + d_4\left(\frac{\overline{RH}}{100}\right) \tag{3.15}$$

$$\frac{\bar{H}_5}{\bar{H}_0} = a_5 + b_5(\bar{T}_{max}) + c_5\left(\frac{\overline{RH}}{100}\right) \tag{3.16}$$

Where a_1 and b_1 are regression constants for H_1. a_2, b_2 and c_3 are regression constants for H_2. a_3, b_3 and c_3 are regression constants for H_3. a_4, b_4, c_4 and d_4 are regression constants for H_4. a_5, b_5 and c_5 are regression constants for H_5. These regression constants were determined by performing the linear regression analysis of $\frac{\bar{H}_{cal}}{\bar{H}_0}$ against each of the climatic parameters used in this study as contained in equations (3.12) to (3.16). The monthly mean values of $\bar{H}_{cal}$ used in this work were estimated using equations (3.2), (3.3) and (3.4). Equations (3.3) and (3.4) were used to calculate the regression constants in equation (3.2).

3.5 Methods of Comparison

Statistical comparisons of the data are usually done using error indicator such the Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE).

These statistical error formulae were obtained from previous researches done in this field by (Chukwuemeka and Nnabuchi, 2009, Marwal et al, 2012, Falayi et al, 2008). t – statistic is also used to validate the significant of the proposed models (Stone, 1993).

3.5.1 Mean Bias Error (MBE)

The MBE provides information on the long – term performance of the correlations by allowing a term by term comparison of the actual deviation between calculated and measured values. A positive MBE represent an overestimation whereas a negative MBE shows an underestimation. A low value of MBE is desired for a good correlation. The ideal value of MBE is zero (Che et al., 2007). The values of MBE represent the systematic error or overall bias. The error equation for MBE is given as;

$$MBE = [\sum(H_{cal} - H_{obs})]/n \tag{3.17}$$

3.5.2 Root Mean Square Error (RMSE)

The Root Mean Square Error (RMSE) provides information on the short – term comparisons of the deviation performance of the correlations by allowing a term by term between the calculated and measure values. The RMSE is a frequently used statistical toold for the measure of the difference between values predicted by a model or an estimator and the values actually observed from the values being modeled or estimated. RMSE is a good measure of precisions. The RMSE indicates the level of scatter that a model produces, thus providing a term by term comparison. It also provides information on the short term performance of the correlations of the actual deviation between the estimated and measured values. The value of RMSE is always positive. Almoxo et al., (2005) and Che et al., (2007) have recommended that a zero value of RMSE is ideal and the lower the RMSE, the more accurate is the estimated value. The values of RMSE represent non – systematic error. The value of RMSE is determined using the equation below;

$$RMSE = [\sum(H_{cal} - H_{obs})^2/n]^{1/2} \tag{3.18}$$

3.5.3 Mean Percentage Error (MPE)

The Mean Percentage Error (MPE) gives long term performance of the examined regression equations, a positive MPE value provides an indication of some amount of overestimation in the estimated values. Negatives values indicate underestimation. A low value of MPE is desirable as proposed by Akpobio and Etuk (2002). MPE is an overall measure of forecast bias, computed from the actual difference between a series of forecasts and actual data points observed. The differences are expressed as percentage of each observed data point, the summed and averaged (Almorox, 2011). MPE is determined using the equation;

$$MPE = \left[\sum \frac{(H_{obs} - H_{cal})}{(H_{0bs})} \times 100\right]/n \tag{3.19}$$

Where H_{obs} is the measured monthly mean global solar radiation value on a horizontal surface, H_{cal} is the calculated value of monthly global radiation on the same surface and n the number of observations.

3.5.4 t-statistic (t – test)

After an estimation of a coefficient, the t-statistic for that coefficient is the ratio of the coefficient to its standard errors. 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 researcher's models. To determine whether or not the equation estimates are statistically significant, Stone (1993) proposed t-stat as:

$$t - stat = \sqrt{\frac{(n-1)MBE^2}{RMSE^2 - MBE^2}} \tag{3.20}$$

The smaller the value of t – stat of a model, the better is the model's performance. To determine whether a model's estimates are statistically significant, one simply has to determine a critical t value obtainable from standard statistical tables, i.e., $t_{\alpha/2}$ at the α level of significance and $n - 1$ degrees of freedom. For the model's estimates to be judged statistically significant at the $1 - \alpha$ confidence level, the calculated, t value must be less than the critical t value (Stone, 1993).

The t-statistic, which has a long history of popular usage, is proposed as a criterion for the more complete evaluation of solar radiation estimation models. In addition to providing a single integrated criterion for the evaluation and comparison of models, it also enables the model tester to determine whether or not a model's predictions are statistically significant at a particular confidence level. The t-statistic is not meant to replace the widely used root mean square and mean bias errors but to supplement them in aiding the model tester to more rapidly and reliably assess a model's performance.

Table 3.1: Latitude and Longitude of Three Cities in each of the Six Geopolitical Zone

Geopolitical Zones	Cities	Latitude (°)	Longitude (°)
South East	Awka	6.207	7.068
	Enugu	6.452	7.510
	Owerri	5.485	7.035
South South	Calabar	4.950	8.325
	Port – Harcourt	4.750	7.000
	Asaba	6.198	6.728
South West	Lagos	6.453	3.396
	Akure	7.250	5.195
	Ado – Ekiti	7.621	5.221
North East	Gombe	10.250	11.167
	Yola	9.230	12.460
	Maiduguri	11.833	13.150
North Central	Abuja	9.067	7.483
	Minna	9.613	6.557
	Ilorin	8.500	4.550
North West	Gusau	12.150	6.667
	Kano	12.000	8.517
	Birnin Kebbi	12.454	4.200

Table 3.2: Solar Radiation and Climate Parameters for Owerri

S/N	MONTH	$\bar{H}_0$ (MJm^{-2} day^{-1})	$\bar{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	$\bar{T}_{MAX}$(°C)	$\overline{RH}$ (%)
1	January	34.15	20.06	6.35	11.58	0.59	0.55	29.56	74.39
2	February	36.13	20.37	6.15	11.74	0.56	0.52	29.87	76.76
3	March	37.55	19.55	5.99	11.95	0.52	0.50	29.03	83.81
4	April	37.55	18.20	5.45	12.18	0.48	0.45	29.06	84.84
5	May	36.44	16.85	5.49	12.37	0.46	0.44	28.59	85.65
6	June	35.56	15.06	5.35	12.46	0.42	0.43	27.16	87.11
7	July	35.80	13.55	3.86	12.4	0.38	0.31	26.49	87.03
8	August	36.77	13.27	3.78	12.24	0.36	0.31	26.49	86.66
9	September	37.21	13.87	4.45	12.02	0.37	0.37	26.86	87.05
10	October	36.31	15.36	4.94	11.79	0.42	0.42	27.35	86.72
11	November	34.47	17.52	5.50	11.61	0.51	0.47	28.33	84.39
12	December	33.31	19.07	6.63	11.54	0.57	0.57	28.89	81.12

Table 3.3: Solar Radiation and Climate Parameters for Enugu

S/N	MONTH	$\bar{H}_0$ (MJm^{-2} day^{-1})	$\bar{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	T_{MAX}(°C)	RH (%)
1	January	33.69	20.60	5.98	11.75	0.61	0.51	30.68	62.36
2	February	35.80	20.92	5.55	11.84	0.58	0.47	30.66	69.17
3	March	37.47	20.55	4.29	11.97	0.55	0.36	29.56	81.28
4	April	37.67	19.01	4.54	12.11	0.50	0.38	29.43	83.95
5	May	36.65	17.01	4.21	12.23	0.46	0.34	28.81	85.01
6	June	35.89	16.15	3.24	11.72	0.45	0.28	27.58	86.25
7	July	36.12	14.85	3.23	11.74	0.41	0.28	26.9	86.43
8	August	36.94	14.15	3.42	11.89	0.38	0.29	26.83	86.10
9	September	37.20	14.85	3.75	11.98	0.40	0.31	27.21	86.51
10	October	36.06	16.58	4.93	11.87	0.46	0.41	27.85	85.60
11	November	34.07	18.75	5.98	11.76	0.55	0.51	28.83	82.62
12	December	32.84	19.93	5.68	11.71	0.61	0.49	29.76	72.78

Table 3.4: Solar Radiation and Climate Parameters for Awka

S/N	MONTH	$\bar{H}_0$ (MJm^{-2} day^{-1})	$\bar{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	T_{MAX}(ºC)	RH (%)
1	January	33.68	20.71	6.22	11.43	0.61	0.54	30.74	61.98
2	February	35.80	20.92	6.94	11.83	0.58	0.59	30.66	69.17
3	March	37.47	20.55	6.92	11.27	0.55	0.61	29.56	81.28
4	April	37.67	19.00	6.12	12.11	0.50	0.51	29.43	83.94
5	May	36.71	17.74	4.52	12.22	0.48	0.37	28.96	84.68
6	June	35.89	16.15	4.38	12.35	0.45	0.35	27.58	86.25
7	July	36.12	14.85	3.83	12.47	0.41	0.31	26.9	86.43
8	August	36.94	14.15	3.45	11.88	0.38	0.29	26.83	86.10
9	September	37.20	14.85	4.78	11.63	0.40	0.41	27.21	86.51
10	October	36.06	16.58	4.97	11.51	0.46	0.43	27.85	85.60
11	November	34.08	18.74	6.31	11.43	0.55	0.55	28.84	82.62
12	December	32.85	19.93	6.95	11.63	0.61	0.60	29.75	72.86

Table 3.5: Solar Radiation and Climate Parameters for Asaba

S/N	MONTH	$\bar{H}_0$ (MJm^{-2} day^{-1})	$\bar{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	T_{MAX} (ºC)	RH (%)
1	January	33.70	20.06	5.83	11.93	0.60	0.49	30.32	66.63
2	February	35.80	20.17	5.12	11.89	0.56	0.43	30.26	72.85
3	March	37.48	20.03	4.09	11.92	0.53	0.34	29.32	83.19
4	April	37.66	18.55	3.98	12.25	0.49	0.32	29.24	85.00
5	May	36.71	17.16	3.85	12.33	0.47	0.31	28.80	85.55
6	June	35.88	15.89	3.47	12.39	0.44	0.28	27.45	86.79
7	July	36.12	14.38	3.10	12.27	0.4	0.25	26.76	86.96
8	August	36.94	13.79	2.96	12.21	0.37	0.24	26.72	86.50
9	September	37.18	14.41	2.65	12.11	0.39	0.22	27.12	87.03
10	October	36.11	16.34	3.16	11.86	0.45	0.27	27.81	86.16
11	November	34.07	18.38	4.05	11.78	0.54	0.34	28.80	83.45
12	December	32.82	19.55	5.56	11.54	0.60	0.48	29.42	76.74

Table 3.6: Solar Radiation and Climate Parameters for Port Harcourt

S/N	MONTH	$\bar{H}_0$ (MJm^{-2} day^{-1})	$\bar{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	T_{MAX} (ºC)	RH (%)
1	January	34.54	18.92	5.95	11.78	0.55	0.51	27.94	78.92
2	February	36.44	19.49	4.93	11.83	0.53	0.42	28.08	81.88
3	March	37.65	17.95	4.54	11.99	0.48	0.38	27.85	84.49
4	April	37.43	16.36	4.76	12.20	0.44	0.39	28.00	84.61
5	May	36.17	15.03	5.10	12.44	0.42	0.41	27.68	84.93
6	June	35.22	12.07	4.85	12.48	0.34	0.39	26.58	85.05
7	July	35.49	11.47	3.56	12.56	0.32	0.28	25.85	84.89
8	August	36.57	12.26	2.86	12.00	0.34	0.24	25.66	84.94
9	September	37.23	12.21	3.66	12.02	0.33	0.30	25.97	85.98
10	October	36.51	13.41	4.87	11.93	0.37	0.41	26.41	85.88
11	November	34.85	15.46	5.68	11.78	0.44	0.48	27.12	84.83
12	December	33.77	18.18	5.86	11.50	0.54	0.51	27.59	82.61

Table 3.7: Solar Radiation and Climate Parameters for Calabar

S/N	MONTH	$\bar{H}_0$ (MJm^{-2} day^{-1})	$\bar{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	T_{MAX} (ºC)	RH (%)
1	January	34.54	20.14	5.10	11.68	0.58	0.44	27.51	78.07
2	February	36.40	20.40	4.58	11.86	0.56	0.39	27.63	80.83
3	March	37.64	18.69	3.75	11.97	0.50	0.31	27.36	83.52
4	April	37.44	16.59	3.97	12.11	0.44	0.33	27.51	83.95
5	May	36.14	15.64	4.38	12.23	0.43	0.36	27.21	84.54
6	June	35.22	12.50	3.63	12.29	0.35	0.30	26.11	85.14
7	July	35.50	11.60	2.43	12.26	0.33	0.20	25.33	85.2
8	August	36.59	11.31	2.01	12.16	0.31	0.17	25.11	85.34
9	September	37.21	11.96	2.21	12.03	0.32	0.18	25.39	85.91
10	October	36.57	13.83	2.93	11.89	0.38	0.25	25.87	85.60
11	November	34.84	16.00	3.85	11.63	0.46	0.33	26.63	84.25
12	December	33.80	18.47	4.96	11.55	0.55	0.43	27.06	81.89

Table 3.8: Solar Radiation and Climate Parameters for Akure

S/N	Month	$\overline{H}_0$ (MJm^{-2} day^{-1})	$\overline{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\overline{N}$ (hrs)	K	$\bar{n}/\overline{N}$	T_{MAX} (ºC)	RH (%)
1	January	33.21	20.39	6.88	11.73	0.61	0.59	30.48	61.28
2	February	35.52	20.81	5.85	11.98	0.59	0.49	30.17	69.48
3	March	37.36	20.75	6.41	12.08	0.56	0.53	29.15	81.57
4	April	37.74	19.25	6.33	12.2	0.51	0.52	28.82	85.16
5	May	36.97	18.11	5.35	12.43	0.49	0.43	28.53	84.96
6	June	36.23	16.43	4.64	12.55	0.45	0.37	27.11	86.80
7	July	36.40	14.73	3.75	12.64	0.40	0.30	26.32	87.28
8	August	37.07	13.56	3.52	12.42	0.37	0.28	26.20	87.09
9	September	37.15	15.16	4.01	12.40	0.41	0.32	26.84	87.13
10	October	35.79	16.95	4.93	11.93	0.47	0.41	27.78	85.69
11	November	33.67	19.43	5.67	11.85	0.58	0.48	28.76	82.05
12	December	32.36	20.11	6.1	11.69	0.62	0.52	29.75	71.29

Table 3.9: Solar Radiation and Climate Parameters for Ado - Ekiti

S/N	Months	$\overline{H}_0$ (MJm^{-2} day^{-1})	$\overline{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\overline{N}$ (hrs)	K	$\bar{n}/\overline{N}$	T_{MAX} (ºC)	RH (%)
1	January	33.21	20.39	5.63	11.56	0.61	0.49	30.48	61.28
2	February	35.52	20.81	5.55	11.85	0.59	0.47	30.17	69.48
3	March	37.36	20.75	5.34	12.16	0.56	0.44	29.15	81.57
4	April	37.74	19.25	4.86	12.28	0.51	0.40	28.81	85.17
5	May	36.96	18.12	4.77	12.51	0.49	0.38	28.41	85.57
6	June	36.23	16.43	4.21	12.68	0.45	0.33	27.11	86.80
7	July	36.40	14.73	3.91	12.71	0.4	0.31	26.32	87.28
8	August	37.07	13.56	3.17	12.43	0.37	0.26	26.20	87.09
9	September	37.15	15.20	3.8	12.26	0.41	0.31	26.85	87.13
10	October	35.78	16.91	4.54	11.78	0.47	0.39	27.78	85.69
11	November	33.66	19.44	4.87	11.63	0.58	0.42	28.76	82.04
12	December	32.35	20.11	5.96	11.52	0.62	0.52	29.76	71.27

Table 4.10: Solar Radiation and Climate Parameters for Lagos

S/N	MONTH	$\overline{H}_0$ (MJm^{-2} day^{-1})	$\overline{H}_m$ (MJm^{-2} day^{-1})	$\overline{n}$ (hrs)	$\overline{N}$ (hrs)	K	$\overline{n}/\overline{N}$	T_{MAX} (ºC)	RH (%)
1	January	33.70	19.24	5.54	11.48	0.57	0.48	28.28	76.46
2	February	35.83	20.31	6.48	11.62	0.57	0.56	28.42	80.27
3	March	37.49	20.23	5.23	12.09	0.54	0.43	28.14	84.61
4	April	37.66	19.01	5.12	12.23	0.5	0.42	28.37	84.52
5	May	36.73	16.91	4.36	12.31	0.46	0.35	28.10	84.61
6	June	35.88	14.33	4.00	12.38	0.40	0.32	27.05	84.91
7	July	36.10	14.44	3.89	12.27	0.40	0.32	26.14	84.65
8	August	36.91	14.90	3.00	12.18	0.40	0.25	25.76	84.93
9	September	37.18	15.08	3.64	11.9	0.41	0.31	26.23	86.08
10	October	36.02	16.47	4.54	11.67	0.46	0.39	26.99	85.39
11	November	34.04	18.63	5.36	11.57	0.55	0.46	27.81	83.63
12	December	32.82	19.36	5.64	11.44	0.59	0.49	28.21	80.32

Table 3.11: Solar Radiation and Climate Parameters for Ilorin

S/N	MONTH	$\overline{H}_0$ (MJm^{-2} day^{-1})	$\overline{H}_m$ (MJm^{-2} day^{-1})	$\overline{n}$ (hrs)	$\overline{N}$ (hrs)	K	$\overline{n}/\overline{N}$	T_{MAX} (ºC)	RH (%)
1	January	32.79	20.55	6.58	11.89	0.63	0.55	31.32	52.94
2	February	35.18	21.54	7.29	11.58	0.61	0.63	31.05	63.02
3	March	37.22	22.12	7.10	11.87	0.59	0.60	30.07	76.5
4	April	37.84	20.71	5.98	12.1	0.55	0.49	29.16	83.73
5	May	37.20	19.22	5.86	12.65	0.52	0.46	28.72	84.22
6	June	36.54	17.47	5.37	12.57	0.48	0.43	27.47	85.52
7	July	36.68	15.19	3.68	12.41	0.41	0.30	26.57	86.45
8	August	37.24	13.95	3.13	12.12	0.37	0.26	26.42	86.38
9	September	37.09	16.18	4.10	11.99	0.44	0.34	27.32	85.77
10	October	35.56	17.97	5.81	11.74	0.51	0.49	28.48	83.37
11	November	33.25	20.15	7.69	11.62	0.61	0.66	29.9	75.52
12	December	31.85	20.33	8.18	11.58	0.64	0.71	31.18	60.43

Table 3.12: Solar Radiation and Climate Parameters for Abuja

S/N	MONTH	$\overline{H}_0$ (MJm^{-2} day^{-1})	$\overline{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\overline{N}$ (hrs)	K	$\bar{n}/\overline{N}$	T_{MAX} (ºC)	RH (%)
1	January	32.33	21.30	6.62	11.50	0.66	0.57	31.65	36.86
2	February	34.87	22.30	7.71	11.60	0.64	0.67	32.19	44.68
3	March	37.10	23.25	7.63	12.50	0.63	0.61	31.12	62.29
4	April	37.88	21.98	6.17	11.90	0.58	0.52	29.12	80.64
5	May	37.46	20.04	6.23	12.20	0.54	0.51	28.32	82.81
6	June	36.84	18.13	5.32	12.40	0.49	0.43	26.94	85.04
7	July	36.95	15.95	4.44	12.50	0.43	0.36	25.97	86.63
8	August	37.38	14.75	3.61	12.50	0.39	0.29	25.72	87.1
9	September	37.06	17.14	4.39	12.30	0.46	0.36	26.83	85.23
10	October	35.29	19.24	5.71	12.00	0.55	0.47	28.17	81.68
11	November	32.89	21.45	6.20	11.80	0.65	0.52	30.36	63.23
12	December	31.75	21.00	6.53	11.60	0.66	0.56	31.13	46.58

Table 3.13: Solar Radiation and Climate Parameters for Minna

S/N	MONTH	$\overline{H}_0$ (MJm^{-2} day^{-1})	$\overline{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\overline{N}$ (hrs)	K	$\bar{n}/\overline{N}$	T_{MAX} (ºC)	RH (%)
1	January	32.32	20.72	6.78	11.43	0.64	0.59	32.55	39.50
2	February	34.86	21.92	7.23	11.89	0.63	0.61	33.00	46.96
3	March	37.10	23.15	6.94	12.34	0.62	0.56	31.93	63.69
4	April	37.91	22.14	6.64	12.56	0.58	0.53	30.11	79.88
5	May	37.44	20.43	6.02	12.63	0.55	0.48	29.33	81.79
6	June	36.83	18.64	4.87	12.67	0.51	0.38	27.97	84.03
7	July	36.95	16.43	4.59	12.68	0.44	0.36	27.00	85.73
8	August	37.39	15.50	4.18	12.62	0.41	0.33	26.78	85.94
9	September	37.05	17.56	5.24	12.08	0.47	0.43	27.80	84.47
10	October	35.32	19.68	7.47	11.91	0.56	0.63	29.03	81.40
11	November	32.82	21.05	8.63	11.73	0.64	0.74	31.18	65.07
12	December	31.39	20.89	8.52	11.48	0.67	0.74	32.63	43.55

Table 3.14: Solar Radiation and Climate Parameters for Yola

S/N	MONTH	$\bar{H}_0$ (MJm^{-2} day^{-1})	$\bar{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	T_{MAX} (ºC)	RH (%)
1	January	32.33	21.54	8.36	11.36	0.67	0.74	33.69	22.32
2	February	34.83	22.79	8.05	11.60	0.65	0.69	35.89	24.34
3	March	37.10	23.77	7.93	11.94	0.64	0.66	36.56	35.49
4	April	37.92	22.76	7.65	12.24	0.6	0.63	32.89	64.96
5	May	37.45	21.13	7.26	12.47	0.56	0.58	31.18	72.84
6	June	36.85	19.51	6.68	12.63	0.53	0.53	29.14	78.92
7	July	36.95	18.25	6.21	12.68	0.49	0.49	27.7	82.46
8	August	37.38	16.98	5.93	12.58	0.45	0.47	27.89	83.24
9	September	37.05	18.64	5.74	12.28	0.50	0.47	28.81	79.06
10	October	35.26	20.93	7.88	11.94	0.59	0.66	30.75	69.98
11	November	32.83	21.82	8.61	11.66	0.66	0.74	33.59	41.4
12	December	31.38	21.22	8.73	11.30	0.68	0.77	33.11	27.77

Table 3.15: Solar Radiation and Climate Parameters for Gombe

S/N	MONTH	$\bar{H}_0$ (MJm^{-2} day^{-1})	$\bar{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	T_{MAX} (ºC)	RH (%)
1	January	31.86	20.95	8.46	11.30	0.66	0.75	33.22	20.46
2	February	34.53	22.61	8.75	11.50	0.65	0.76	35.90	20.23
3	March	36.94	23.86	8.10	11.60	0.65	0.70	37.63	26.01
4	April	37.97	23.23	8.00	12.30	0.61	0.65	34.76	55.95
5	May	37.68	22.40	8.13	12.60	0.59	0.65	32.99	64.60
6	June	37.16	20.77	7.74	12.70	0.56	0.61	30.23	74.51
7	July	37.21	18.64	5.22	12.50	0.50	0.42	28.17	81.12
8	August	37.52	17.59	5.14	12.50	0.47	0.41	27.58	83.14
9	September	37.00	19.49	6.38	12.40	0.53	0.52	29.23	78.00
10	October	35.00	21.23	7.64	11.90	0.61	0.64	31.52	65.81
11	November	32.36	21.03	8.93	11.70	0.65	0.76	33.68	37.14
12	December	30.85	20.37	8.65	11.50	0.66	0.76	32.78	25.35

Table 3.16: Solar Radiation and Climate Parameters for Maiduguri

S/N	MONTH	$\bar{H}_0$ (MJm^{-2} day^{-1})	$\bar{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	T_{MAX} (ºC)	RH (%)
1	January	31.39	20.65	8.84	11.32	0.66	0.78	32.83	18.42
2	February	34.19	22.90	8.33	11.66	0.67	0.71	35.98	15.32
3	March	36.89	24.47	7.69	11.82	0.66	0.65	38.9	15.32
4	April	38.04	24.10	7.46	12.18	0.63	0.61	38.16	38.84
5	May	37.89	23.05	7.68	12.54	0.61	0.61	36.76	47.09
6	June	37.45	21.25	7.01	12.69	0.57	0.55	33.34	61.19
7	July	37.44	19.46	5.78	12.81	0.52	0.45	30.09	73.55
8	August	37.59	17.95	5.96	12.63	0.48	0.47	28.74	79.3
9	September	36.90	20.12	7.23	12.15	0.55	0.6	30.85	70.72
10	October	34.75	21.63	8.30	11.95	0.62	0.69	34.37	47.72
11	November	31.96	21.52	8.87	11.58	0.67	0.77	34.87	27.85
12	December	30.36	20.18	8.46	11.26	0.67	0.75	32.79	22.73

Table 3.17: Solar Radiation and Climate Parameters for Brinin – Kebbi

S/N	MONTH	$\bar{H}_0$ (MJm^{-2} day^{-1})	$\bar{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	T_{MAX} (ºC)	RH (%)
1	January	30.89	19.86	8.83	11.35	0.64	0.78	33.49	18.63
2	February	33.82	22.40	7.46	11.58	0.66	0.64	36.32	18.41
3	March	36.62	24.33	7.59	11.81	0.66	0.64	38.81	22.03
4	April	38.06	24.52	7.74	12.15	0.64	0.64	38.31	42.20
5	May	38.10	23.66	7.88	12.35	0.62	0.64	36.11	52.91
6	June	37.71	22.82	7.34	12.59	0.61	0.58	32.54	66.44
7	July	37.69	19.96	6.11	12.78	0.53	0.48	29.92	75.85
8	August	37.72	18.43	5.13	12.66	0.49	0.41	29.39	78.32
9	September	36.84	20.44	5.57	12.37	0.55	0.45	30.79	74.80
10	October	34.46	21.52	6.97	12.01	0.62	0.58	33.93	57.75
11	November	31.53	20.52	8.25	11.94	0.65	0.69	35.18	33.83
12	December	29.83	19.62	8.56	11.62	0.66	0.74	33.37	25.08

Table 3.18: Solar Radiation and Climate Parameters for Gusau

S/N	MONTH	$\bar{H}_0$ (MJm^{-2} day^{-1})	$\bar{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	T_{MAX} (ºC)	RH (%)
1	January	30.9	20.24	7.14	11.50	0.65	0.62	32.15	19.5
2	February	33.82	22.61	7.55	11.81	0.67	0.64	34.98	18.75
3	March	36.62	24.37	7.34	11.99	0.67	0.61	37.57	21.72
4	April	38.07	24.82	6.67	12.10	0.65	0.55	36.3	48.34
5	May	38.07	23.90	6.21	12.21	0.63	0.51	33.86	61.78
6	June	37.71	23.11	5.81	12.25	0.61	0.47	30.42	74.85
7	July	37.70	20.00	4.59	11.40	0.53	0.40	28.24	81.42
8	August	37.75	18.53	4.87	11.51	0.49	0.42	27.92	82.27
9	September	36.85	20.98	6.36	11.65	0.57	0.55	29.21	79.59
10	October	34.45	21.51	6.59	11.75	0.62	0.56	32.29	62.06
11	November	31.51	20.59	6.92	11.85	0.65	0.58	33.84	33.11
12	December	29.85	19.85	7.23	11.93	0.67	0.61	31.96	24.66

Table 3.19: Solar Radiation and Climate Parameters for Kano

S/N	MONTH	$\bar{H}_0$ (MJm^{-2} day^{-1})	$\bar{H}_m$ (MJm^{-2} day^{-1})	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	T_{MAX} (ºC)	RH (%)
1	January	30.91	20.40	8.54	11.29	0.66	0.76	30.85	18.7
2	February	33.79	22.98	8.05	11.43	0.68	0.70	33.96	16.22
3	March	36.61	25.05	8.36	12.02	0.68	0.70	37.12	16.43
4	April	38.08	25.35	8.24	12.23	0.67	0.67	37.2	40.1
5	May	38.07	24.25	8.48	12.40	0.64	0.68	35.39	52.82
6	June	37.71	22.80	7.42	12.48	0.60	0.59	31.48	69.13
7	July	37.71	20.32	6.30	12.44	0.54	0.51	28.88	78.19
8	August	37.74	19.21	6.00	12.30	0.51	0.49	28.31	80.58
9	September	36.87	21.06	6.54	12.10	0.57	0.54	30.14	74.34
10	October	34.50	21.38	7.30	11.55	0.62	0.63	33.56	52.06
11	November	31.52	20.54	8.48	11.33	0.65	0.75	33.55	28.61
12	December	29.84	19.87	8.63	11.25	0.67	0.77	30.9	23.32

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Estimation of Global Solar Radiation

Figure 4.1 to figure 4.18 show the measured global solar radiation and all the estimated global solar radiation obtained using empirical equations developed for different cities under study. The values of the measured global solar radiation and all estimated global solar radiations for each city are presented in table 1 to table 18 shown in the appendix.

4.1.1 **Global Solar Radiation for Owerri**

Figure 4.1 shows the graph of monthly mean global solar radiation plotted against months of the year for Owerri. The result shows that H_m has peak value of 20.37 $MJm^{-2}day^{-1}$ in February and least value of 13.27 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 21.02 $MJm^{-2}day^{-1}$ in March and least value of 15.85 $MJm^{-2}day^{-1}$ in July. H_2 has peak value of 20.99 $MJm^{-2}day^{-1}$ in March and least value of 15.81 $MJm^{-2}day^{-1}$ in July. H_3 has peak value of 21.08 $MJm^{-2}day^{-1}$ in March and least value of 15.78 $MJm^{-2}day^{-1}$ in July. H_4 has peak value of 21.16 $MJm^{-2}day^{-1}$ in March and least value of 15.77 $MJm^{-2}day^{-1}$ in July. H_5 has peak value of 21.43 $MJm^{-2}day^{-1}$ in February and least value of 13.27 $MJm^{-2}day^{-1}$ in July. This result shows that peak values of global solar radiation determined for Owerri using our models occurred during March and least values occurred during July except for H_5 which has peak value during February.

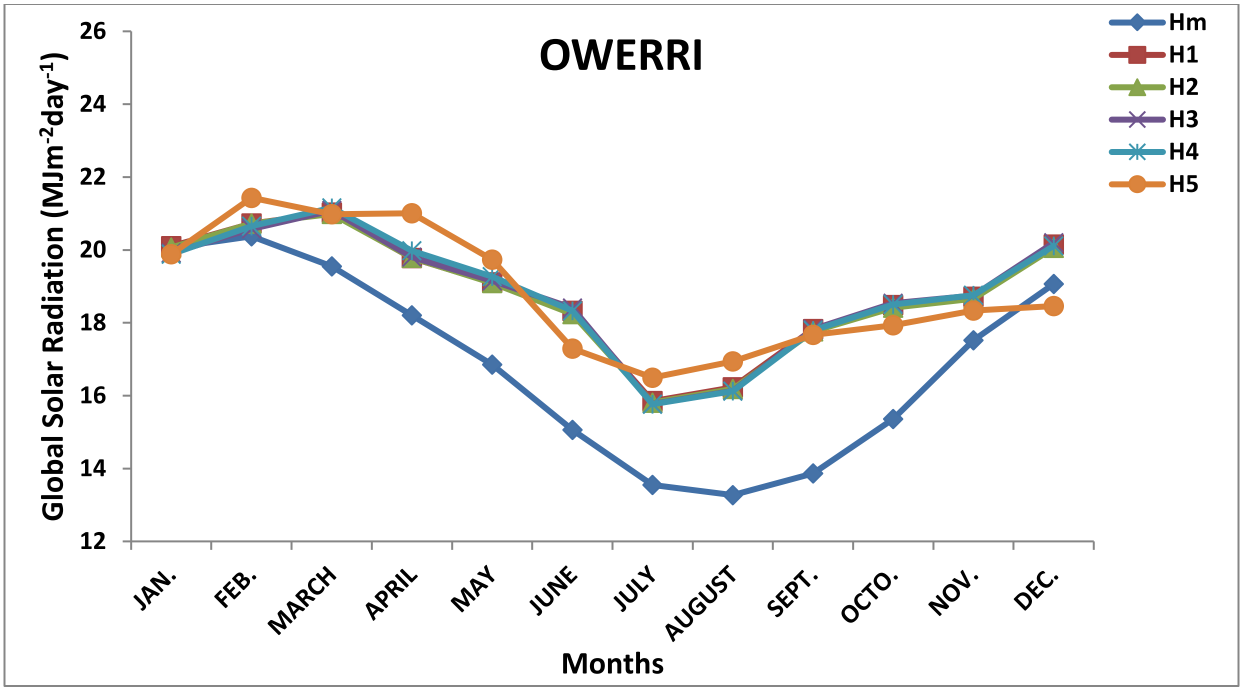

Fig. 4.1: Graph of Global Solar Radiations versus Months of the Years (2000 – 2010) for Owerri

4.1.2 Global Solar Radiation for Enugu

Figure 4.2 shows the graph of monthly mean global solar radiation plotted against months of the year for Enugu. The result shows that H_m has peak value of 20.92 $MJm^{-2}day^{-1}$ in February and least value of 14.15 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 20.29 $MJm^{-2}day^{-1}$ in November and least value of 14.80 $MJm^{-2}day^{-1}$ in June. H_2 has peak value of 20.55 $MJm^{-2}day^{-1}$ in February and least value of 13.36 $MJm^{-2}day^{-1}$ in July. H_3 has peak value of 21.30 $MJm^{-2}day^{-1}$ in February and least value of 14.21 $MJm^{-2}day^{-1}$ in August. H_4 has peak value of 22.85 $MJm^{-2}day^{-1}$ in February and least value of 16.20 $MJm^{-2}day^{-1}$ in July. H_5 has peak value of 24.98 $MJm^{-2}day^{-1}$ in February and least value of 19.32 $MJm^{-2}day^{-1}$ in July.

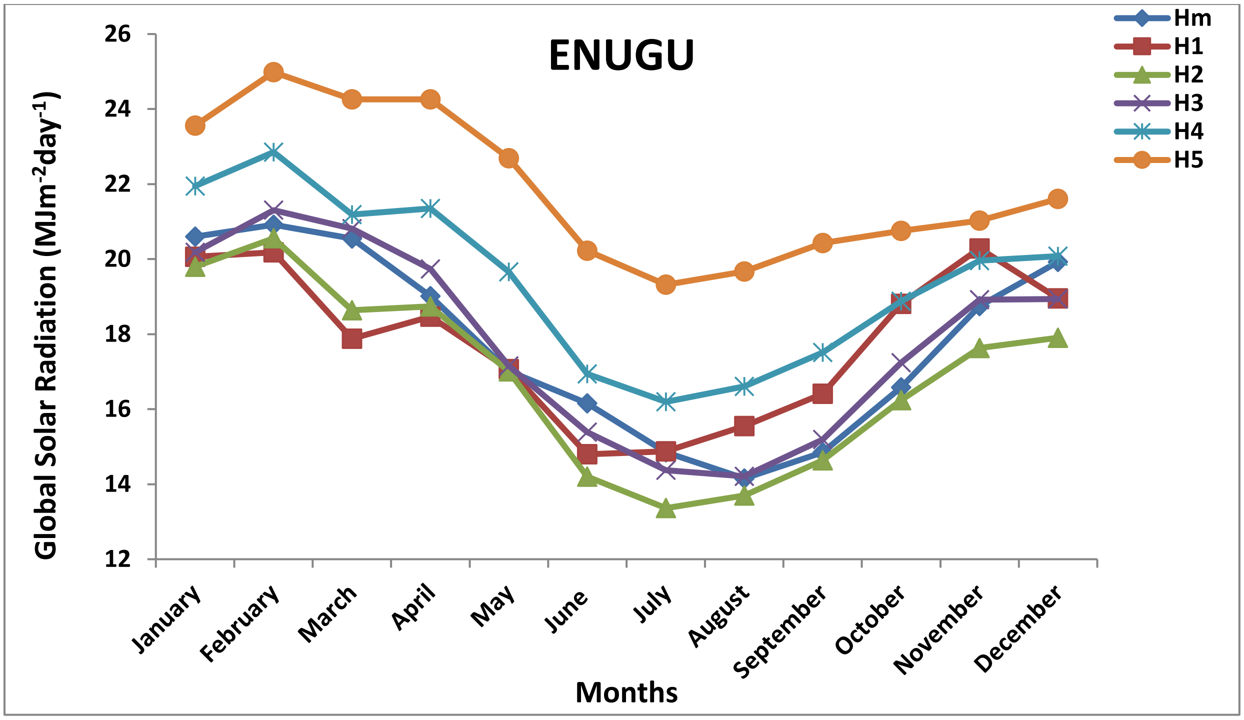

Fig. 4.2: Graph of Global Solar Radiations versus Months of the Years (2000 – 2010) for Enugu

4.1.3 Global Solar Radiation for Awka

Figure 4.3 shows the graph of monthly mean global solar radiation plotted against months of the year for Awka. The result shows that H_m has peak value of 20.92 $MJm^{-2}day^{-1}$ in February and least value of 14.15 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 22.23 $MJm^{-2}day^{-1}$ in March and least value of 14.49 $MJm^{-2}day^{-1}$ in August. H_2 has peak value of 21.95 $MJm^{-2}day^{-1}$ in February and least value of 14.54 $MJm^{-2}day^{-1}$ in July. H_3 has peak value of 21.55 $MJm^{-2}day^{-1}$ in February and least value of 14.74 $MJm^{-2}day^{-1}$ in July. H_4 has peak value of 21.61 $MJm^{-2}day^{-1}$ in February and least value of 14.34 $MJm^{-2}day^{-1}$ in July. H_5 has peak value of 21.69 $MJm^{-2}day^{-1}$ in February and least value of 14.50 $MJm^{-2}day^{-1}$ in July.

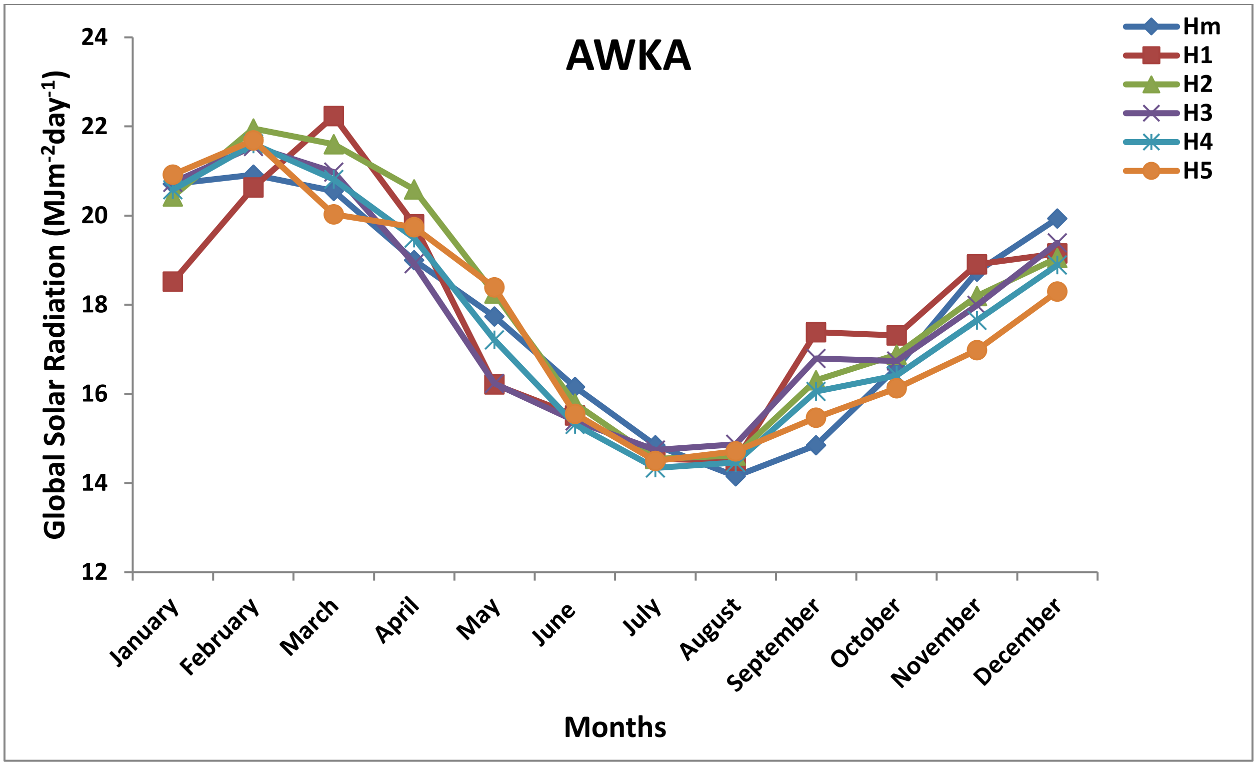

Fig. 4.3.: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Awka

4.1.4 Global Solar Radiation for Asaba

Figure 4.4 shows the graph of monthly mean global solar radiation plotted against months of the year for Asaba. The result shows that H_m has peak value of 20.17 MJm^{-2}day^{-1} in February and least value of 13.79 MJm^{-2}day^{-1} in August. H_1 has peak value of 20.75 MJm^{-2}day^{-1} in January and least value of 14.64 MJm^{-2}day^{-1} in September. H_2 has peak value of 20.42 MJm^{-2}day^{-1} in February and least value of 14.15 MJm^{-2}day^{-1} in July. H_3 has peak value of 20.57 MJm^{-2}day^{-1} in December and least value of 14.26 MJm^{-2}day^{-1} in September. H_4 has peak value of 20.38 MJm^{-2}day^{-1} in February and least value of 14.34 MJm^{-2}day^{-1} in September. H_5 has peak value of 21.18 MJm^{-2}day^{-1} in February and least value of 14.50 MJm^{-2}day^{-1} in July.

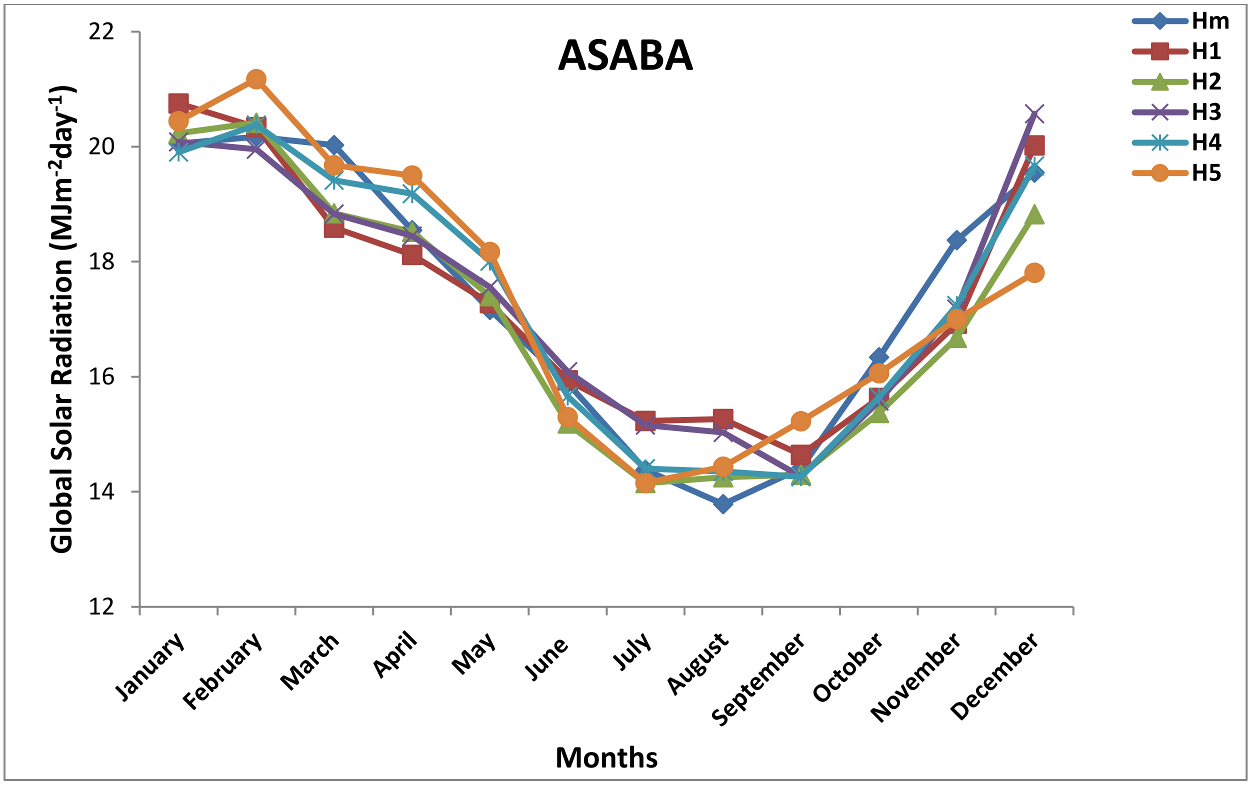

Fig. 4.4: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Asaba

4.1.5 Global Solar Radiation for Port – Harcourt

Figure 4.5 shows the graph of monthly mean global solar radiation plotted against months of the year for Port - Harcourt. The result shows that H_m has peak value of 19.49 $MJm^{-2}day^{-1}$ in February and least value of 11.47 $MJm^{-2}day^{-1}$ in July. H_1 has peak value of 18.12 $MJm^{-2}day^{-1}$ in January and least value of 11.37 $MJm^{-2}day^{-1}$ in August. H_2 has peak value of 18.18 $MJm^{-2}day^{-1}$ in February and least value of 10.78 $MJm^{-2}day^{-1}$ in August. H_3 has peak value of 20.54 $MJm^{-2}day^{-1}$ in January and least value of 12.02 $MJm^{-2}day^{-1}$ in August. H_4 has peak value of 19.80 $MJm^{-2}day^{-1}$ in January and least value of 11.41 $MJm^{-2}day^{-1}$ in

August. H_5 has peak value of 19.68 $MJm^{-2}day^{-1}$ in January and least value of 11.89 $MJm^{-2}day^{-1}$ in August.

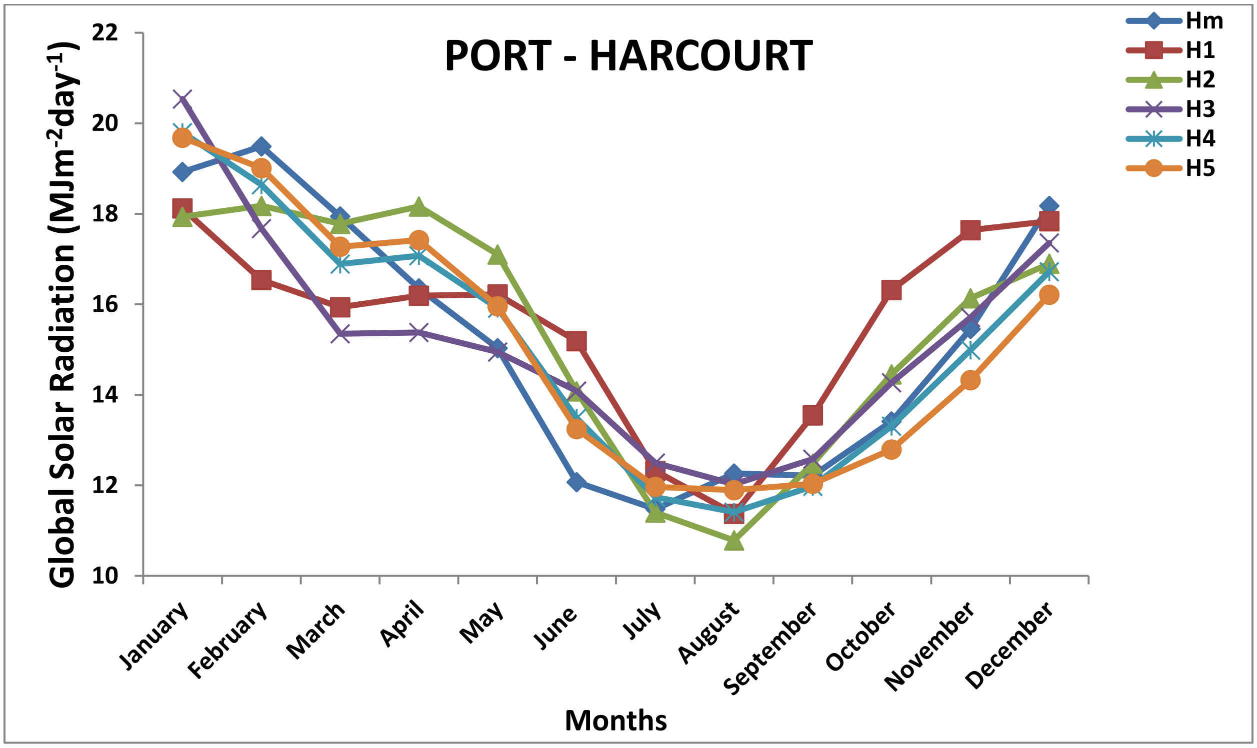

Fig. 4.5: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Port – Harcourt

4.1.6 Global Solar Radiation for Calabar

Figure 4.6 shows the graph of monthly mean global solar radiation plotted against months of the year for Calabar. The result shows that H_m has peak value of 20.40 $MJm^{-2}day^{-1}$ in February and least value of 11.31 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 19.46 $MJm^{-2}day^{-1}$ in January and least value of 10.78 $MJm^{-2}day^{-1}$ in August. H_2 has peak value of 19.45 $MJm^{-2}day^{-1}$ in January and least value of 10.87 $MJm^{-2}day^{-1}$ in August. H_3 has peak value of 21.16 $MJm^{-2}day^{-1}$ in January and least value of 11.57 $MJm^{-2}day^{-1}$ in August. H_4 has peak value of 20.77 $MJm^{-2}day^{-1}$ in January and least value of 11.27 $MJm^{-2}day^{-1}$ in August. H_5

has peak value of 20.40 $MJm^{-2}day^{-1}$ in January and least value of 11.16 $MJm^{-2}day^{-1}$ in August.

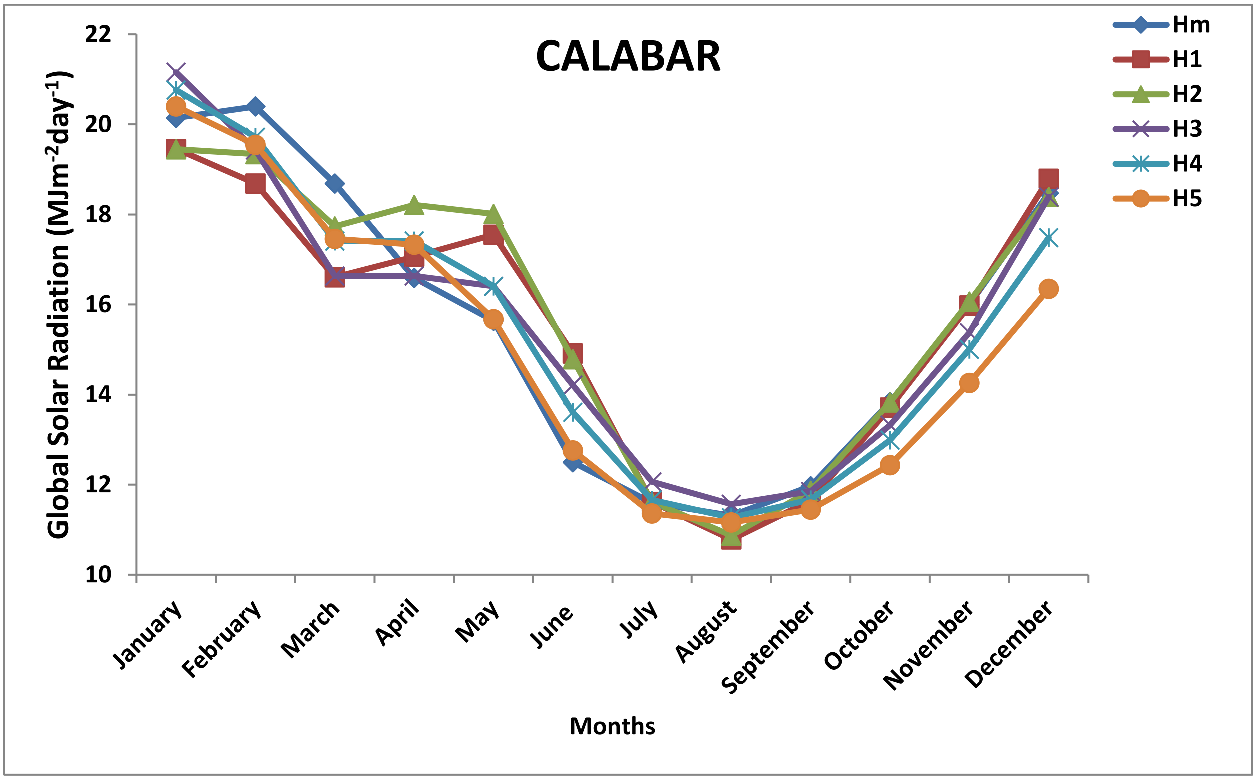

Fig. 4.6: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Calabar

4.1.7 Global Solar Radiation for Akure

Figure 4.7 shows the graph of monthly mean global solar radiation plotted against months of the year for Akure. The result shows that H_m has peak value of 20.81 $MJm^{-2}day^{-1}$ in February and least value of 13.56 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 21.70 $MJm^{-2}day^{-1}$ in March and least value of 14.14 $MJm^{-2}day^{-1}$ in August. H_2 has peak value of 20.76 $MJm^{-2}day^{-1}$ in February and least value of 13.77 $MJm^{-2}day^{-1}$ in August. H_3 has peak value of 21.83 $MJm^{-2}day^{-1}$ in January and least value of 14.66 $MJm^{-2}day^{-1}$ in August. H_4 has peak value of 20.71 $MJm^{-2}day^{-1}$ in February and least value of 13.85 $MJm^{-2}day^{-1}$ in August. H_5

has peak value of 21.60 $MJm^{-2}day^{-1}$ in February and least value of 14.22 $MJm^{-2}day^{-1}$ in August.

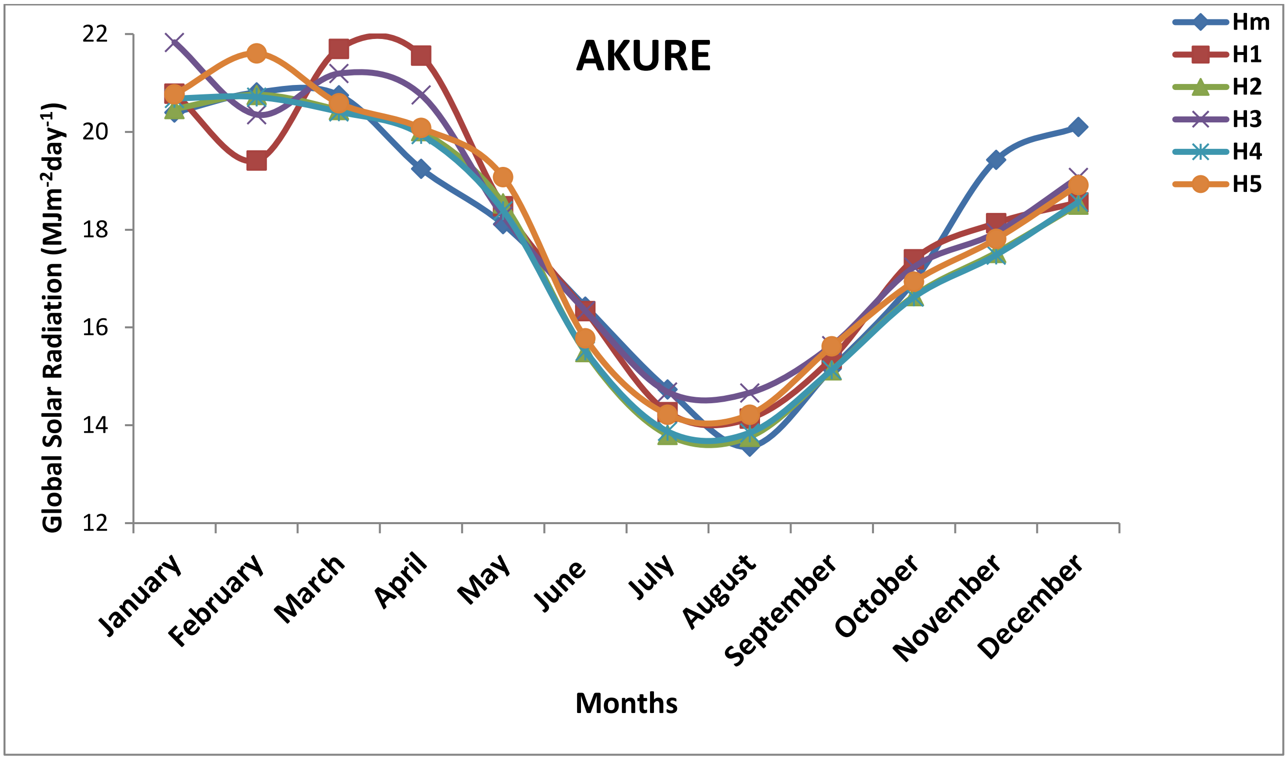

Fig. 4.7: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Akure

4.1.8 Global Solar Radiation for Ado - Ekiti

Figure 4.8 shows the graph of monthly mean global solar radiation plotted against months of the year for Ado - Ekiti. The result shows that H_m has peak value of 20.81 $MJm^{-2}day^{-1}$ in February and least value of 13.56 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 19.67 $MJm^{-2}day^{-1}$ in March and least value of 14.46 $MJm^{-2}day^{-1}$ in August. H_2 has peak value of 19.59 $MJm^{-2}day^{-1}$ in March and least value of 14.78 $MJm^{-2}day^{-1}$ in August. H_3 has peak value of 19.67 $MJm^{-2}day^{-1}$ in March and least value of 14.64 $MJm^{-2}day^{-1}$ in August. H_4 has peak value of 19.71 $MJm^{-2}day^{-1}$ in March and least value of 14.66 $MJm^{-2}day^{-1}$ in August.

H_5 has peak value of 19.75 $MJm^{-2}day^{-1}$ in February and least value of 15.20 $MJm^{-2}day^{-1}$ in July.

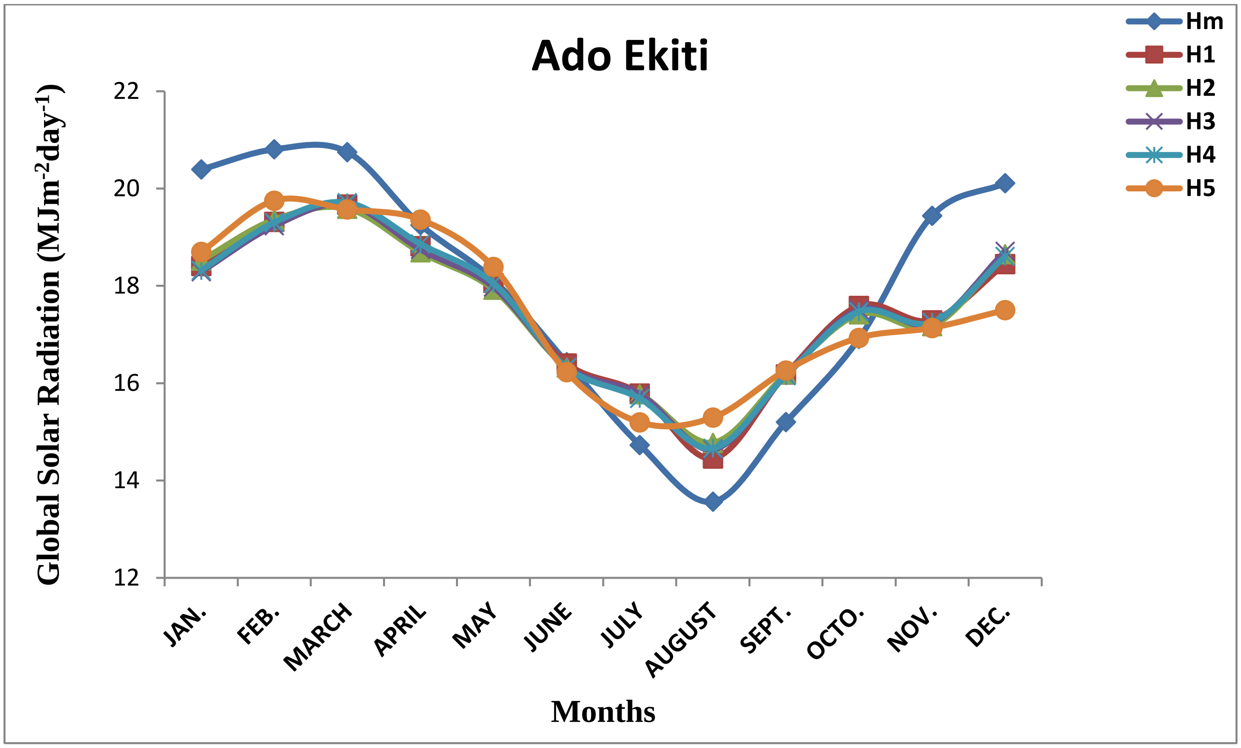

Fig. 4.8: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Ado – Ekiti

4.1.9 Global Solar Radiation for Lagos

Figure 4.9 shows the graph of monthly mean global solar radiation plotted against months of the year for Lagos. The result shows that H_m has peak value of 20.31 $MJm^{-2}day^{-1}$ in February and least value of 14.33 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 21.80 $MJm^{-2}day^{-1}$ in February and least value of 13.71 $MJm^{-2}day^{-1}$ in August. H_2 has peak value of 21.54 $MJm^{-2}day^{-1}$ in February and least value of 13.53 $MJm^{-2}day^{-1}$ in August. H_3 has peak value of 21.73 $MJm^{-2}day^{-1}$ in January and least value of 13.95 $MJm^{-2}day^{-1}$ in August. H_4 has peak value of 21.44 $MJm^{-2}day^{-1}$ in February and least value of 13.78 $MJm^{-2}day^{-1}$ in

August. H_5 has peak value of 20.22 $MJm^{-2}day^{-1}$ in February and least value of 14.22 $MJm^{-2}day^{-1}$ in August.

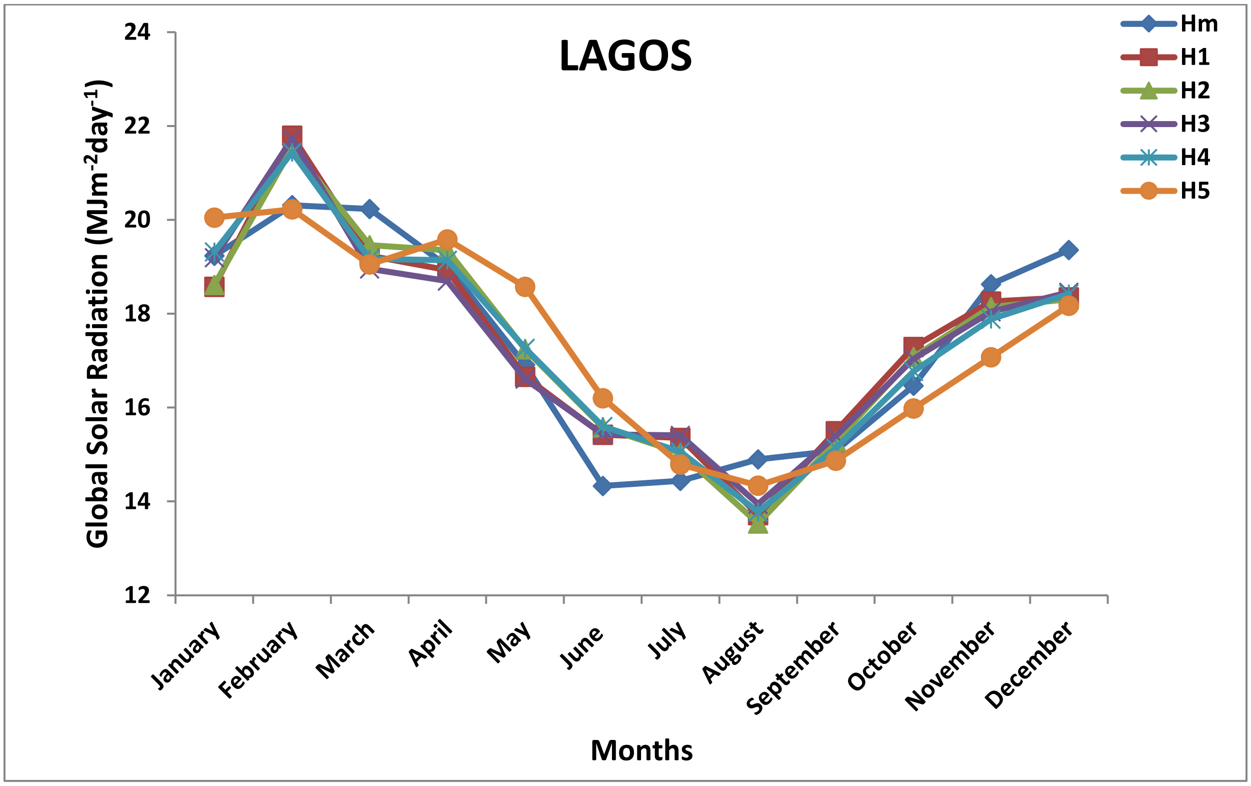

Fig. 4.9: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Lagos

4.1.10 Global Solar Radiation for Ilorin

Figure 4.10 shows the graph of monthly mean global solar radiation plotted against months of the year for Ilorin. The result shows that H_m has peak value of 22.12 $MJm^{-2}day^{-1}$ in March and least value of 13.95 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 22.02 $MJm^{-2}day^{-1}$ in March and least value of 14.49 $MJm^{-2}day^{-1}$ in August. H_2 has peak value of 22.06 $MJm^{-2}day^{-1}$ in February and least value of 14.60 $MJm^{-2}day^{-1}$ in August. H_3 has peak value of 21.89 $MJm^{-2}day^{-1}$ in February and least value of 14.78 $MJm^{-2}day^{-1}$ in August. H_4 has peak value of 22.07 $MJm^{-2}day^{-1}$ in March and least value of 14.53 $MJm^{-2}day^{-1}$ in August.

H_5 has peak value of 22.16 MJm^{-2}day^{-1} in March and least value of 14.62 MJm^{-2}day^{-1} in August.

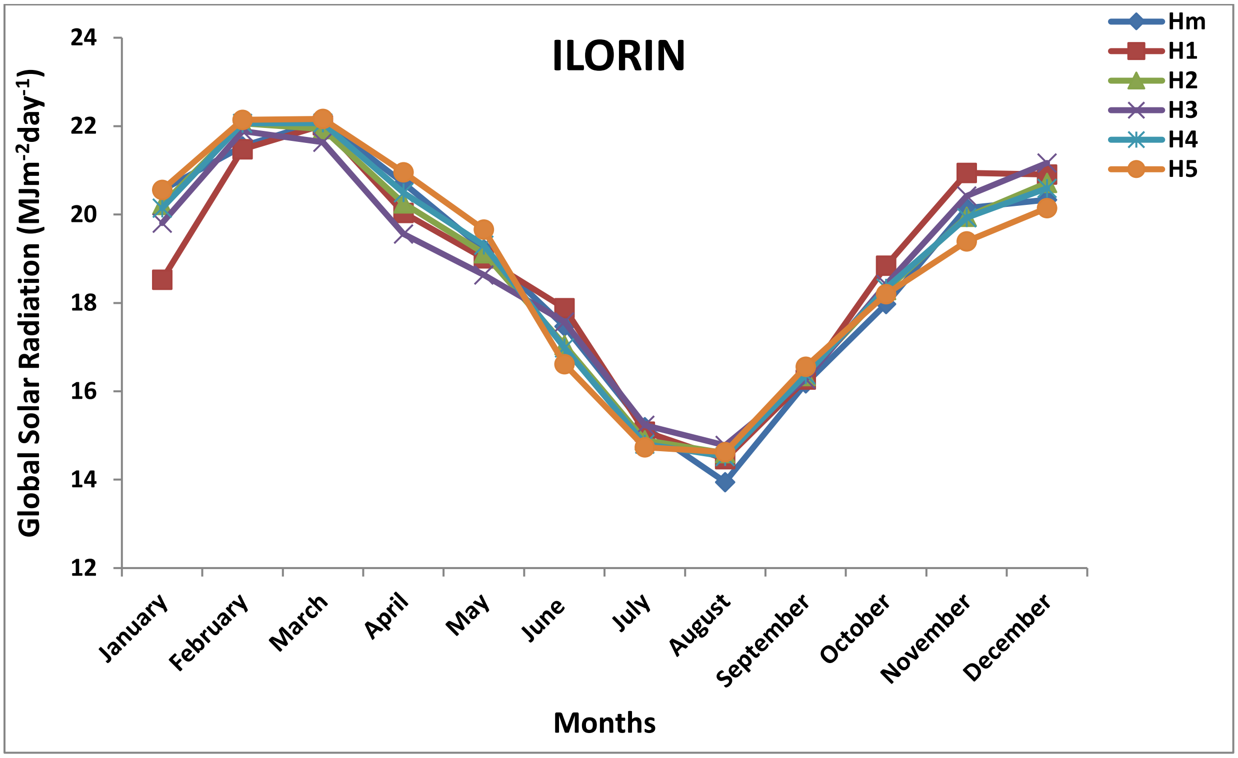

Fig. 4.10: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Ilorin

4.1.11 Global Solar Radiation for Abuja

Figure 4.11 shows the graph of monthly mean global solar radiation plotted against months of the year for Abuja. The result shows that H_m has peak value of 23.25 MJm^{-2}day^{-1} in March and least value of 14.75 MJm^{-2}day^{-1} in August. H_1 has peak value of 24.18 MJm^{-2}day^{-1} in February and least value of 15.02 MJm^{-2}day^{-1} in August. H_2 has peak value of 23.92 MJm^{-2}day^{-1} in February and least value of 15.96 MJm^{-2}day^{-1} in August. H_3 has peak value of 25.87 MJm^{-2}day^{-1} in February and least value of 15.47 MJm^{-2}day^{-1} in August. H_4 has peak value of 24.22 MJm^{-2}day^{-1} in March and least value of 15.80 MJm^{-2}day^{-1} in July.

H_5 has peak value of 24.16 $MJm^{-2}day^{-1}$ in March and least value of 15.74 $MJm^{-2}day^{-1}$ in August.

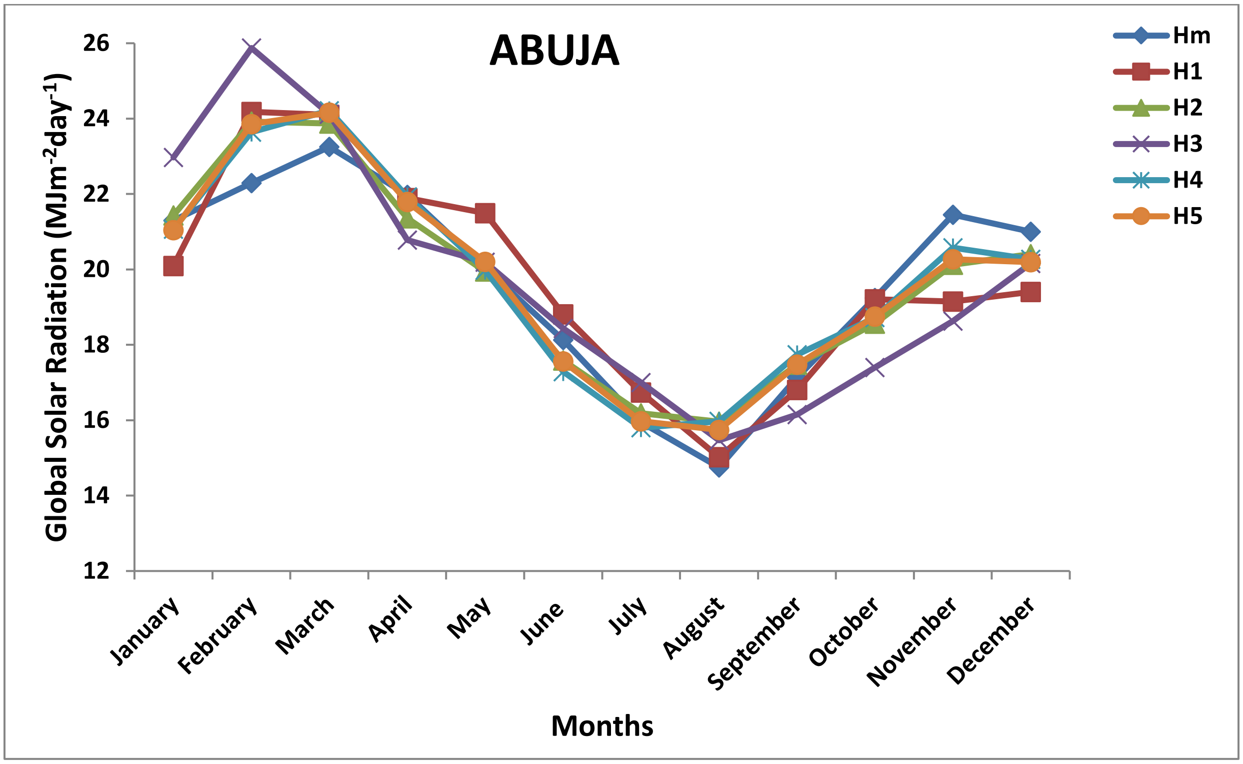

Fig. 4.11: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Abuja

4.1.12 Global Solar Radiation for Minna

Figure 4.12 shows the graph of monthly mean global solar radiation plotted against months of the year for Minna. The result shows that H_m has peak value of 23.15 $MJm^{-2}day^{-1}$ in March and least value of 15.50 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 21.44 $MJm^{-2}day^{-1}$ in March and least value of 16.78 $MJm^{-2}day^{-1}$ in August. H_2 has peak value of 22.84 $MJm^{-2}day^{-1}$ in March and least value of 16.38 $MJm^{-2}day^{-1}$ in August. H_3 has peak value of 21.99 $MJm^{-2}day^{-1}$ in February and least value of 16.94 $MJm^{-2}day^{-1}$ in August. H_4 has peak value of 23.30 $MJm^{-2}day^{-1}$ in March and least value of 16.15 $MJm^{-2}day^{-1}$ in August. H_5 has peak value of 23.90 $MJm^{-2}day^{-1}$ in March and least value of 16.34 $MJm^{-2}day^{-1}$ in August.

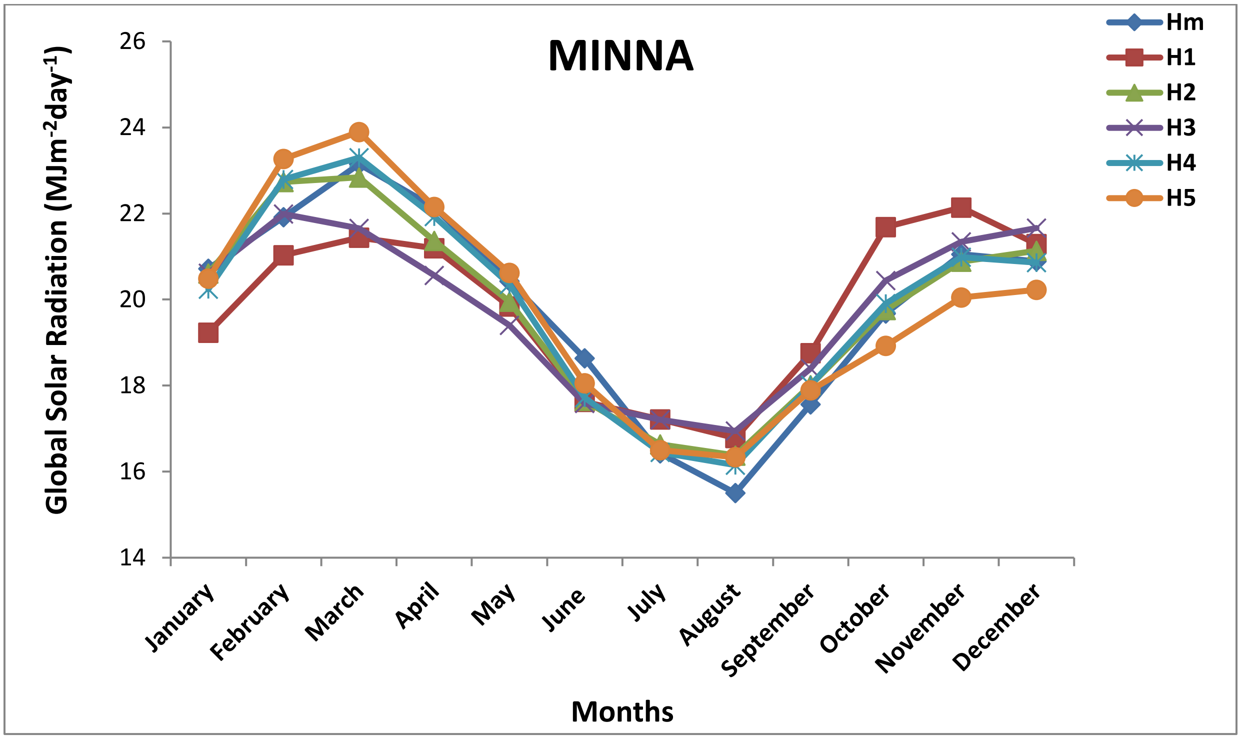

Fig. 4.12: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Minna

4.1.13 Global Solar Radiation for Yola

Figure 4.13 shows the graph of monthly mean global solar radiation plotted against months of the year for Yola. The result shows that H_m has peak value of 23.77 $MJm^{-2}day^{-1}$ in March and least value of 16.98 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 22.91 $MJm^{-2}day^{-1}$ in March and least value of 17.88 $MJm^{-2}day^{-1}$ in September. H_2 has peak value of 24.02 $MJm^{-2}day^{-1}$ in March and least value of 18.04 $MJm^{-2}day^{-1}$ in August. H_3 has peak value of 23.26 $MJm^{-2}day^{-1}$ in March and least value of 18.10 $MJm^{-2}day^{-1}$ in September. H_4 has peak value of 23.91 $MJm^{-2}day^{-1}$ in March and least value of 17.98 $MJm^{-2}day^{-1}$ in August. H_5 has peak value of 24.94 $MJm^{-2}day^{-1}$ in March and least value of 18.51 $MJm^{-2}day^{-1}$ in July.

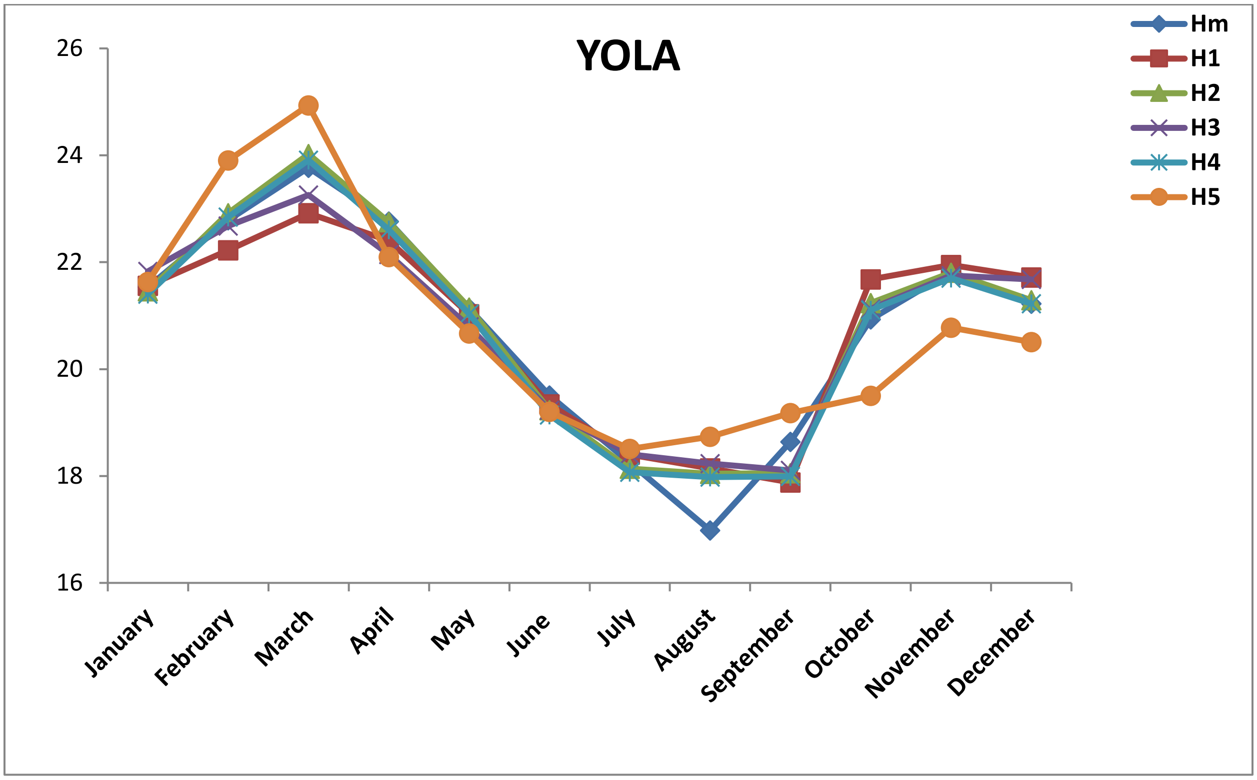

Fig. 4.13: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Yola

4.1.14 Global Solar Radiation for Gombe

Figure 4.14 shows the graph of monthly mean global solar radiation plotted against months of the year for Gombe. The result shows that H_m has peak value of 23.86 $MJm^{-2}day^{-1}$ in March and least value of 17.59 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 23.72 $MJm^{-2}day^{-1}$ in March and least value of 17.97 $MJm^{-2}day^{-1}$ in July. H_2 has peak value of 23.72 $MJm^{-2}day^{-1}$ in March and least value of 17.98 $MJm^{-2}day^{-1}$ in July and August. H_3 has peak value of 23.46 $MJm^{-2}day^{-1}$ in March and least value of 18.18 $MJm^{-2}day^{-1}$ in July. H_4 has peak value of 23.64 $MJm^{-2}day^{-1}$ in March and least value of 17.58 $MJm^{-2}day^{-1}$ in August. H_5 has peak value of 25.06 $MJm^{-2}day^{-1}$ in March and least value of 19.05 $MJm^{-2}day^{-1}$ in August.

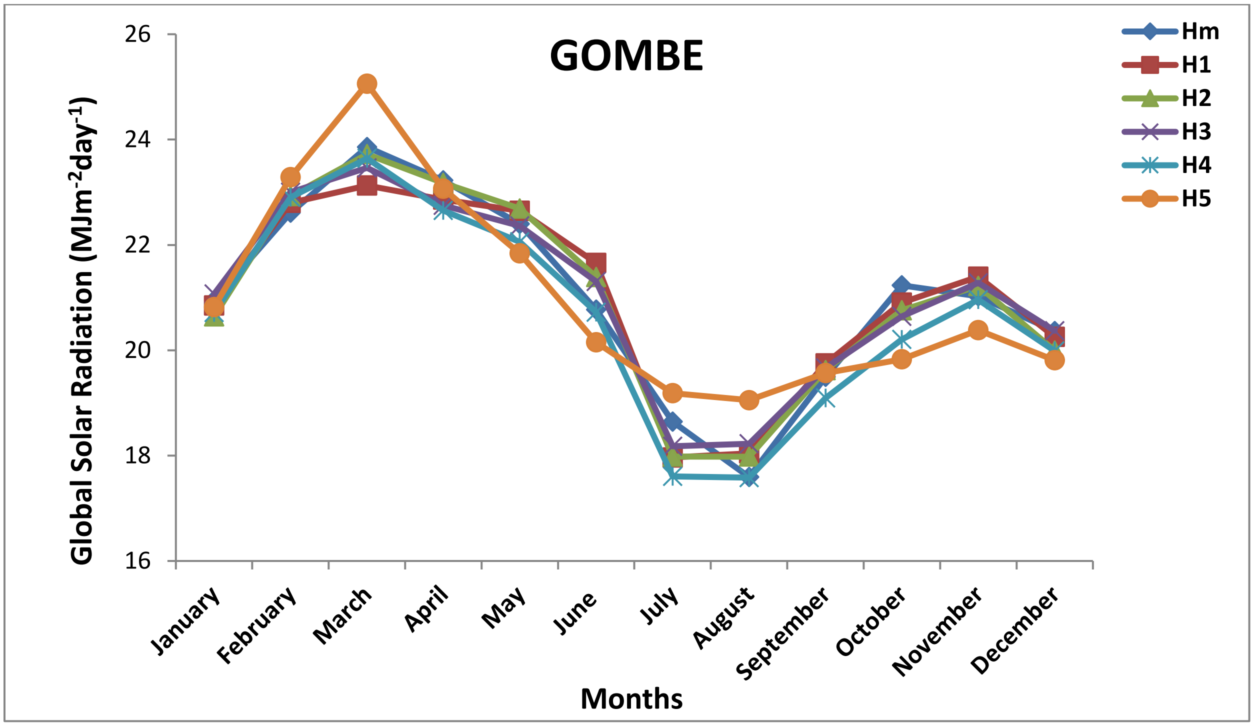

Fig. 4.14: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Gombe

4.1.15 Global Solar Radiation for Maiduguri

Figure 4.15 shows the graph of monthly mean global solar radiation plotted against months of the year for Maiduguri. The result shows that H_m has peak value of 24.47 $MJm^{-2}day^{-1}$ in March and least value of 17.95 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 22.71 $MJm^{-2}day^{-1}$ in March and least value of 18.98 $MJm^{-2}day^{-1}$ in July. H_2 has peak value of 24.22 $MJm^{-2}day^{-1}$ in March and least value of 18.41 $MJm^{-2}day^{-1}$ in August. H_3 has peak value of 24.57 $MJm^{-2}day^{-1}$ in March and least value of 19.10 $MJm^{-2}day^{-1}$ in August. H_4 has peak value of 24.65 $MJm^{-2}day^{-1}$ in March and least value of 18.53 $MJm^{-2}day^{-1}$ in August. H_5 has peak value of 25.38 $MJm^{-2}day^{-1}$ in March and least value of 18.94 $MJm^{-2}day^{-1}$ in July.

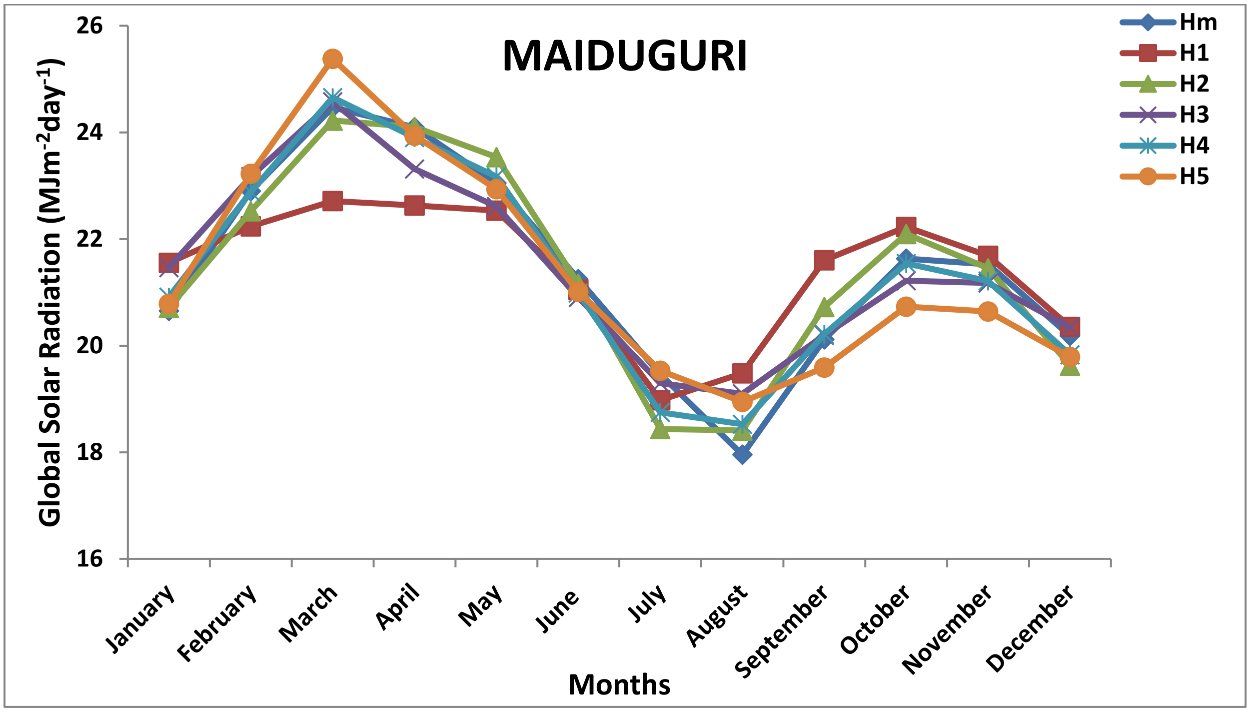

Fig. 4.15: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Maiduguri

4.1.16 Global Solar Radiation for Birnin Kebbi

Figure 4.16 shows the graph of monthly mean global solar radiation plotted against months of the year for Birnin Kebbi. The result shows that H_m has peak value of 24.53 $MJm^{-2}day^{-1}$ in April and least value of 18.43 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 23.89 $MJm^{-2}day^{-1}$ in April and least value of 19.71 $MJm^{-2}day^{-1}$ in August. H_2 has peak value of 24.20 $MJm^{-2}day^{-1}$ in April and least value of 18.59 $MJm^{-2}day^{-1}$ in August. H_3 has peak value of 23.80 $MJm^{-2}day^{-1}$ in April and least value of 19.88 $MJm^{-2}day^{-1}$ in August. H_4 has peak value of 25.01 $MJm^{-2}day^{-1}$ in April and least value of 19.81 $MJm^{-2}day^{-1}$ in August. H_5 has peak value of 25.12 $MJm^{-2}day^{-1}$ in March and least value of 20.02 $MJm^{-2}day^{-1}$ in July.

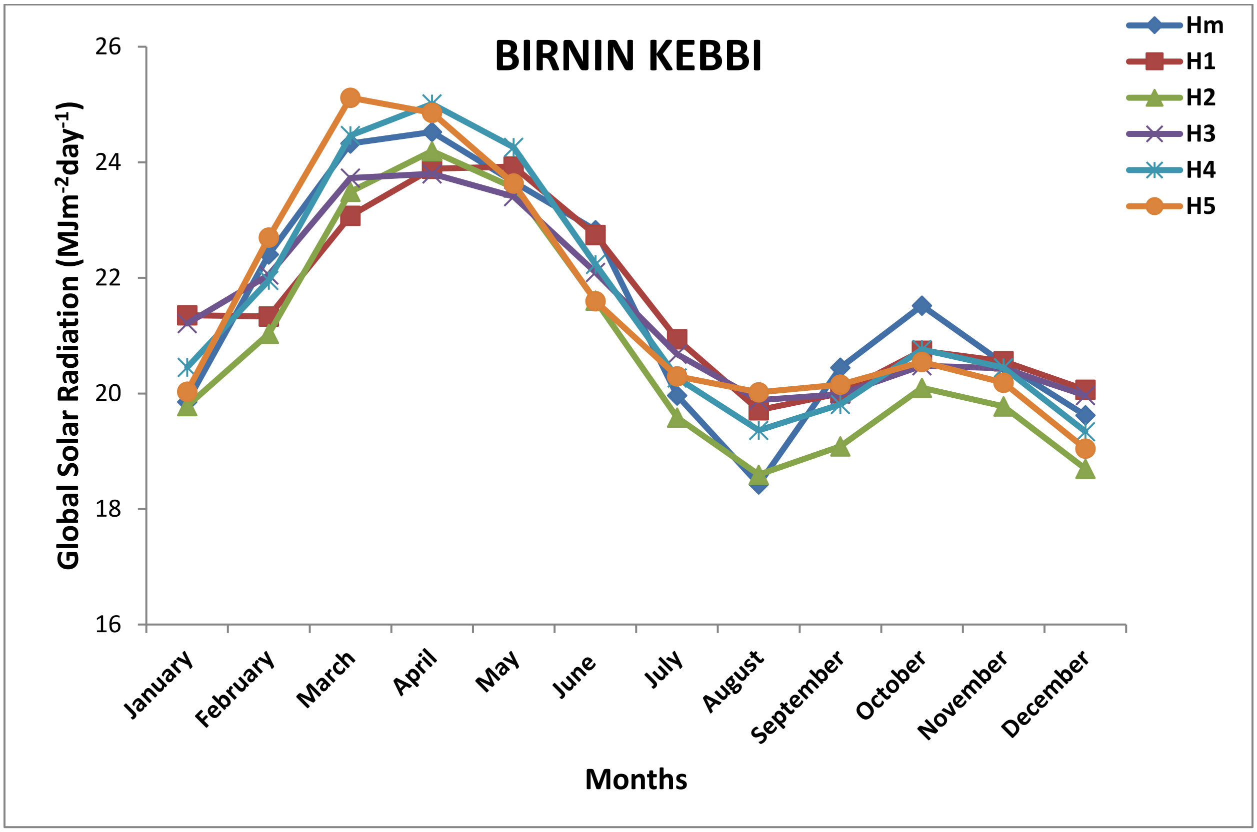

Fig. 4.16: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Brinin- Kebbi.

4.1.17 Global Solar Radiation for Gusau

Figure 4.17 shows the graph of monthly mean global solar radiation plotted against months of the year for Gusau. The result shows that H_m has peak value of 24.82 $MJm^{-2}day^{-1}$ in April and least value of 18.53 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 24.27 $MJm^{-2}day^{-1}$ in March and least value of 19.65 $MJm^{-2}day^{-1}$ in December. H_2 has peak value of 25.47 $MJm^{-2}day^{-1}$ in March and least value of 19.30 $MJm^{-2}day^{-1}$ in December. H_3 has peak value of 24.54 $MJm^{-2}day^{-1}$ in March and least value of 19.84 $MJm^{-2}day^{-1}$ in December. H_4

has peak value of 25.33 $MJm^{-2}day^{-1}$ in March and least value of 19.27 $MJm^{-2}day^{-1}$ in December. H_5 has peak value of 25.48 $MJm^{-2}day^{-1}$ in March and least value of 19.23 $MJm^{-2}day^{-1}$ in December

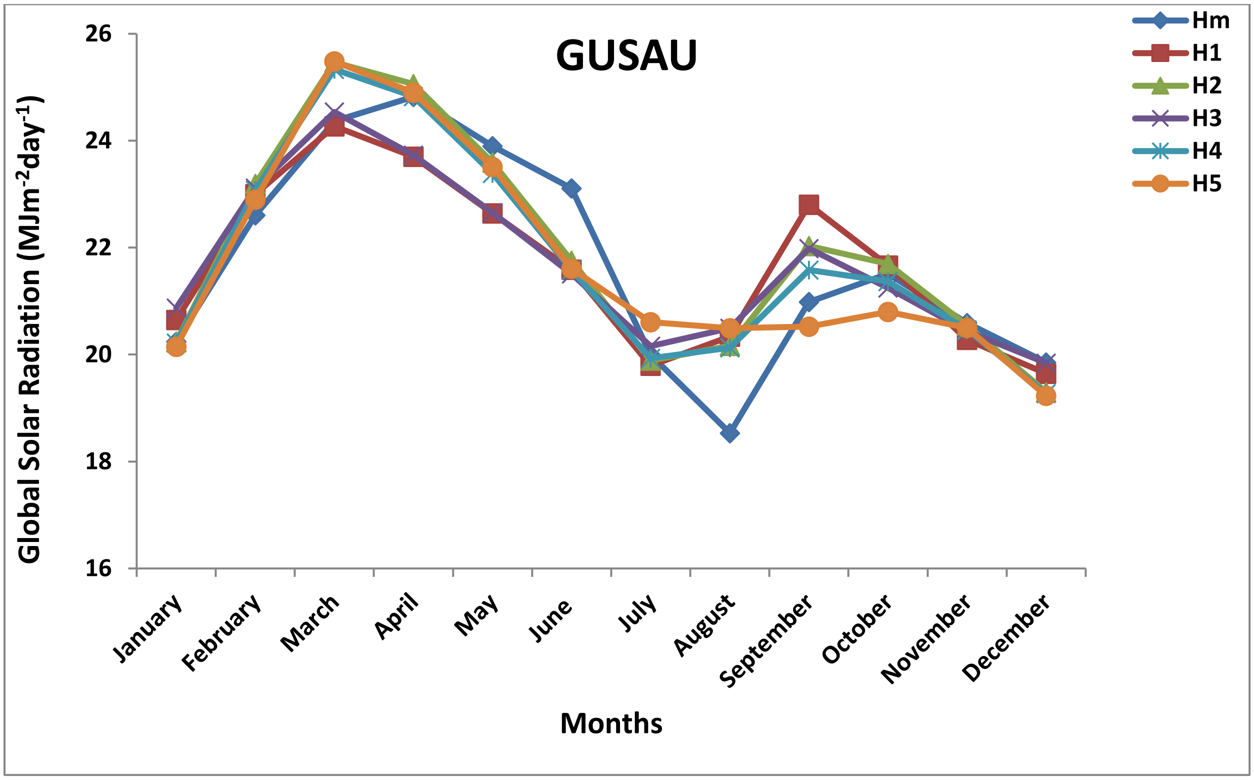

Fig. 4.17: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Gusau.

4.1.18 Global Solar Radiation for Kano

Figure 4.18 shows the graph of monthly mean global solar radiation plotted against months of the year for Kano. The result shows that H_m has peak value of 25.35 $MJm^{-2}day^{-1}$ in April and least value of 19.21 $MJm^{-2}day^{-1}$ in August. H_1 has peak value of 24.48 $MJm^{-2}day^{-1}$ in March and least value of 20.24 $MJm^{-2}day^{-1}$ in August. H_2 has peak value of 25.36 $MJm^{-2}day^{-1}$ in April and least value of 19.77 $MJm^{-2}day^{-1}$ in December. H_3 has peak value of

24.51 $MJm^{-2}day^{-1}$ in March and least value of 20.34 $MJm^{-2}day^{-1}$ in December. H_4 has peak value of 25.26 $MJm^{-2}day^{-1}$ in April and least value of 19.70 $MJm^{-2}day^{-1}$ in December. H_5 has peak value of 25.70 $MJm^{-2}day^{-1}$ in March and least value of 19.39 $MJm^{-2}day^{-1}$ in December.

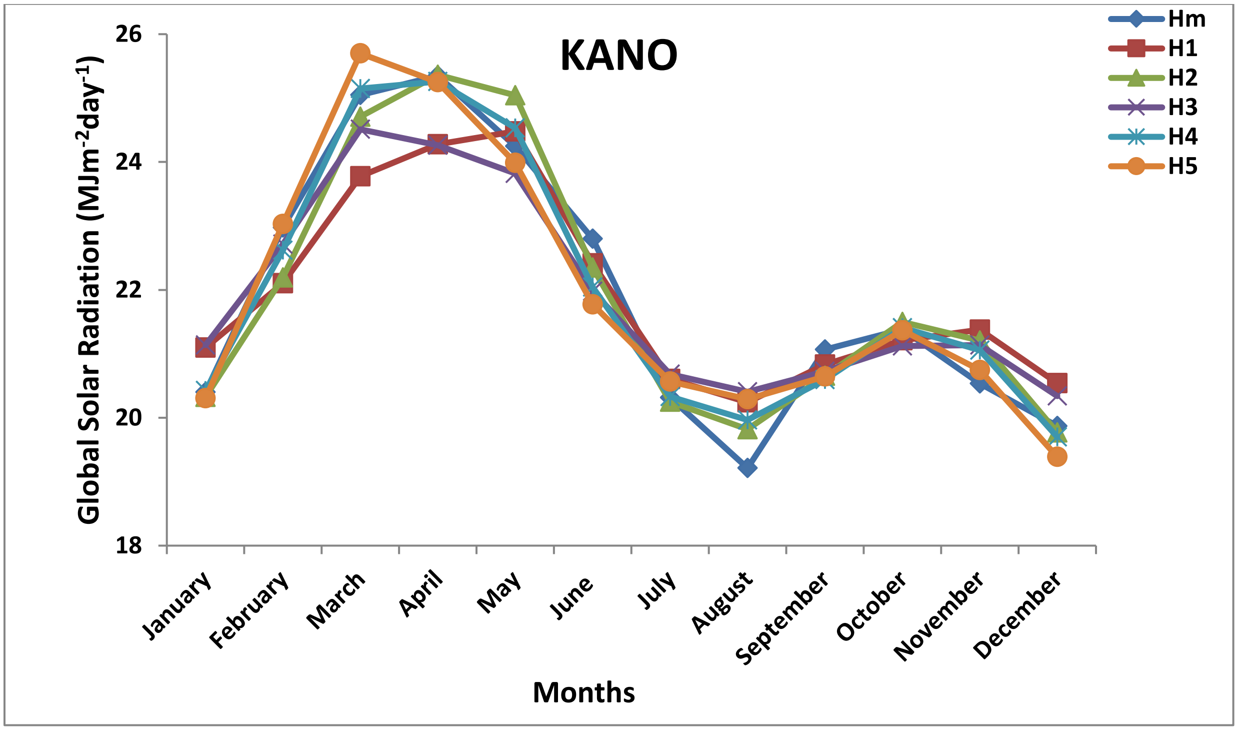

Fig. 4.18: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Kano

4.2 Error Analysis of the Estimated Global Solar Radiation

Statistical error analysis was carried out on estimated global solar radiation obtained using the developed models. The error analysis carried out were Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE) and t – stat (t – test). The results of the error analysis were presented in table 4.1 to table 4.6.

Table 4.1 presents the statistical error values of the empirical equations developed for Awka, Owerri and Enugu cities in south eastern Nigeria. Among the three cities studied in the south east, Enugu has the best set of empirical equation based on the values of statistical error indictors used for the evaluation as shown in table 4.19 above. Owerri has the worst result among the cities. According to t – stat results of the cities; estimated global radiation was overestimated with $H_1 = H_0\left(0.251 + 0.616\left(\frac{\bar{n}}{\bar{N}}\right)\right)$ being overestimated more than other empirical equations developed for Owerri. Awka has estimated global solar radiations which correlate with the measured global solar radiation. The best empirical equation for estimating global solar radiation Awka is $H_3 = H_0\left(0.662 + 0.420\left(\frac{\bar{n}}{\bar{N}}\right) - 0.443\left(\frac{RH}{100}\right)\right)$ with t – stat value of 0.050 while the worst empirical equation is $H_2 = H_0\left(-0.717 + 0.229\left(\frac{\bar{n}}{\bar{N}}\right) + 0.039(\bar{T}_{max})\right)$ with t – stat value of 1.4. Enugu has estimated global solar radiation values that correlate well with the measured global solar radiation obtained from NASA. The two empirical models developed for Enugu $H_1 = H_0\left(0.195 + 0.787\left(\frac{\bar{n}}{\bar{N}}\right)\right)$ and $H_3 = H_0\left(-0.0296 + 0.282\left(\frac{\bar{n}}{\bar{N}}\right) + 2.355\left(\frac{RH}{100}\right)\right)$ performed well considering the low values of their t – stat which are 0.0045 and 0.0425. $H_1 = H_0\left(0.195 + 0.787\left(\frac{\bar{n}}{\bar{N}}\right)\right)$ gives the best correlation for Enugu while $H_5 = H_0\left(-0.0.864 + 0.0463(\bar{T}_{max}) - 0.181\left(\frac{\overline{RH}}{100}\right)\right)$ gives the worst correlation with t – stat value of 10.96.

Table 4.1: Statistical Error Values of the Modeled Empirical Equations for South Eastern Cities

CITIES	SOUTH EAST ZONE					
OWERRI	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	1.964721	1.921624	1.951574	1.964548	1.951791
	RMSE	2.283303	2.239857	2.293584	2.295483	2.390249
	MPE	-12.8165	-12.5464	-12.7433	-12.7969	-12.8281
	t-stat	5.601356	5.538195	5.371745	5.487583	4.691576
AWKA	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	0.044511	0.335494	0.012804	-0.11314	-0.14963
	RMSE	1.254576	0.85558	0.84848	0.702286	0.868922
	MPE	-0.56126	-1.9321	-0.2702	0.573145	0.725326
	t-stat	0.117743	1.413754	0.050053	0.541394	0.579807
ENUGU	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	-0.0019	-0.91174	0.006732	1.652304	4.117707
	RMSE	1.377858	1.163203	0.525573	1.843632	4.303561
	MPE	-0.60064	5.108441	-0.02746	-9.75862	-24.1947
	t-stat	0.004578	4.18622	0.042488	6.700617	10.91633

Table 4.2 gives the statistical error values of the empirical modeled equations developed for Asaba, Calabar and Port – Harcourt in south southern zone of Nigeria. From the values of their t – stat, the best proposed empirical equation among the five equations for Asaba is $H_1 = H_0\left(0.214 + 0.822\left(\frac{\bar{n}}{\bar{N}}\right)\right)$ with a t – stat values of 0.0126 while $H_2 = H_0\left(-0.428 + 0.491\left(\frac{\bar{n}}{\bar{N}}\right) + 0.026(\bar{T}_{max})\right)$ with t – stat value of 1.940 is the most undesirable empirical equation. Calabar has estimated global solar radiations which correlate with the measured global solar radiation. The best performed empirical equation for the estimation of mean global solar radiation in Calabar is $H_3 = H_0\left(1.633 + 0.645\left(\frac{\bar{n}}{\bar{N}}\right) - 1.668\left(\frac{RH}{100}\right)\right)$ with t – stat value of 0.0327 while the worst performed

empirical equation for Calabar is $H_5 = H_0\left(0.833 + 0.0530(\bar{T}_{max}) - 2.178\left(\frac{\overline{RH}}{100}\right)\right)$ with t – stat of 2.249. The estimated global solar radiation for Port – Harcourt obtained using developed empirical equations correlate well with the measured global solar radiation obtained from the archives of NASA. The best performed empirical equation is $H_3 = H_0\left(2.119 + 0.49\left(\frac{\bar{n}}{\bar{N}}\right) - 2.245\left(\frac{RH}{100}\right)\right)$ which has t – stat value of 0.083 while the worst is $H_1 = H_0\left(0.120 + 0.801\left(\frac{\bar{n}}{\bar{N}}\right)\right)$ with a t – stat value of 0.671.

Table 4.2: Statistical Error Values of the Modeled Empirical Equations for South Southern Cities

Cities	**SOUTH SOUTH ZONE**					
ASABA	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	0.003213	-0.37635	0.004206	-0.04768	0.021174
	RMSE	0.846361	0.745404	0.760537	0.558329	0.897895
	MPE	-0.35492	2.069262	-0.30052	0.202473	-0.26303
	t-stat	0.012591	1.939963	0.018344	0.284276	0.078233
PORT - HARCOURT	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	0.367495	0.215124	-0.03261	-0.07209	-0.08269
	RMSE	1.852365	1.284299	1.302841	0.869329	0.938249
	MPE	-3.92186	-1.93667	-0.70656	0.169114	0.2228
	t-stat	0.671337	0.563506	0.083048	0.275995	0.293442
CALABAR	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	-0.02849	0.252389	-0.00928	-0.14549	-0.57864
	RMSE	1.222328	1.161431	0.942068	0.803862	1.03107
	MPE	-0.41154	-2.07251	-0.44505	0.696195	3.565734
	t-stat	0.077322	0.738376	0.032656	0.610335	2.248798

Table 4.3 presents the statistical error indictors and their numerical values for the developed empirical equations for the three cities of Ado – Ekiti, Lagos and Akure in south western Nigeria. For Ado – Ekiti, the t –stat values for the developed empirical equations indicate that the global solar radiation obtained using these empirical equations are in line

with the measured global solar radiation. $H_5 = H_0\left(0.0388 + 0.00613(\bar{T}_{max}) - 0.657\left(\frac{\overline{RH}}{100}\right)\right)$ with t – stat of 1.166 gives the best correlation with the measure global solar radiation while $H_3 = H_0\left(0.163 + 0.731\left(\frac{\bar{n}}{\bar{N}}\right)0.0528\left(\frac{RH}{100}\right)\right)$ with t – stat of 1.286 gives the worst result. Our developed empirical equations for estimating global solar radiation at Akure give good results. The t – stat results of the five models developed suggested that all the developed empirical equations can be used to estimate global solar radiation at Akure. The empirical equation $H_5 = H_0\left(-1.106 + 0.0567(\bar{T}_{max}) + 0.00493\left(\frac{\overline{RH}}{100}\right)\right)$ with t – stat value of 0.0232 performed best while $H_2 = H_0\left(-0.834 + 0.186\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0444(\bar{T}_{max})\right)$ with a t – stat value of 1.633 is the worst empirical equation. All the developed empirical equations for Lagos performed very well when compared the t – stat values of all the five equations developed. All the five developed equations for Lagos can be used to estimate global solar radiation. Among the empirical equations developed for Lagos, $H_5 = H_0\left(-0.040 + 0.0490(\bar{T}_{max}) - 0.982\left(\frac{\overline{RH}}{100}\right)\right)$ with a t – stat value of 0.00259 is the best while $H_2 = H_0\left(-0.181 + 0.623\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0153(\bar{T}_{max})\right)$ with a t – stat value of 0.0861 is the worst. This result shows that using maximum temperature and relative humidity for estimation of global solar radiation in south western Nigeria give optimum result compared to other empirical equations for each city studied.

Table 4.3: Statistical Error Values of the Modeled Empirical Equations for South Western Cities

Cities	SOUTH WEST ZONE					
ADO - EKITI	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	-0.43999	-0.44271	-0.45132	-0.44153	-0.4483737
	RMSE	1.231741	1.23701	1.24874	1.232247	1.352342
	MPE	1.66372	1.644074	1.702952	1.66367	1.66642852
	t-stat	1.268416	1.271175	1.285604	1.272915	1.165567
AKURE	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	0.038016	-0.37967	0.191472	-0.37419	-0.00562
	RMSE	1.053068	0.859393	0.893927	0.850088	0.804685
	MPE	-0.3346	2.09183	-1.24885	2.045638	-0.05101
	t-stat	0.11981	1.633294	0.727274	1.625872	0.023179
LAGOS	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	0.01426	0.021517	0.000914	0.007189	0.000819
	RMSE	0.872673	0.829101	0.841137	0.78266	1.048484
	MPE	-0.29637	-0.28415	-0.2365	-0.21399	-0.31167
	t-stat	0.054202	0.086102	0.003605	0.030467	0.00259

Table 4.4 presents the statistical error values of the developed empirical equation for the estimation of mean global solar radiation for Ilorin, Minna and Abuja in north central zone of Nigeria. All the developed empirical equation for estimating global solar radiation in Ilorin performed well. The t – stat values of 0.00148 and 0.212 for $H_3 = H_0\left(0.434 + 0.488\left(\frac{\bar{n}}{\bar{N}}\right) - 0.189\left(\frac{RH}{100}\right)\right)$ and $H_5 = H_0\left(-1.378 + 0.0608(\bar{T}_{max}) + 0.190\left(\frac{\overline{RH}}{100}\right)\right)$ respectively clearly indicated that H_3 performed best while H_5 is the worst empirical equation for Ilorin. The five empirical equations developed for estimating global solar radiation at Minna are good according to their t – stat values. $H_1 = H_0\left(0.264 + 0.558\left(\frac{\bar{n}}{\bar{N}}\right)\right)$ with t – stat value of 0.281 gives estimated global solar radiation

values that closely correlate with the measured global solar radiation from NASA while $H_4 = H_0\left(-0.652 + 0.204\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0341(\bar{T}_{max}) + 0.120\left(\frac{\overline{RH}}{100}\right)\right)$ with a t - stat value of 0.351 is the worst performed empirical equation developed for Minna. In Abuja, all the five empirical equations developed are all good for the estimation of global solar radiation. $H_1 = H_0\left(0.178 + 0.772\left(\frac{\bar{n}}{\bar{N}}\right)\right)$ with t – stat value of 0.0882 performed best while $H_4 = H_0\left(-1.247 - 0.215\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0620(\bar{T}_{max}) + 0.163\left(\frac{\overline{RH}}{100}\right)\right)$ with a t – stat value of 0.247 is the worst empirical equation developed for Abuja.

Table 4.4: Statistical Error Values of the Modeled Empirical Equations for North central Cities

CITIES	**NORTH CENTRAL ZONE**					
ILORIN	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	0.007317	0.005061	0.000264	0.020557	0.030834
	RMSE	0.751961	0.370273	0.594114	0.353077	0.483826
	MPE	-0.21953	-0.10947	-0.21073	-0.15849	-0.20031
	t-stat	0.032273	0.045339	0.001476	0.193429	0.211795
MINNA	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	0.010157	-0.01357	-0.02469	0.04881	0.025291
	RMSE	1.197865	0.554235	0.981031	0.463901	0.686713
	MPE	-0.49257	-0.07667	-0.27966	-0.30223	-0.17256
	t-stat	0.028125	0.081203	0.083513	0.350911	0.122229
ABUJA	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	0.031585	0.024951	0.05359	0.056601	0.041092
	RMSE	1.187911	0.813378	1.648229	0.761026	0.769891
	MPE	-0.28515	-0.28104	-0.29398	-0.37814	-0.28956
	t-stat	0.088216	0.101787	0.107893	0.247357	0.177275

Table 4.5 presents the statistical error values of the developed empirical equations for the north eastern zone of Nigeria. After from the 4th empirical equation developed, all other empirical equations developed for estimating global solar radiation at Gombe performed well. $H_5 = H_0\left(0.431 + 0.0077(\bar{T}_{max}) - 0.163\left(\frac{\overline{RH}}{100}\right)\right)$ with a t – stat value of 0.0361 performed best while $H_4 = H_0\left(0.270 + 0.382\left(\frac{\bar{n}}{\bar{N}}\right) + 0.00315(\bar{T}_{max}) - 0.0384\left(\frac{\overline{RH}}{100}\right)\right)$ with a t – stat value of 2.950 performed worst. All the empirical equations developed for estimation of global solar radiation at Maiduguri performed well. $H_3 = H_0\left(0.577 + 0.183\left(\frac{\bar{n}}{\bar{N}}\right) - 0.196\left(\frac{RH}{100}\right)\right)$ with a t – stat value of 0.0359 gives the best performance while $H_4 = H_0\left(0.284 + 0.275\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0057(\bar{T}_{max}) - 0.107\left(\frac{\overline{RH}}{100}\right)\right)$ with a t – stat value of 0.609 is the worst performed empirical equation developed for Maiduguri. Empirical equations developed for estimation of global solar radiation for Yola are good considering their t – stat values of the empirical equations. Among the five equations developed, $H_1 = H_0\left(0.162 + 0.686\left(\frac{\bar{n}}{\bar{N}}\right)\right)$ with a t – stat value of 0.056 performed best while $H_2 = H_0\left(0.0302 + 0.522\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0074(\bar{T}_{max})\right)$ with a t – stat value of 0.556 is the worst.

Table 4.5: Statistical Error Values of the Modeled Empirical Equations for North East Cities

	NORTH EAST ZONE					
GOMBE	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	0.007461	-0.00533	0.01212	-0.33612	-0.00962
	RMSE	0.459519	0.374107	0.396455	0.505714	0.805757
	MPE	-0.08425	0.032833	-0.11976	1.634396	-0.03619
	t-stat	0.053855	0.047263	0.10144	2.950372	0.039609
MAIDUGURI	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	-0.02172	-0.02524	0.005681	-0.05927	-0.06597
	RMSE	0.9987	0.46625	0.525486	0.328293	0.582102
	MPE	-0.22503	0.114887	-0.15816	0.267223	0.289377
	t-stat	0.072147	0.179808	0.035858	0.608797	0.378296
YOLA	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	-0.00962	0.062933	-0.00893	-0.02726	0.024548
	RMSE	0.574934	0.380915	0.503917	0.375748	0.933494
	MPE	-0.09356	-0.33993	-0.09175	0.090552	-0.26322
	t-stat	0.055495	0.555593	0.058813	0.241246	0.087247

Table 4.6 presents the statistical error calculation for developed empirical equation for the estimation of global solar radiation for Birnin Kebbi, Kano and Gusau in north western part of Nigeria. According to the t –stat value of these developed equations, all the equations relatively performed well. In Birnin Kebbi, four of the five empirical equations are good for estimating global solar radiation more than the remaining one. $H_5 = H_0\left(0.410 + 0.00792(\bar{T}_{max}) - 0.143\left(\frac{\overline{RH}}{100}\right)\right)$ with a t – stat value of 0.0338 performed best while $H_2 = H_0\left(0.133 + 0.308\left(\frac{\bar{n}}{\bar{N}}\right) + 0.008(\bar{T}_{max})\right)$ with a t – stat value of 4.409 is the worst for estimating global solar radiation at Birnin Kebbi. In Gusau, $H_3 = H_0\left(0.429 + 0.421\left(\frac{\bar{n}}{\bar{N}}\right) - 0.0781\left(\frac{RH}{100}\right)\right)$ with a t – stat value of 0.0184 performed best while $H_2 =$

$H_0\left(0.122 + 0.426\left(\frac{\bar{n}}{\bar{N}}\right) + 0.00815(\bar{T}_{max})\right)$ with a t – stat value of 0.864 is the worst empirical equation developed for Gusau. In kano, $H_2 = H_0\left(0.121 + 0.428\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0069(\bar{T}_{max})\right)$ with a t – stat value of 0.0112 is the best performed empirical equation while $H_3 = H_0\left(0.495 + 0.277\left(\frac{\bar{n}}{\bar{N}}\right) - 0.111\left(\frac{RH}{100}\right)\right)$ with a t – stat value of 0.154 is the worst empirical equation for estimating global solar radiation at Kano.

Table 4.6: Statistical Error Values of the Modeled Empirical Equations for North Western Cities

CITIES	**NORTH WEST ZONE**					
BIRNIN – KEBBI	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	0.020746	-0.71575	-0.03142	0.022165	0.007494
	RMSE	0.868012	0.895638	0.789675	0.543387	0.735414
	MPE	-0.3614	3.30081	-0.10758	-0.13738	-0.0927
	t-stat	0.079292	4.40918	0.132087	0.135398	0.033798
GUSAU	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	-0.01164	0.201207	0.00532	0.054026	0.014615
	RMSE	1.011009	0.798565	0.955433	0.765301	0.87105
	MPE	-0.21244	-1.00008	-0.30402	-0.3406	-0.17459
	t-stat	0.038183	0.863518	0.018467	0.23472	0.055656
KANO	**Errors**	**H1**	**H2**	**H3**	**H4**	**H5**
	MBE	-0.02105	-0.00157	-0.03075	-0.00954	-0.01216
	RMSE	0.741466	0.464074	0.661532	0.396431	0.520248
	MPE	-0.15804	-0.03592	-0.09497	-0.00433	0.015177
	t-stat	0.094176	0.011222	0.154358	0.079848	0.077513

4.2 Developed Empirical Equation Obtained and their Regression Constants

The developed equations for estimation of global solar radiation are presented in table 7 to table 24 for each city studied. The R^2 values which show the measure of the closeness of the estimated global solar radiation values to their corresponding measured global solar radiation values were also presented in the tables. Best performed empirical equations for each of the city studied were presented in table 4.25. The choice of best performed equations were done using the t – stat values. Equation with least values of t – stat for each city were regarded as the best.

Table 4.7: Empirical Equations Developed for Owerri

Models	Empirical Equations	**R^2 Values**
I	$H_1 = H_0\left(0.251 + 0.616\left(\frac{\bar{n}}{\bar{\bar{N}}}\right)\right)$	**0.991**
II	$H_2 = H_0\left(0.213 + 0.595\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.00164(\bar{T}_{max})\right)$	**0.991**
III	$H_3 = H_0\left(0.150 + 0.651\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0931\left(\frac{RH}{100}\right)\right)$	**0.993**
IV	$H_4 = H_0\left(0.0203 + 0.610\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.00442(\bar{T}_{max}) + 0.130\left(\frac{\overline{RH}}{100}\right)\right)$	**0.995**
V	$H_5 = H_0\left(-0.518 + 0.0381(\bar{T}_{max}) + 0.035\left(\frac{\overline{RH}}{100}\right)\right)$	**0.800**

Table 4.8: Empirical Equations Developed for Enugu

Models	Empirical Equations	**R^2 Values**
I	$H_1 = H_0\left(0.195 + 0.787\left(\frac{\bar{n}}{\bar{\bar{N}}}\right)\right)$	**0.780**
II	$H_2 = H_0\left(-0.740 + 0.318\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0380(\bar{T}_{max})\right)$	**0.930**
III	$H_3 = H_0\left(-0.0296 + 0.282\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 2.355\left(\frac{RH}{100}\right)\right)$	**0.963**
IV	$H_4 = H_0\left(-0.598 + 0.302\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0362(\bar{T}_{max}) - 0.0723\left(\frac{\overline{RH}}{100}\right)\right)$	**0.931**
V	$H_5 = H_0\left(-0.0.864 + 0.0463(\bar{T}_{max}) - 0.181\left(\frac{\overline{RH}}{100}\right)\right)$	**0.892**

Table 4.9: Empirical Equations Developed for Awka

Models	Empirical Equations	R^2 Values
I	$H_1 = H_0\left(0.212 + 0.621\left(\frac{\bar{n}}{\bar{\bar{N}}}\right)\right)$	**0.780**
II	$H_2 = H_0\left(-0.717 + 0.229\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.039(\bar{T}_{max})\right)$	**0.922**
III	$H_3 = H_0\left(0.662 + 0.420\left(\frac{\bar{n}}{\bar{N}}\right) - 0.443\left(\frac{RH}{100}\right)\right)$	**0.912**
IV	$H_4 = H_0\left(-0.157 + 0.261\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0252(\bar{T}_{max}) - 0.23\left(\frac{\overline{RH}}{100}\right)\right)$	**0.937**
V	$H_5 = H_0\left(-0.724 + 0.0471(\bar{T}_{max}) + 0.161\left(\frac{\overline{RH}}{100}\right)\right)$	**0.899**

Table 4.10: Empirical Equations Developed for Asaba

Models	Empirical Equations	R^2 Values
I	$H_1 = H_0\left(0.214 + 0.822\left(\frac{\bar{n}}{\bar{\bar{N}}}\right)\right)$	**0.902**
II	$H_2 = H_0\left(-0.428 + 0.491\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.026(\bar{T}_{max})\right)$	**0.942**
III	$H_3 = H_0\left(-0.181 + 1.073\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.379\left(\frac{RH}{100}\right)\right)$	**0.920**
IV	$H_4 = H_0\left(-0.802 + 0.736\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0260(\bar{T}_{max}) + 0.367\left(\frac{\overline{RH}}{100}\right)\right)$	**0.958**
V	$H_5 = H_0\left(-0.756 + 0.0492(\bar{T}_{max}) + 1.194\left(\frac{\overline{RH}}{100}\right)\right)$	**0.883**

Table 4.11: Empirical Equations Developed for Port – Harcourt

Models	Empirical Equations	R^2 Values
I	$H_1 = H_0\left(0.120 + 0.801\left(\frac{\bar{n}}{\bar{N}}\right)\right)$	**0.626**
II	$H_2 = H_0\left(-1.323 + 0.329\left(\frac{\bar{n}}{\bar{N}}\right) + 0.060(\bar{T}_{max})\right)$	**0.816**
III	$H_3 = H_0\left(2.119 + 0.49\left(\frac{\bar{n}}{\bar{N}}\right) - 2.245\left(\frac{RH}{100}\right)\right)$	**0.808**
IV	$H_4 = H_0\left(0.530 + 0.199\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0462(\bar{T}_{max}) - 1.708\left(\frac{\overline{RH}}{100}\right)\right)$	**0.912**
V	$H_5 = H_0\left(0.475 + 0.0571(\bar{T}_{max}) - 1.901\left(\frac{\overline{RH}}{100}\right)\right)$	**0.894**

Table 4.12: Empirical Equations Developed for Calabar

Models	Empirical Equations	R^2 Values
I	$H_1 = H_0\left(0.131 + 0.99\left(\frac{\bar{n}}{\bar{N}}\right)\right)$	**0.869**
II	$H_2 = H_0\left(-0.598 + 0.706\left(\frac{\bar{n}}{\bar{N}}\right) + 0.030(\bar{T}_{max})\right)$	**0.887**
III	$H_3 = H_0\left(1.633 + 0.645\left(\frac{\bar{n}}{\bar{N}}\right) - 1.668\left(\frac{RH}{100}\right)\right)$	**0.923**
IV	$H_4 = H_0\left(0.882 + 0.315\left(\frac{\bar{n}}{\bar{N}}\right) + 0.034(\bar{T}_{max}) - 1.734\left(\frac{\overline{RH}}{100}\right)\right)$	**0.944**
V	$H_5 = H_0\left(0.833 + 0.0530(\bar{T}_{max}) - 2.178\left(\frac{\overline{RH}}{100}\right)\right)$	**0.932**

Table 4.13: Empirical Equations Developed for Akure

Models	Empirical Equations	**R^2 Values**
I	$H_1 = H_0\left(0.153 + 0.806\left(\frac{\bar{n}}{\bar{N}}\right)\right)$	**0.872**
II	$H_2 = H_0\left(-0.834 + 0.186\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0444(\bar{T}_{max})\right)$	**0.926**
III	$H_3 = H_0\left(0.451 + 0.634\left(\frac{\bar{n}}{\bar{N}}\right) - 0.275\left(\frac{RH}{100}\right)\right)$	**0.908**
IV	$H_4 = H_0\left(-0.631 + 0.230\left(\frac{\bar{n}}{\bar{N}}\right) + 0.038(\bar{T}_{max}) - 0.0644\left(\frac{\overline{RH}}{100}\right)\right)$	**0.927**
V	$H_5 = H_0\left(-1.106 + 0.0567(\bar{T}_{max}) + 0.00493\left(\frac{\overline{RH}}{100}\right)\right)$	**0.922**

Table 4.14: Empirical Equations Developed for Ado Ekiti

Models	Empirical Equations	**R^2 Values**
I	$H_1 = H_0\left(0.224 + 0.685\left(\frac{\bar{n}}{\bar{N}}\right)\right)$	**0.994**
II	$H_2 = H_0\left(0.191 + 0.658\left(\frac{\bar{n}}{\bar{N}}\right) + 0.00152(\bar{T}_{max})\right)$	**0.994**
III	$H_3 = H_0\left(0.163 + 0.731\left(\frac{\bar{n}}{\bar{N}}\right)0.0528\left(\frac{RH}{100}\right)\right)$	**0.996**
IV	$H_4 = H_0\left(0.0422 + 0.661\left(\frac{\bar{n}}{\bar{N}}\right) + 0.00478(\bar{T}_{max}) + 0.0685\left(\frac{\overline{RH}}{100}\right)\right)$	**0.997**
V	$H_5 = H_0\left(0.0388 + 0.00613(\bar{T}_{max}) - 0.657\left(\frac{\overline{RH}}{100}\right)\right)$	**0.923**

Table 4.15: Empirical Equations Developed for Lagos

Models	Empirical Equations	R^2 Values
I	$H_1 = H_0\left(0.184 + 0.761\left(\frac{\bar{n}}{\bar{\bar{N}}}\right)\right)$	**0.883**
II	$H_2 = H_0\left(-0.181 + 0.623\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0153(\bar{T}_{max})\right)$	**0.894**
III	$H_3 = H_0\left(0.522 + 0.680\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) - 0.367\left(\frac{RH}{100}\right)\right)$	**0.892**
IV	$H_4 = H_0\left(0.160 + 0.515\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0171(\bar{T}_{max}) - 0.417\left(\frac{\overline{RH}}{100}\right)\right)$	**0.906**
V	$H_5 = H_0\left(-0.040 + 0.0490(\bar{T}_{max}) - 0.982\left(\frac{\overline{RH}}{100}\right)\right)$	**0.828**

Table 4.16: Empirical Equations Developed for Ilorin

Models	Empirical Equations	R^2 Values
I	$H_1 = H_0\left(0.234 + 0.598\left(\frac{\bar{n}}{\bar{\bar{N}}}\right)\right)$	**0.932**
II	$H_2 = H_0\left(-0.484 + 0.251\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0307(\bar{T}_{max})\right)$	**0.985**
III	$H_3 = H_0\left(0.434 + 0.488\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) - 0.189\left(\frac{RH}{100}\right)\right)$	**0.962**
IV	$H_4 = H_0\left(-0.724 + 0.212\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0378(\bar{T}_{max}) + 0.07\left(\frac{\overline{RH}}{100}\right)\right)$	**0.987**
V	$H_5 = H_0\left(-1.378 + 0.0608(\bar{T}_{max}) + 0.190\left(\frac{\overline{RH}}{100}\right)\right)$	**0.975**

Table 4.17: Empirical Equations Developed for Abuja

Models	Empirical Equations	R^2 Values
I	$H_1 = H_0\left(0.178 + 0.772\left(\frac{\bar{n}}{\bar{\bar{N}}}\right)\right)$	**0.851**
II	$H_2 = H_0\left(-0.577 + 0.021\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0388(\bar{T}_{max})\right)$	**0.934**
III	$H_3 = H_0\left(0.401 + 0.555\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) - 0.166\left(\frac{RH}{100}\right)\right)$	**0.892**
IV	$H_4 = H_0\left(-1.247 - 0.215\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0620(\bar{T}_{max}) + 0.163\left(\frac{\overline{RH}}{100}\right)\right)$	**0.944**
V	$H_5 = H_0\left(-0.876 + 0.0471(\bar{T}_{max}) - 0.0985\left(\frac{\overline{RH}}{100}\right)\right)$	**0.940**

Table 4.18: Empirical Equations Developed for Minna

Models	Empirical Equations	R^2 Values
I	$H_1 = H_0\left(0.264 + 0.558\left(\frac{\bar{n}}{\bar{\bar{N}}}\right)\right)$	**0.827**
II	$H_2 = H_0\left(-0.290 + 0.225\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0244(\bar{T}_{max})\right)$	**0.965**
III	$H_3 = H_0\left(0.470 + 0.398\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) - 0.173\left(\frac{RH}{100}\right)\right)$	**0.891**
IV	$H_4 = H_0\left(-0.652 + 0.204\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0341(\bar{T}_{max}) + 0.120\left(\frac{\overline{RH}}{100}\right)\right)$	**0.975**
V	$H_5 = H_0\left(-0.970 + 0.0473(\bar{T}_{max}) + 0.163\left(\frac{\overline{RH}}{100}\right)\right)$	**0.941**

4.19: Empirical Equations Developed for Yola

Models	Empirical Equations	R^2 Values
I	$H_1 = H_0\left(0.162 + 0.686\left(\frac{\bar{n}}{\bar{N}}\right)\right)$	**0.954**
II	$H_2 = H_0\left(0.0302 + 0.522\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0074(\bar{T}_{max})\right)$	**0.981**
III	$H_3 = H_0\left(0.295 + 0.539\left(\frac{\bar{n}}{\bar{N}}\right) - 0.0737\left(\frac{RH}{100}\right)\right)$	**0.965**
IV	$H_4 = H_0\left(0.0522 + 0.511\left(\frac{\bar{n}}{\bar{N}}\right) + 0.007(\bar{T}_{max}) - 0.00884\left(\frac{\overline{RH}}{100}\right)\right)$	**0.981**
V	$H_5 = H_0\left(0.390 + 0.00951(\bar{T}_{max}) - 0.185\left(\frac{\overline{RH}}{100}\right)\right)$	**0.874**

Table 4.20: Empirical Equations Developed for Gombe

Models	Empirical Equations	R^2 Values
I	$H_1 = H_0\left(0.269 + 0.513\left(\frac{\bar{n}}{\bar{N}}\right)\right)$	**0.961**
II	$H_2 = H_0\left(0.189 + 0.431\left(\frac{\bar{n}}{\bar{N}}\right) + 0.00407(\bar{T}_{max})\right)$	**0.973**
III	$H_3 = H_0\left(0.360 + 0.416\left(\frac{\bar{n}}{\bar{N}}\right) - 0.0553\left(\frac{RH}{100}\right)\right)$	**0.971**
IV	$H_4 = H_0\left(0.270 + 0.382\left(\frac{\bar{n}}{\bar{N}}\right) + 0.00315(\bar{T}_{max}) - 0.0384\left(\frac{\overline{RH}}{100}\right)\right)$	**0.977**
V	$H_5 = H_0\left(0.431 + 0.0077(\bar{T}_{max}) - 0.163\left(\frac{\overline{RH}}{100}\right)\right)$	**0.875**

Table 4.21: Empirical Equations Developed for Maiduguri

Models	Empirical Equations	R^2 Values
I	$H_1 = H_0\left(0.261 + 0.545\left(\frac{\bar{n}}{\bar{N}}\right)\right)$	**0.814**
II	$H_1 = H_0\left(0.0319 + 0.434\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0088(\bar{T}_{max})\right)$	**0.958**
III	$H_3 = H_0\left(0.577 + 0.183\left(\frac{\bar{n}}{\bar{N}}\right) - 0.196\left(\frac{RH}{100}\right)\right)$	**0.946**
IV	$H_4 = H_0\left(0.284 + 0.275\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0057(\bar{T}_{max}) - 0.107\left(\frac{\overline{RH}}{100}\right)\right)$	**0.980**
V	$H_5 = H_0\left(0.608 + 0.003(\bar{T}_{max}) - 0.240\left(\frac{\overline{RH}}{100}\right)\right)$	**0.933**

Table 4.22: Empirical Equations Developed for Brinin - Kebbi

Models	Empirical Equations	R^2 Values
I	$H_1 = H_0\left(0.339 + 0.4.53\left(\frac{\bar{n}}{\bar{N}}\right)\right)$	**0.793**
II	$H_2 = H_0\left(0.133 + 0.308\left(\frac{\bar{n}}{\bar{N}}\right) + 0.008(\bar{T}_{max})\right)$	**0.922**
III	$H_3 = H_0\left(0.504 + 0.260\left(\frac{\bar{n}}{\bar{N}}\right) - 0.105\left(\frac{RH}{100}\right)\right)$	**0.832**
IV	$H_4 = H_0\left(0.188 + 0.268\left(\frac{\bar{n}}{\bar{N}}\right) + 0.00808(\bar{T}_{max}) - 0.0265\left(\frac{\overline{RH}}{100}\right)\right)$	**0.924**
V	$H_5 = H_0\left(0.410 + 0.00792(\bar{T}_{max}) - 0.143\left(\frac{\overline{RH}}{100}\right)\right)$	**0.865**

Table 4.23: Empirical Equations Developed for Gusau

Models	**Empirical Equations**	**R^2 Values**
I	$H_1 = H_0\left(0.262 + 0.654\left(\frac{\bar{n}}{\bar{N}}\right)\right)$	**0.762**
II	$H_2 = H_0\left(0.122 + 0.426\left(\frac{\bar{n}}{\bar{N}}\right) + 0.00815(\bar{T}_{max})\right)$	**0.857**
III	$H_3 = H_0\left(0.429 + 0.421\left(\frac{\bar{n}}{\bar{N}}\right) - 0.0781\left(\frac{RH}{100}\right)\right)$	**0.788**
IV	$H_4 = H_0\left(0.204 + 0.342\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0076(\bar{T}_{max}) - 0.0338\left(\frac{\overline{RH}}{100}\right)\right)$	**0.861**
V	$H_5 = H_0\left(0.399 + 0.00857(\bar{T}_{max}) - 0.116\left(\frac{\overline{RH}}{100}\right)\right)$	**0.819**

Table 4.24: Empirical Equations Developed for Kano

Models	Empirical Equations	**R^2 Values**
I	$H_1 = H_0\left(0.271 + 0.544\left(\frac{\bar{n}}{\bar{N}}\right)\right)$	**0.850**
II	$H_2 = H_0\left(0.121 + 0.428\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0069(\bar{T}_{max})\right)$	**0.943**
III	$H_3 = H_0\left(0.495 + 0.277\left(\frac{\bar{n}}{\bar{N}}\right) - 0.111\left(\frac{RH}{100}\right)\right)$	**0.886**
IV	$H_4 = H_0\left(0.292 + 0.250\left(\frac{\bar{n}}{\bar{N}}\right) + 0.0063(\bar{T}_{max}) - 0.0785\left(\frac{\overline{RH}}{100}\right)\right)$	**0.960**
V	$H_5 = H_0\left(0.486 + 0.00655(\bar{T}_{max}) - 0.166\left(\frac{\overline{RH}}{100}\right)\right)$	**0.933**

Table 4.25: Best Performed Empirical Equations Developed for Estimation of Global Solar Radiation at different Sites in Nigeria

Cities	Best Models	t - stat
Awka	$H_3 = H_0\left(0.662 + 0.420\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) - 0.443\left(\frac{RH}{100}\right)\right)$	0.050
Enugu	$H_1 = H_0\left(0.195 + 0.787\left(\frac{\bar{n}}{\bar{\bar{N}}}\right)\right)$	0.0045
Owerri	$H_5 = H_0\left(-0.518 + 0.0381(\bar{T}_{max}) + 0.035\left(\frac{\overline{RH}}{100}\right)\right)$	4.692
Calabar	$H_3 = H_0\left(1.633 + 0.645\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) - 1.668\left(\frac{RH}{100}\right)\right)$	0.0327
Port – Harcourt	$H_3 = H_0\left(2.119 + 0.49\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) - 2.245\left(\frac{RH}{100}\right)\right)$	0.083
Asaba	$H_1 = H_0\left(0.214 + 0.822\left(\frac{\bar{n}}{\bar{\bar{N}}}\right)\right)$	0.0126
Lagos	$H_5 = H_0\left(-0.040 + 0.0490(\bar{T}_{max}) - 0.982\left(\frac{\overline{RH}}{100}\right)\right)$	0.00259
Akure	$H_5 = H_0\left(-1.106 + 0.0567(\bar{T}_{max}) + 0.00493\left(\frac{\overline{RH}}{100}\right)\right)$	0.0232
Ado – Etiti	$H_5 = H_0\left(0.0388 + 0.00613(\bar{T}_{max}) - 0.657\left(\frac{\overline{RH}}{100}\right)\right)$	1.166
Gombe	$H_5 = H_0\left(0.431 + 0.0077(\bar{T}_{max}) - 0.163\left(\frac{\overline{RH}}{100}\right)\right)$	0.0361
Yola	$H_1 = H_0\left(0.162 + 0.686\left(\frac{\bar{n}}{\bar{\bar{N}}}\right)\right)$	0.056
Maiduguri	$H_3 = H_0\left(0.577 + 0.183\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) - 0.196\left(\frac{RH}{100}\right)\right)$	0.0359
Abuja	$H_1 = H_0\left(0.178 + 0.772\left(\frac{\bar{n}}{\bar{\bar{N}}}\right)\right)$	0.0882
Minna	$H_1 = H_0\left(0.264 + 0.558\left(\frac{\bar{n}}{\bar{\bar{N}}}\right)\right)$	0.281
Ilorin	$H_3 = H_0\left(0.434 + 0.488\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) - 0.189\left(\frac{RH}{100}\right)\right)$	0.00148
Gusau	$H_3 = H_0\left(0.429 + 0.421\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) - 0.0781\left(\frac{RH}{100}\right)\right)$	0.0184
Kano	$H_2 = H_0\left(0.121 + 0.428\left(\frac{\bar{n}}{\bar{\bar{N}}}\right) + 0.0069(\bar{T}_{max})\right)$	0.0112
Birnin Kebbi	$H_5 = H_0\left(0.410 + 0.00792(\bar{T}_{max}) - 0.143\left(\frac{\overline{RH}}{100}\right)\right)$	0.0338

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

We have successfully used some measured meteorological data to estimate and analyze the total solar radiation within the six geopolitical zones in Nigeria, by applying the linear regression empirical model established by Angstrom (1924) and modified by page (1964). The Angstrom – Page sunshine based linear regression model for estimation of global solar radiation was modified using other meteorological data to obtain other multiple linear regression equations which can be used to estimate global solar radiation in the eighteen sites studied.

Statistical error evaluations of the estimated global solar radiation that were obtained using the developed empirical equations were carried out to determine the best and worst empirical equations for each site. The statistical error analysis carried out were MBE, RMSE, MPE and t – stat. The t – stat was used to make decisions on the empirical equation for each site that is the best and which one is the worst. According to Stone (1993), zero values of t – stat are desirable. Therefore, developed empirical equations with t – stat close to zero are regarded as the best while those that are far from zero are regarded as the worst empirical equations. The choice of t – stat as an overall statistical error tool for evaluation is due to its dependence on the other two statistical error formulae (MBE and RMSE) that were calculated in this work.

5.2 Conclusion

This work shows that in the absence of global solar radiation data, reliable estimates can be made from easily available meteorological observations of possible sunshine hours, temperature and relative humidity along with extraterrestrial solar radiation using different models we developed.

The best model for Awka is H_3 with t – stat value of 0.050. Enugu has H_1 as its best model with t – stat value of 0.0045 while Owerri has H_5 as its best model with t – stat value of 4.692. The models for South East zone show that global solar radiation for Owerri could be overestimated using our developed models while that of Awka and Enugu are good for the estimation of global solar radiation within the regions.

In South South region of Nigeria, the best model for estimation of global solar radiation for Calabar, Port – Harcourt and Asaba are H_3, H_3 and H_1 respectively. The best model equation for Calabar has a t – stat value of 0.0327. The best model equation for Port – Harcourt has a t – stat value of 0.0830 while that of Asaba has a t – stat value of 0.01256. These model equations developed for these cities could be used for the estimation of global solar radiation in these cities.

Models equations developed for the Cities studied in South West zone which include Lagos, Akure and Ado – Ekiti performed well and could be used to estimate global solar radiation in these cities. The best model equation for Lagos is H_5 with t – stat value of 0.00259. the best model equation for Akure is H_5 with t – stat value of 0.0232 while the best model for the Ado – Ekiti is H_5 with t – stat value of 1.166. These equations show that for good estimation of global solar radiation within the South West zone in Nigeria that the combination of maximum temperature and relative humidity is preferred over the other model equations.

In North Eastern Nigeria, the developed models for the estimation of global solar radiation for the three cities of Gombe, Yola and Maiduguri performed well and could be used for the estimation of global solar radiation. The best model for Gombe is H_5 with t – stat value of 0.0361. The best model for Yola is H_1 with t – stat value of 0.056 while the best model for Maiduguri is H_3 with t – stat value of 0.0359. These results show that for Gombe, the model which depends on the maximum temperature and relative humidity is preferred, for Yola the model which depends on the ration of sunshine hours is preferred while for Maiduguri, the model which depends on the ratio of sunshine hours and relative humidity is preferred.

The models developed for the estimation of global solar radiation in North central geopolitical zone of Nigeria are good and could be used in estimating global solar radiation for sites around the locations. The cities considered in the North central zone are Abuja, Minna and Ilorin. The best model for the estimation of global solar radiation for Abuja is H_1 with t – stat value of 0.0882. The best model for Minna is H_1 with t – stat of 0.281 while the best model for Ilorin is H_3 with t – stat value of 0.00148.

In the North West zone of Nigeria, models for estimation of global solar radiation in Kano, Gusau and Birnin Kebbi were developed. All the developed models for these three cities are good for the estimation of global solar radiation. The best model for Kano is H_2 with t – stat value of 0.0112. The best for Gusau is H_3 with t – stat value of 0.0184 while the best model for Birnin Kebbi is H_5 with t – stat of 0.0388.

The global solar radiation intensity obtained with these models can be used in the design, analysis and performance estimation of solar energy conversion systems which is gradually but steadily gaining ground in Nigeria and the world at large.

5.3 Recommendations

Future research and development work is recommended as follows:

i. Future researchers should expand this research work in terms of the usage of other available meteorological data and make solar radiation estimation more accurate. Also the use of more complex multiple linear regression, quadratic analysis and polynomials analysis of the meteorological data should be tried for these sites.

ii. Development of solar maps in Nigeria – Maps of solar radiation are important for solar energy applications as they can illustrate the optimal regions for locating solar energy systems, such as solar PV or thermal power plants. To develop solar maps, solar radiation availability in different locations spread wide across the different climate zones is required. The developed global solar radiation models could help to establish solar maps for Nigeria, which would be beneficial for the solar energy implications and building designs.

iii. Other approaches for estimation of global solar radiation in Nigeria such as Artificial neural networks should be considered. A lack of significant improvement in global solar radiation predictions using Artificial Neural Networks (ANNs) in Nigeria was observed compared with the linear regression. From literature, estimation of Global Solar Radiation using Artificial Neural Networks (ANNs) is still a green field in Nigeria and it is believed that there are rooms for further development through different approaches, such as re-selections of the input climatic variables and/or using other types of neural networks.

Nevertheless, there is a need for continual efforts towards improving the accuracy of estimation which is an essential qualification for precise and correct design and simulation studies. It would be worthwhile to quote the remark by Myers (2005), "the challenge for solar radiation models in the 21st century is to reduce the uncertainty in measured data, as well as develop more robust models (i.e., fewer input parameters and smaller residuals, under a wider variety of conditions).

REFERENCES

Adejumo A. O., Suleiman E. A., Okagbue H. I. (2017). Exploration of solar radiation data from three geo-political zones in Nigeria. Data in Brief, Vol. 13, pp. 60 – 68.

Agbo G.A, Baba, A and Obiekezie, T.N (2010), ‘ Empirical models for the correlation of monthly average global solar radiation with sunshine hours at Minna, Niger State, Nigeria’, Journal of Basic Physical Research, 1(1), 41-47

Akpabio L. E., Udo S. O. and Etuk S. E., (2005), Modeling Global Solar Radiation for a Tropical Location: Onne, Nigeria, Turkish Journal of Physics, 29, 63 – 68.

Akpabio, L.E and Etuk, S.E (2003), ‘Relationship between Global Solar Radiation and Sunshine Duration for Onne, Nigeria’, Turkish Journal Physics, 27, 161–167

Almorox J., (2011), Estimating Global Solar radiation from Common Meteorological Data in Aranjuez, Spain, Turkish Journal of Physics, 35, 53 – 64.

Angstrom A (1924), ‘Solar and Terrestrial Radiation’, Quarterly Journal of Royal Meteorological Society, 50, 121-125

Augustine C. and Nnabuchi M. N. (2009), Relationship between global solar radiation and sunshine hours for Calabar, Port Harcourt and Enugu, Nigeria. International Journal of Physical Sciences Vol. 4 (4), pp. 182-188.

Augustine C. and Nnabuchi, M. N. (2010), Analysis of Some Meteorological Data for Some Selected Cities in the Eastern and Southern Zone of Nigeria’, African Journal of Environmental Science and Technology, 4 (2), 92–99.

Babatunde E. B. (2007), Solar Energy, A Friendly Renewable Energy Option for Nigeria, Public Lecture Series, Volume 15, Covenant University Press Canaanland, Km. 10, Idiroko Road, Ota, Ogun State, Nigeria

Barr A. G., McGuin, S. M. and Cheng, S. B. (1996): Comparison of methods to estimate daily Global solar irradiation from other climatic variables on the Canadian Prairies. Solar Energy 56(2) 13-224.

Black, T.N; Bonython, C.W and Prescett, J.A (1954), ‘Solar Rdaiation and Duration of Sun-shine’, Q.J.R. Metero. Soc. 80: 231–235.

Burari F. W. and Sambo A. S., (2001) Model for the prediction of global solar radiation for Bauchi us2ing Meteorological Data, Nigeria Journal of Renewable Energy, 91, 30–33.

Che H. Z., Shi G. Y., Zhang X. Y., Zhao J. Q. and Li Y., (2007), Analysis of Sky Condition using 40 years Records of Solar Radiation data in China, Theor. Appli. Climatol., 89, 83 – 94.

Chegaar, M and Chibani, A (2000), ‘ A Simple Method for Computing Global Solar Radiation’, Rev. Energ. Ren: Chemss 111–115

Chukwuemeka A. and Nnabuchi M. N. (2009), Solar Radiation in Port Harcourt: Correlation with Sunshine Duration, The Pacific Journal of Science and Technology, 10(1), 861 – 865.

Cooper P. I. (1969), The Absorption of Radiation on Solar Stills, Solar Energy, 12(3), 333 – 346.

Duffie, J.A. and Beckman,W.A (2006). Solar Engineering of Thermal Processes, 3rd Edn., John Wiley and Sons, New York.

Falayi E. O., Adepitan J. O. and Rabiu A. B., (2008), Empirical Models for the Correlation of Global Solar Radiation with Meteorological Data for Iseyin, Nigeria, International Journal of Physical Science, 3(9), 210 – 216.

Frere E.T., (1980), Estimation and prediction of global solar radiation over Greece, Solar Energy, 24: 63-70.

Gana N. N. and Akpootu D. O. (2013), Estimation of global solar radiation using four sunshine based models in Kebbi, North-Western, Nigeria, Advances in Applied Science Research, 2013, 4(5):409-421.

Garba M. B., Muhammad A., Musa M. and Mohammed A. G. (2018). Assessing the Performance of Global Solar Radiation Empirical Equations in Sokoto, Nigeria Using Meteorological Parameters. Nigerian Journal of Technology, Vol. 37, No. 2, pp. 358 – 364.

Gooding 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. Agron J. 91, 845-85.

Gopinathan, K.K (1988), 'A new Model for Estimating Total Solar Radiation', Solar and Wind Technology, 5(1); 107–109.

Hankins Mark (1995): Solar Electric Systems for Africa Common Science Council. Marlborough House, Pall Mall, London.

Hoyt, D.V (1978), 'A Model for the Calculation of Solar Global Insolation', Solar Energy, 21:27–35.

Innocent A. J, Jacob O. E, Chibuzo G. C, James I. and Odeh D. O, (2015), Estimation of Global Solar Radiation In Gusau, Nigeria. International Journal of Research in Engineering and Technology (Impact Journal) Vol. 3, Issue 2, pp. 27-32.

International Energy Agency, (2015), Energy and Climate Change, World Energy Outlook Special Report; Executive Summary, Paris, France.

Iqbal, M (1983), An Introduction to Solar Radiation, Academy Press, New York.

Ituen E. E., Esen N. U., Nwokolo S. C. and Udo E.G., (2012), Prediction of Global Solar Radiation using Relative Humidity, Maximum Temperature and Sunshine Hours in Uyo, in Niger Delta Region, Nigeria, Advances in Applied Science Research, Vol. 3(4), pp. 1923 – 1937.

Kizu Shoichi (1998): Systematic errors in estimating by empirical formulas. Journal of Oceanography 54: 165- 177.

Liu, Y.H and Jordan, R.C (1960), 'The Interrelationship and Characteristic Distribution of direct, Diffuse and Total Solar Radiation from Metrological Data', Solar Energy, 4: 1–19

Martin C.L. and Goswamid Y. (2005), Solar Energy Pocket References. International Solar Energy Society, ISBN: 0977128202

Marwal V. K,. Punia R. C., Sengar N., Mahawa S. and Dashora P., (2012), A Comparative Study of Correlation Functions for Estimation of Monthly Mean Daily Global Solar

Radiation for Jaiper, Rajathan, India, Indian Journal of Science and Technology, 5, 2729 – 2732.

Medugu, D.W and Yakubu D (2011), 'Estima-tion of mean monthly global solar radiation in Yola, Nigeria, Using Angstrom Model', Ad-vances in Applied Science Research, 2(2): 414–421

Mfon David Umoh, Sunday O. Udo and Ye-Obong N. Udoakah (2013), Estimation of global solar radiation on horizontal surface from sunshine hours and other meteorological parameters for Calabar, Nigeria, Journal of Asian Scientific Research, 3(11): 1083-1089.

Muhammad Jamilu Ya'u, Muhammad Abdullahi Gele, Yerima Yusif Ali, and Abdulkarim Mika'il Alhaji (2018). Global Solar Radiation Models: A Review. *Journal of Photonic Materials and Technology*. Vol. 4, No. 1, 2018, pp. 26-32.

Musa B., Zangina U. and Aminu M. (2012), Estimation of Global Solar Radiation In Maiduguri, Nigeria Using Angstrom Model, Asian Research Publishing Network (ARPN) Journal of Engineering and Applied Sciences, VOL. 7, NO. 12, pp. 1623 – 1627.

Myers, D R. (2005), Solar radiation modeling and measurements for renewable energy applications: Data and model quality. Energy, 30(9), pp.1517-1531.

Nnabuchi M. N., Ekpe J. E. and Ibeh G. F. (2013) Estimation of Global Solar Radiation in Onitsha and Calabar using Empirical models, Communications in Applied Science, Vol. 1, number 1, pp. 25 – 37.

Nwokoye A.O.C. (2009), Measurement of Instantaneous Solar Insolation and average daily ambient temperature in Awka, Nigeria. Natural and Applied Sciences Journal. 10(2) 110 – 111.

Nwokoye A.O.C. and Ike C.U. (2003), Measurements of Global Radiation Constant (Intensity) at Awka using Pyranometer. Nigerian Journal of Renewable Energy, 11 (1&2), 1-8.

Ogolo E. O. (2014), Estimation of global solar radiation in Nigeria using a modified Angstrom model and the trend analysis of the allied meteorological components. Indian J Radio Space Phys; Vol. 43, pp. 213–24.

Okeke, P.N. and Soon, W.H. (1994), Introduction to Astronomy and Astrophysics.

Okonkwo, G.N and Nwokoye, A.O.C., (2014), Analysis of Solar Energy Parameters in Bida, Nigeria, European Scientific Journal May 2014 edition vol.10, No.15, pp. 116 - 131

Okundamiya M. S., Emagbetere J. O. and Ogujor E. A. (2016) Evaluation of various global solar radiation models for Nigeria, International Journal of Green Energy, Vol. 13(5), pp. 505 – 512.

Okundamiya, M. S. and Nzeako, A. N., (2010), 'Empirical model for estimating global solar radiation on horizontal surfaces for selected ci-ties in the six geopolitical zones in Nigeria', Research Journal of Applied Science, Engineering and Technology, 2(8): 805–812.

Olayinka S., (2011), Estimation of Global and Diffuse Solar Radiations for Selected Cities in Nigeria, International Journal of Energy and Enviromental Engineering, 2(3), 13 – 33.

Osuji R. U., (2003): An evaluation of institutional framework for Renewable Energy Education in Nigeria. Nigerian Journal of Solar Energy 14, 25-35.

Page, J. K., (1961), 'The Estimation of Monthly Mean Values of Daily Total Short Wave Radiation on Vertical and Inclined Surface from Sunshine Records for Latitude 40oN – 40oS', Proceedings of UN Conference on New Sources of Energy, 4(598), 378–390.

Pandey B., Gnawali C. L., Aryal R. P. and Poudyal K. N. (2018). Prediction of global solar radiation using meteorological parameters on empirical model at mountain Region Jumla, Nepal, *Research Journal of Chemical Sciences* Vol. 8(1), 23 – 29.

Prescott, J. A., (1940), Evaporation from a Water Surface in Relation to Solar Radiation. Trans Roy Soc Aust 64, 114 – 48.

Radosavljevic, J. and Dordevic, A.,(2001) Defining of the Intensity of Solar Radiation on Horizontal and Oblique Surfaces on Earth, FactaUniversitatis, Series: Working and Living Environmental Protection 2(1) 77 – 86.

Sabbagh, J.A; Syigh, A.A.M and El- Salam, E.M.A (1977), 'Estimation of the Total Solar Radiation from Meteorological Data', Solar Energy, 19: 307–311.

Stone R. J. (1993) Improved statistical procedure for the evaluation of solar radiation estimation models. Solar Energy, 51(4):288–91.

Sunday Olayinka (2011), Estimation of global and diffuse solar radiations for selected cities in Nigeria, International Journal of Energy and Environmental Engineering, 2(3), 13 – 33.

Tiwari, G.N and Sangeeta, S.S (1977), Solar Thermal Engineering System, Narosa Publishing House, New Delhi, India.

Valko P. (1966). Die Himmelsstrahlung in ihrerBeziehungzu den _erschiedenen Parametern. Archive for Meteorology, Geophysics and Bioclimatology, Ser. B, 14: 336–359.

Vijayakumar, G., Kummert, M., Klein, S.A. and Beckman, W.A., (2005), Analysis of short-term solar radiation data, SolarEnergy, 79(5), 495–504.

APPENDIX

Table 1: Measured and Calculated Global Solar Radiation for Owerri

MONTH	H_m (MJm^{-2} day^{-1})	a	b	H_1 (MJm^{-2} day^{-1})	H_2 (MJm^{-2} day^{-1})	H_3 (MJm^{-2} day^{-1})	H_4 (MJm^{-2} day^{-1})	H_5 (MJm^{-2} day^{-1})
January	20.06	0.30	0.52	20.10	20.07	19.91	19.88	19.88
February	20.37	0.29	0.53	20.73	20.73	20.58	20.65	21.43
March	19.55	0.29	0.55	21.02	20.99	21.08	21.16	20.98
April	18.2	0.27	0.59	19.78	19.79	19.80	19.98	21.01
May	16.85	0.27	0.59	19.11	19.09	19.15	19.27	19.73
June	15.06	0.26	0.60	18.33	18.24	18.41	18.33	17.29
July	13.55	0.22	0.68	15.85	15.81	15.78	15.77	16.49
August	13.27	0.22	0.68	16.22	16.19	16.13	16.12	16.94
September	13.87	0.24	0.64	17.83	17.76	17.83	17.79	17.67
October	15.36	0.26	0.61	18.48	18.41	18.53	18.50	17.93
November	17.52	0.28	0.57	18.71	18.66	18.75	18.76	18.33
December	19.07	0.31	0.5	20.15	20.06	20.20	20.11	18.46

Table 2: Measured and Calculated Global Solar Radiation for Enugu

MONTH	H_m (MJm^{-2} day^{-1})	a	b	H_1 (MJm^{-2} day^{-1})	H_2 (MJm^{-2} day^{-1})	H_3 (MJm^{-2} day^{-1})	H_4 (MJm^{-2} day^{-1})	H_5 (MJm^{-2} day^{-1})
January	20.60	0.29	0.55	20.06	19.80	20.18	21.95	23.56
February	20.92	0.27	0.57	20.18	20.55	21.30	22.85	24.98
March	20.55	0.24	0.65	17.88	18.64	20.81	21.19	24.26
April	19.01	0.24	0.64	18.47	18.74	19.74	21.35	24.26
May	17.01	0.23	0.66	17.06	17.01	17.15	19.66	22.69
June	16.15	0.21	0.71	14.80	14.20	15.39	16.94	20.23
July	14.85	0.21	0.71	14.87	13.36	14.37	16.20	19.32
August	14.15	0.22	0.70	15.55	13.69	14.21	16.61	19.67
September	14.85	0.22	0.68	16.41	14.64	15.19	17.51	20.43
October	16.58	0.26	0.61	18.81	16.24	17.24	18.88	20.75
November	18.75	0.29	0.55	20.29	17.63	18.92	19.96	21.02
December	19.93	0.28	0.56	18.95	17.91	18.94	20.08	21.60

Table 3: Measured and Calculated Global Solar Radiation for Awka

MONTH	H_m (MJm^{-2} day^{-1})	a	b	H_1 (MJm^{-2} day^{-1})	H_2 (MJm^{-2} day^{-1})	H_3 (MJm^{-2} day^{-1})	H_4 (MJm^{-2} day^{-1})	H_5 (MJm^{-2} day^{-1})
January	20.71	0.30	0.52	18.52	20.43	20.75	20.58	20.92
February	20.92	0.31	0.49	20.63	21.95	21.55	21.61	21.69
March	20.55	0.32	0.47	22.23	21.60	20.98	20.81	20.03
April	19.00	0.29	0.55	19.81	20.59	18.92	19.5	19.74
May	17.74	0.24	0.64	16.21	18.25	16.23	17.21	18.39
June	16.15	0.24	0.65	15.51	15.78	15.39	15.31	15.55
July	14.85	0.22	0.69	14.55	14.54	14.74	14.34	14.50
August	14.15	0.22	0.70	14.49	14.62	14.87	14.46	14.71
September	14.85	0.26	0.61	17.38	16.31	16.79	16.06	15.46
October	16.58	0.26	0.60	17.31	16.88	16.74	16.41	16.13
November	18.74	0.30	0.52	18.91	18.20	17.99	17.65	16.98
December	19.93	0.32	0.48	19.15	19.05	19.39	18.89	18.29

Table 4: Measured and Calculated Global Solar Radiation for Asaba

MONTH	H_m (MJm^{-2} day^{-1})	a	b	H_1 (MJm^{-2} day^{-1})	H_2 (MJm^{-2} day^{-1})	H_3 (MJm^{-2} day^{-1})	H_4 (MJm^{-2} day^{-1})	H_5 (MJm^{-2} day^{-1})
January	20.06	0.28	0.56	20.75	20.23	20.08	19.90	20.44
February	20.17	0.26	0.60	20.34	20.42	19.96	20.38	21.18
March	20.03	0.23	0.66	18.59	18.84	18.83	19.42	19.68
April	18.55	0.23	0.67	18.12	18.52	18.45	19.18	19.50
May	17.16	0.22	0.68	17.28	17.40	17.56	18.01	18.17
June	15.89	0.21	0.70	15.94	15.19	16.09	15.66	15.30
July	14.38	0.21	0.72	15.23	14.15	15.16	14.40	14.15
August	13.79	0.20	0.73	15.27	14.25	15.03	14.36	14.44
September	14.41	0.19	0.75	14.64	14.30	14.26	14.26	15.22
October	16.34	0.21	0.71	15.63	15.37	15.58	15.64	16.06
November	18.38	0.23	0.66	16.92	16.68	17.18	17.24	17.00
December	19.55	0.28	0.56	20.02	18.82	20.57	19.67	17.81

Table 5: Measured and Calculated Global Solar Radiation for Port - Harcourt

MONTH	H_m ($MJm^{-2} day^{-1}$)	a	b	H_1 ($MJm^{-2} day^{-1}$)	H_2 ($MJm^{-2} day^{-1}$)	H_3 ($MJm^{-2} day^{-1}$)	H_4 ($MJm^{-2} day^{-1}$)	H_5 ($MJm^{-2} day^{-1}$)
January	18.92	0.29	0.55	18.12	17.94	20.54	19.80	19.68
February	19.49	0.26	0.61	16.54	18.18	17.67	18.64	19.01
March	17.95	0.25	0.64	15.94	17.78	15.35	16.89	17.27
April	16.36	0.25	0.63	16.19	18.17	15.38	17.07	17.42
May	15.03	0.26	0.61	16.22	17.10	14.95	15.91	15.96
June	12.07	0.25	0.63	15.19	14.08	14.09	13.48	13.24
July	11.47	0.22	0.70	12.31	11.40	12.50	11.74	11.97
August	12.26	0.20	0.73	11.37	10.78	12.02	11.41	11.89
September	12.21	0.22	0.69	13.55	12.48	12.58	11.98	12.03
October	13.41	0.26	0.61	16.32	14.46	14.27	13.31	12.79
November	15.46	0.28	0.56	17.64	16.13	15.71	14.99	14.32
December	18.18	0.29	0.54	17.84	16.89	17.36	16.72	16.21

Table 6: Measured and Calculated Global Solar Radiation for Calabar

MONTH	H_m ($MJm^{-2} day^{-1}$)	a	b	H_1 ($MJm^{-2} day^{-1}$)	H_2 ($MJm^{-2} day^{-1}$)	H_3 ($MJm^{-2} day^{-1}$)	H_4 ($MJm^{-2} day^{-1}$)	H_5 ($MJm^{-2} day^{-1}$)
January	20.14	0.27	0.60	19.46	19.45	21.16	20.77	20.40
February	20.40	0.25	0.63	18.69	19.34	19.43	19.71	19.55
March	18.69	0.23	0.68	16.60	17.74	16.63	17.41	17.46
April	16.59	0.23	0.67	17.06	18.21	16.63	17.41	17.33
May	15.64	0.24	0.65	17.55	18.01	16.40	16.41	15.67
June	12.50	0.22	0.69	14.91	14.79	14.21	13.61	12.76
July	11.60	0.19	0.76	11.62	11.62	12.06	11.66	11.36
August	11.31	0.18	0.78	10.78	10.87	11.57	11.27	11.16
September	11.96	0.18	0.77	11.64	11.87	11.85	11.67	11.45
October	13.83	0.20	0.73	13.71	13.83	13.32	12.99	12.43
November	16.00	0.23	0.67	15.98	16.07	15.37	15.01	14.26
December	18.47	0.26	0.60	18.80	18.39	18.39	17.49	16.35

Table 7: Measured and Calculated Global Solar Radiation for Akure

MONTH	H_m ($MJm^{-2}day^{-1}$)	a	b	H_1 ($MJm^{-2}day^{-1}$)	H_2 ($MJm^{-2}day^{-1}$)	H_3 ($MJm^{-2}day^{-1}$)	H_4 ($MJm^{-2}day^{-1}$)	H_5 ($MJm^{-2}day^{-1}$)
January	20.39	0.31	0.49	20.78	20.47	21.83	20.68	20.77
February	20.81	0.28	0.56	19.42	20.76	20.35	20.71	21.60
March	20.75	0.29	0.53	21.70	20.45	21.19	20.41	20.58
April	19.25	0.29	0.54	21.56	20.02	20.76	19.95	20.08
May	18.11	0.26	0.60	18.48	18.54	18.28	18.39	19.08
June	16.43	0.24	0.64	16.34	15.50	16.34	15.52	15.78
July	14.73	0.22	0.69	14.27	13.81	14.68	13.88	14.22
August	13.56	0.21	0.70	14.14	13.77	14.66	13.85	14.22
September	15.16	0.23	0.68	15.37	15.13	15.63	15.13	15.61
October	16.95	0.26	0.61	17.39	16.65	17.24	16.62	16.94
November	19.43	0.28	0.57	18.14	17.53	17.94	17.48	17.81
December	20.11	0.29	0.54	18.56	18.52	19.07	18.56	18.91

Table 8: Measured and Calculated Global Solar Radiation for Ado Ekiti

MONTH	H_m ($MJm^{-2}day^{-1}$)	a	b	H_1 ($MJm^{-2}day^{-1}$)	H_2 ($MJm^{-2}day^{-1}$)	H_3 ($MJm^{-2}day^{-1}$)	H_4 ($MJm^{-2}day^{-1}$)	H_5 ($MJm^{-2}day^{-1}$)
January	20.39	0.28	0.56	18.41	18.52	18.29	18.32	18.70
February	20.81	0.27	0.58	19.32	19.36	19.24	19.30	19.75
March	20.75	0.26	0.60	19.67	19.59	19.67	19.71	19.57
April	19.25	0.25	0.63	18.82	18.69	18.75	18.86	19.36
May	18.12	0.25	0.64	18.06	17.93	17.98	18.05	18.39
June	16.43	0.23	0.67	16.40	16.33	16.34	16.33	16.23
July	14.73	0.22	0.69	15.79	15.78	15.78	15.69	15.20
August	13.56	0.21	0.72	14.46	14.78	14.64	14.66	15.30
September	15.20	0.22	0.69	16.18	16.19	16.16	16.16	16.26
October	16.91	0.25	0.63	17.59	17.42	17.51	17.47	16.93
November	19.44	0.26	0.61	17.29	17.18	17.23	17.25	17.14
December	20.11	0.29	0.54	18.45	18.66	18.71	18.61	17.50

Table 9: Measured and Calculated Global Solar Radiation for Lagos

MONTH	H_m (MJm^{-2} day^{-1})	a	b	H_1 (MJm^{-2} day^{-1})	H_2 (MJm^{-2} day^{-1})	H_3 (MJm^{-2} day^{-1})	H_4 (MJm^{-2} day^{-1})	H_5 (MJm^{-2} day^{-1})
January	19.24	0.28	0.56	18.58	18.61	19.19	19.32	20.05
February	20.31	0.30	0.51	21.80	21.54	21.73	21.44	20.22
March	20.23	0.26	0.60	19.24	19.46	18.96	19.17	19.05
April	19.01	0.26	0.61	18.93	19.35	18.70	19.14	19.59
May	16.91	0.24	0.65	16.66	17.24	16.61	17.26	18.58
June	14.33	0.23	0.68	15.42	15.58	15.43	15.60	16.20
July	14.44	0.23	0.68	15.35	15.03	15.41	15.06	14.79
August	14.90	0.20	0.73	13.71	13.53	13.95	13.78	14.34
September	15.08	0.22	0.69	15.50	15.28	15.40	15.14	14.87
October	16.47	0.25	0.63	17.29	17.08	17.04	16.77	15.98
November	18.63	0.27	0.58	18.26	18.15	18.04	17.89	17.07
December	19.36	0.28	0.56	18.35	18.31	18.46	18.43	18.18

Table 10: Measured and Calculated Global Solar Radiation for Ilorin

MONTH	H_m (MJm^{-2} day^{-1})	a	b	H_1 (MJm^{-2} day^{-1})	H_2 (MJm^{-2} day^{-1})	H_3 (MJm^{-2} day^{-1})	H_4 (MJm^{-2} day^{-1})	H_5 (MJm^{-2} day^{-1})
January	20.55	0.30	0.52	18.52	20.22	19.80	20.15	20.56
February	21.54	0.33	0.47	21.48	22.06	21.89	22.06	22.14
March	22.12	0.32	0.49	22.02	21.93	21.64	22.07	22.16
April	20.71	0.28	0.56	20.04	20.25	19.56	20.49	20.96
May	19.22	0.27	0.58	19.01	19.13	18.63	19.31	19.66
June	17.47	0.26	0.61	17.88	17.05	17.57	16.99	16.62
July	15.19	0.22	0.70	15.09	14.90	15.23	14.81	14.73
August	13.95	0.21	0.72	14.47	14.60	14.78	14.53	14.62
September	16.18	0.23	0.66	16.26	16.35	16.27	16.37	16.55
October	17.97	0.28	0.56	18.84	18.29	18.42	18.34	18.20
November	20.15	0.34	0.44	20.94	19.95	20.42	19.93	19.39
December	20.33	0.35	0.41	20.91	20.72	21.16	20.59	20.15

Table 11: Measured and Calculated Global Solar Radiation for Abuja

MONTH	H_m ($MJm^{-2}day^{-1}$)	a	b	H_1 ($MJm^{-2}day^{-1}$)	H_2 ($MJm^{-2}day^{-1}$)	H_3 ($MJm^{-2}day^{-1}$)	H_4 ($MJm^{-2}day^{-1}$)	H_5 ($MJm^{-2}day^{-1}$)
January	21.30	0.31	0.50	20.09	21.43	22.97	21.07	21.04
February	22.30	0.34	0.44	24.18	23.92	25.87	23.64	23.86
March	23.25	0.32	0.48	24.10	23.87	24.12	24.22	24.16
April	21.98	0.29	0.54	21.89	21.36	20.78	21.92	21.79
May	20.04	0.29	0.55	21.50	19.95	20.19	19.99	20.21
June	18.13	0.26	0.60	18.81	17.58	18.43	17.29	17.56
July	15.95	0.24	0.66	16.73	16.18	17.00	15.80	15.98
August	14.75	0.22	0.70	15.02	15.96	15.47	15.97	15.74
September	17.14	0.24	0.66	16.81	17.47	16.15	17.74	17.48
October	19.24	0.28	0.57	19.21	18.56	17.39	18.72	18.75
November	21.45	0.29	0.54	19.15	20.13	18.63	20.58	20.27
December	21.00	0.30	0.51	19.40	20.40	20.16	20.27	20.20

Table 12: Measured and Calculated Global Solar Radiation for Minna

MONTH	H_m ($MJm^{-2}day^{-1}$)	a	b	H_1 ($MJm^{-2}day^{-1}$)	H_2 ($MJm^{-2}day^{-1}$)	H_3 ($MJm^{-2}day^{-1}$)	H_4 ($MJm^{-2}day^{-1}$)	H_5 ($MJm^{-2}day^{-1}$)
January	20.72	0.31	0.49	19.23	20.61	20.61	20.24	20.48
February	21.92	0.32	0.48	21.03	22.73	21.99	22.79	23.27
March	23.15	0.30	0.51	21.44	22.84	21.65	23.30	23.90
April	22.14	0.29	0.54	21.19	21.37	20.56	21.93	22.15
May	20.43	0.28	0.57	19.84	19.95	19.40	20.35	20.62
June	18.64	0.25	0.64	17.62	17.64	17.59	17.72	18.05
July	16.43	0.24	0.65	17.22	16.63	17.21	16.45	16.50
August	15.50	0.23	0.67	16.78	16.38	16.94	16.15	16.34
September	17.56	0.26	0.60	18.75	18.01	18.40	18.01	17.89
October	19.68	0.32	0.47	21.69	19.76	20.44	19.90	18.92
November	21.05	0.36	0.39	22.14	20.88	21.34	20.98	20.05
December	20.89	0.36	0.39	21.29	21.13	21.66	20.86	20.23

Table 13: Measured and Calculated Global Solar Radiation for Yola

MONTH	H_m ($MJm^{-2} day^{-1}$)	a	b	H_1 ($MJm^{-2} day^{-1}$)	H_2 ($MJm^{-2} day^{-1}$)	H_3 ($MJm^{-2} day^{-1}$)	H_4 ($MJm^{-2} day^{-1}$)	H_5 ($MJm^{-2} day^{-1}$)
January	21.54	0.36	0.39	21.56	21.46	21.83	21.41	21.63
February	22.79	0.35	0.42	22.22	22.92	22.68	22.85	23.90
March	23.77	0.34	0.44	22.91	24.02	23.26	23.91	24.94
April	22.76	0.32	0.47	22.40	22.75	22.15	22.61	22.09
May	21.13	0.31	0.50	21.02	21.15	20.79	21.03	20.67
June	19.51	0.29	0.54	19.34	19.23	19.23	19.14	19.20
July	18.25	0.28	0.56	18.40	18.13	18.41	18.07	18.51
August	16.98	0.27	0.58	18.14	18.04	18.23	17.98	18.74
September	18.64	0.27	0.58	17.88	18.06	18.10	17.99	19.18
October	20.93	0.34	0.45	21.68	21.24	21.13	21.11	19.50
November	21.82	0.36	0.39	21.95	21.81	21.75	21.70	20.78
December	21.22	0.37	0.37	21.71	21.29	21.68	21.22	20.51

Table 14: Measured and Calculated Global Solar Radiation for Gombe

MONTH	H_m ($MJm^{-2} day^{-1}$)	a	b	H_1 ($MJm^{-2} day^{-1}$)	H_2 ($MJm^{-2} day^{-1}$)	H_3 ($MJm^{-2} day^{-1}$)	H_4 ($MJm^{-2} day^{-1}$)	H_5 ($MJm^{-2} day^{-1}$)
January	20.95	0.36	0.38	20.85	20.65	21.07	20.72	20.82
February	22.61	0.37	0.38	22.80	22.92	23.00	22.90	23.29
March	23.86	0.35	0.42	23.13	23.72	23.46	23.64	25.06
April	23.23	0.33	0.45	22.86	23.18	22.75	22.65	23.07
May	22.40	0.33	0.46	22.65	22.69	22.36	22.06	21.84
June	20.77	0.32	0.48	21.66	21.39	21.30	20.72	20.15
July	18.64	0.26	0.62	17.97	17.98	18.18	17.60	19.19
August	17.59	0.25	0.62	18.04	17.98	18.23	17.58	19.05
September	19.49	0.29	0.55	19.75	19.62	19.67	19.09	19.57
October	21.23	0.33	0.46	20.91	20.76	20.64	20.21	19.83
November	21.03	0.37	0.37	21.40	21.22	21.28	20.96	20.38
December	20.37	0.37	0.38	20.26	19.99	20.37	19.99	19.81

Table 15: Measured and Calculated Global Solar Radiation for Maiduguri

MONTH	H_m (MJm^{-2} day^{-1})	a	b	H_1 (MJm^{-2} day^{-1})	H_2 (MJm^{-2} day^{-1})	H_3 (MJm^{-2} day^{-1})	H_4 (MJm^{-2} day^{-1})	H_5 (MJm^{-2} day^{-1})
January	20.65	0.37	0.37	21.55	20.71	21.46	20.91	20.79
February	22.90	0.35	0.41	22.24	22.52	23.17	22.88	23.22
March	24.47	0.33	0.46	22.71	24.22	24.57	24.65	25.38
April	24.10	0.32	0.48	22.63	24.10	23.32	23.90	23.94
May	23.05	0.32	0.48	22.53	23.54	22.61	23.17	22.93
June	21.25	0.30	0.52	21.05	21.16	20.90	20.99	21.02
July	19.46	0.27	0.59	18.98	18.44	19.29	18.75	19.53
August	17.95	0.27	0.58	19.48	18.41	19.10	18.53	18.94
September	20.12	0.31	0.49	21.60	20.73	20.20	20.22	19.59
October	21.63	0.34	0.43	22.23	22.09	21.22	21.54	20.73
November	21.52	0.37	0.38	21.68	21.45	21.18	21.21	20.64
December	20.18	0.36	0.39	20.35	19.63	20.34	19.83	19.79

Table 16: Measured and Calculated Global Solar Radiation for Birnin Kebbi

MONTH	H_m (MJm^{-2} day^{-1})	a	b	H_1 (MJm^{-2} day^{-1})	H_2 (MJm^{-2} day^{-1})	H_3 (MJm^{-2} day^{-1})	H_4 (MJm^{-2} day^{-1})	H_5 (MJm^{-2} day^{-1})
January	19.86	0.37	0.37	21.35	19.78	21.21	20.45	20.03
February	22.40	0.33	0.46	21.33	21.03	22.05	21.95	22.70
March	24.33	0.33	0.46	23.08	23.49	23.73	24.46	25.12
April	24.52	0.33	0.47	23.89	24.20	23.80	25.01	24.86
May	23.66	0.33	0.47	23.93	23.56	23.40	24.26	23.63
June	22.82	0.31	0.50	22.75	21.61	22.09	22.24	21.60
July	19.96	0.27	0.58	20.94	19.58	20.68	20.27	20.30
August	18.43	0.25	0.63	19.71	18.59	19.88	19.36	20.02
September	20.44	0.26	0.60	20.00	19.09	19.99	19.81	20.15
October	21.52	0.31	0.51	20.74	20.10	20.48	20.76	20.54
November	20.52	0.34	0.43	20.55	19.78	20.43	20.44	20.19
December	19.62	0.36	0.40	20.07	18.70	19.96	19.34	19.04

Table 17: Measured and Calculated Global Solar Radiation for Gusau

MONTH	H_m (MJm^{-2} day^{-1})	a	b	H_1 (MJm^{-2} day^{-1})	H_2 (MJm^{-2} day^{-1})	H_3 (MJm^{-2} day^{-1})	H_4 (MJm^{-2} day^{-1})	H_5 (MJm^{-2} day^{-1})
January	20.24	0.32	0.48	20.65	20.24	20.87	20.22	20.15
February	22.61	0.33	0.46	23.00	23.19	23.12	23.07	22.90
March	24.37	0.32	0.48	24.27	25.47	24.54	25.33	25.48
April	24.82	0.30	0.53	23.70	25.06	23.73	24.82	24.90
May	23.90	0.28	0.56	22.64	23.60	22.65	23.39	23.51
June	23.11	0.27	0.58	21.59	21.76	21.51	21.58	21.60
July	20.00	0.25	0.63	19.79	19.89	20.16	19.93	20.61
August	18.53	0.26	0.61	20.34	20.16	20.50	20.13	20.49
September	20.98	0.30	0.53	22.80	22.03	21.98	21.58	20.52
October	21.51	0.30	0.52	21.67	21.69	21.25	21.37	20.80
November	20.59	0.31	0.50	20.28	20.55	20.44	20.47	20.50
December	19.85	0.32	0.49	19.65	19.30	19.84	19.27	19.23

Table 18: Measured and Calculated Global Solar Radiation for Kano

MONTH	H_m (MJm^{-2} day^{-1})	a	b	H_1 (MJm^{-2} day^{-1})	H_2 (MJm^{-2} day^{-1})	H_3 (MJm^{-2} day^{-1})	H_4 (MJm^{-2} day^{-1})	H_5 (MJm^{-2} day^{-1})
January	20.40	0.36	0.38	21.10	20.33	21.13	20.42	20.31
February	22.98	0.35	0.42	22.11	22.20	22.71	22.62	23.03
March	25.05	0.34	0.43	23.78	24.71	24.51	25.15	25.70
April	25.35	0.34	0.44	24.28	25.36	24.26	25.26	25.25
May	24.25	0.34	0.43	24.48	25.04	23.82	24.53	23.99
June	22.80	0.31	0.50	22.41	22.35	21.98	22.05	21.77
July	20.32	0.28	0.56	20.61	20.25	20.68	20.33	20.57
August	19.21	0.28	0.57	20.24	19.82	20.41	19.97	20.29
September	21.06	0.29	0.53	20.83	20.66	20.73	20.60	20.65
October	21.38	0.32	0.47	21.21	21.50	21.12	21.41	21.37
November	20.54	0.36	0.39	21.38	21.21	21.14	21.06	20.75