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Dear Sir/Ma,

**RE: REQUEST FOR SIGNING AND STAMPING FOR MSc PROJECT DISSERTATION**

I write on behalf of ADEBAYO SUNDAY ADENIYI (Matric. No. 82604) who has requested our Department to provide him with a signed and stamped copy of his MSc project dissertation in respect of his completed MSc degree in Mechanical Engineering. The effective date of award of his M.Sc degree was 24th September, 2007.

Please find attached the document signed and stamped as requested.

Thank you.

Yours faithfully,

19/11/2021

**Dr. I. F. Odesola**
**Ag. Head of Department**

# EMPIRICAL MODELS FOR ESTIMATION OF CLEARNESS INDEX IN NIGERIA

**BY**

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**B.Sc (Hons) MECHANICAL ENGINEERING (IBADAN)**

**MATRIC NO. 82604**

**A PROJECT IN THE DEPARTMENT OF MACHNICAL ENGINEERING**

**SUBMITTED TO THE FACULTY OF TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE OF**

**UNIVERSITY OF IBADAN**

**MAY 2007**

# ABSTRACT

Knowledge of clearness index is essential in the design and assessment of solar application systems. Clearness index is the ratio of global solar radiation and extraterrestrial solar radiation. However, actual measurements of global solar radiation are generally made only at a few places because of the cost of the equipment required as well as the care, skill and cost needed for its maintenance and re-calibration. Therefore this study is aimed at development of Angstrom-Prescott based empirical regression models for estimation of clearness index values for Nigerian locations based on sunshine duration hour. Ten empirical regression equations (Linear, Quadratic, Compound, Growth, Logarithm, Cubic, S' Exponent, Inverse and Power) were investigated using daily sunshine duration hour data values of 24 ground stations obtained from Nigeria meteorological agency (NIMEF) Oshodi, and averaged monthly values extraterrestrial solar radiation Ho obtained from NASA surface meteorology and Solar Energy SSE Satellites dataset for the same period 1983 – 1993. Twenty of the twenty four locations were observed to have fairly high $R^2$ values ranging from 67.202% to 94.286%. The remaining four locations have lower $R^2$ values ranging from 1.836% to 42.724%. The remaining four locations have lower $R^2$ values ranging from 1.836% to 42.724%. The observed high values of $R^2$ for twenty out of the twenty – four locations confirmed the general applicability of Angstrom Prescott Models to Nigerian locations. Result also shows that best estimation for different locations are obtained for different models. For the twenty four locations exponent functions have best predictive efficiencies for nine locations (37.50%), cubic functions six location (25.00%) while quadratic, power and S functions have best predictive efficiencies in three locations each (12.50%). Therefore exponent function defined in the form was found to have the highest and most general applicability for Nigerian locations. Solar maps depicting monthly averaged values of clearness index $K_t$ for the 12 months as well as a trend analysis of Clearness. Index of the studied locations with months were also developed in the study. Minimum values were observed to occur between June and August while maximum values occur between November and February for most Nigerian locations. These roughly correspond to the rainy and dry seasons in the country. The models are accurate for the prediction of Clearness index values based on sunshine durations hour. The exponent models are useful for the preliminary design of solar application systems as well as for providing supporting tools for agricultural and meteorological research activities in Nigeria.

## CERTIFICATION

I certify that Adebayo, Sunday Adeniyi of the Department of Mechanical Engineering, University of Ibadan, Ibadan, Nigeria, carried out this project work under my supervision.

| | |
|---|---|
| 15/05/07. | 15/05/2007 |
| ................................ | ................................ |
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## DEDICATION

I wish to dedicate this project work to the Almighty God for seeing me through the thick and thin of this research work

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## ACKNOWLEDGMENT

Firstly I wish to acknowledge the priceless guidance I received from my supervisor, Dr. David Fadare, my figurative football coach who guided me well in kicking the ball of research towards the goal post when it was passed to me. Your open-mindedness and multidisciplinary approach in research work is worthy of emulation.

I also wish to acknowledge in very great measure the contribution made by Drs. Salary and ESD Afrifa, and oilier members of staff of the Dept of Mechanical Engineering for their relentless support during this period of study.

Also of immense value is the support of Mr. & Mrs. J.O Adebayo my parents, - your words of wisdom keep me going everyday.

I also wish to acknowledge the kind support of my best friend Ifeyinwa Nzeadibe. Your love makes big things look small for me.

Lastly I wish to acknowledge the numerous people I came in contact with during this research work such as Mr. Oniarah of NIMET, Oshodi; Mr. Eniayenwu of IITA, Ibadan; Dr Mrs. Ngozi Amucheazi, the Acting librarian, UNN, Nsukka,; Dr Oparaku of Center for Energy Research & Training, UNN, Nsukka; Mr. Olu Onafeso of Geography Dept, OOU, Ago-Iwoye; Engr Idowu Ogunsola of Industrial Engrg Dept, U.I, Ibadan , Sola Orimogunje, Bimbo and a lot of people whose contributions made this project work a huge success. Thank you all.

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# CHAPTER ONE

# INTRODUCTION

## 1.1 ENERGY RESOURCES POTENTIAL AND UTILIZATION IN NIGERIA

Energy can simply be grouped into two: Renewable Energy and Non-Renewable Energy. Renewable Energy RE includes solar, wind, hydro, oceanic, geothermal, biomass, and other sources of energy that are derived from "sun energy", and are thus renewed indefinitely. Non-Renewable Energy NRE, on the other hand, includes fossil fuel (petroleum and natural gas), coal, nuclear resources, etc. Even with the various harmful effects of NRE utilization on the environment; their price volatility, and their insecurity of supply; fossil fuel still enjoys increasing use today. Significant gains have been made in creating awareness by government agencies, researchers and non-governmental organizations that only RE could last forever and the choice we make in RE development now will pay off later in an efficient, clean, convenient, and affordable energy future.

On a local scale however, Nigeria is an energy-resource rich country. She is blessed with both- NRE such as crude oil, natural gas, coal, uranium ores, and RE like solar, wind, biomass, biogas, hydro, oceanic, geothermal and other sources (if energy, that are derived from "sun energy", and are thus renewed indefinitely. Nigeria is also human resource rich with a total population of 140 million by the 2006 population census and an annual population growth rate of about 2.8% (NPC 2006).

Chendo (2001) estimates the NRE potentials of Nigeria. According, to him, the reserve for crude oil in Nigeria stood at about 23 billion barrels in 1998, natural gas 4293 billion cubic meters in 1999. Coal and lignite stood at 2.7 billion tonnes, tar sands at 31 billion barrels of oil equivalent and large-scale hydropower potentials also stood at 10, 6000MW.

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On the other hand, efforts are still on going to produce comprehensive survey and mapping of Renewable Energy in Nigeria. It is however clear that the solar, wind, nuclear, tidal and hydropower energy potentials of the country are very enormous and under-utilized.

## 1.2 REVIEW OF RENEWABLE ENERGY (SOLAR) ISSUES AND ACTIVITIES IN NIGERIA

The *ESMAP Technical Paper 073/05 (ESMAP 2005)* gave a comprehensive report on most existing renewable energy activities in Nigeria. The report was subsequent to the UNDP/WORLD BANK and ECN jointly sponsored workshop in March 2001. The overall objective of the workshop was to examine approaches to expanding the use of renewable energy technologies through identifying barriers to renewable energy market development, and to offer strategies for removing these barriers.

At the ESMAP workshop, Prof C.E. Okeke in a paper titled *"Renewable Energy Technology Development in Nigeria," (ESMAP 2005),* highlighted the unique contributions of the Energy Commission of Nigeria, ECN, and its research centers in the areas of solar water heaters, solar crop and manure dryers, improved wood and other domestic solid fuel stoves, solar cookers and solar energy application in poultry production.

He explained the benefits of solar PV by presenting examples of some solar PV electrification projects in Nigeria and the results of two surveys of PV systems installation carried out by the ECN. The results gave the status of these systems in nine states of the country and areas of application via water pumping, refrigeration, lighting, village electrification, and radio, telecommunications, and TV.

In addition to the ESMAP workshop, RE policy issues were critically addressed and reported in the *"Communique of the National Workshop on Creating Demand and Removing Barriers to Renewable Energy Market* Development in *Nigeria"* (ECN 2005), organized by the Energy Commission of Nigeria, in collaboration with the United States Agency for International Development, the World Bank, the United Nations Development Program, the African Development Bank, the Government of Norway, and Shell Petroleum Development Company Nigeria, Limited. The main objectives of the workshop were to identify all barriers militating against renewable energy market development in Nigeria; propose strategies for the removal of the identified barriers and propose comprehensive RE development program for Nigeria. The workshop was also aimed at reviewing and improving solar and wind maps for the whole Of Nigeria as well as improvement of small-scale hydro potential data and mapping.

At present, the Federal Government of Nigeria is making a efforts at producing a comprehensive Renewable Energy Master plan for the country. This research work is aimed.at estimating solar radiation for Nigeria using polynomial regression models in consonant with the ongoing Master plan.

### 1.3 OBJECTIVES OF THE PROJECT

The objectives of this project work are to:

1. Estimate the total yearly extraterrestrial solar radiation incident on the entire landmass of Nigeria using geometrical calculation and monthly averaged extraterrestrial solar radiation data of all grids measured by NASA SSE satellites.
2. Develop polynomial empirical regression models for estimating Clearness indices $K_T$ of 24 locations in Nigeria.
3. Investigate the polynomial function with highest general applicability for estimating the monthly averaged Clearness Indices $K_T$, in Nigeria, as an appropriate tool for the design, sizing .and assessment of solar application systems.

### 1.4 JUSTIFICATIONS OF THE PROJECT

There are only few ground locations in Nigeria where global solar radiations are measured in Nigeria. Clearness Index is the ratio of global solar radiation and extra terrestrial solar radiation. However NASA SSE data covers Nigeria entirely. This widely reported scarcity of Clearness index data; and the need for a general, yet easy-to-carry-out method of estimation of Clearness Index $K_T$, in the design and performance analysis of solar powered system as well as ecophysiological and agricultural studies for all locations in Nigeria for any month of the year justifies this project research work.

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## 1.5 SCOPS OF THE PROJECT

This project work covers twenty-four locations in Nigeria. The data covers the period 1983-1993. The twenty-four locations are scattered across Nigeria and include: Akure, Bauchi, Benin, Bida, Calabar, Enugu, Gusau, Ibadan, Ikeja, Ilorin, Jos, Kaduna, Kano, Lokoja, Maiduguri, Ogoja, Oshogbo, Ported Harcourt, Potiskum, Shaki, Sokoto, Warri, Yelwa, and Yola. The project work involves both ground and satellite data.

## 1.6 LIMITATIONS OF THE PROJECT

This project work provides maps for easy estimation of monthly averaged Clearness index values for 24 locations in Nigeria.

It also provides graphs showing the trends of monthly averaged values with months of the year.

The monthly averaged Clearness index is the essential input variable for the sizing and design of solar energy (photovoltaic) powered systems, which could be used for applications such as water pumping, refrigeration, lighting, heating as well as ecophysiological studies involving meteorological data.

However, the results of the study are not recommended for locations outside Nigeria and four locations in Nigeria. This was because of the low $R^2$ values observed for models at these four locations. These four models might not perform than models proposed by other authors for those locations.

Two typical applications of solar energy system are shown in figures 1.1 and 1.2.

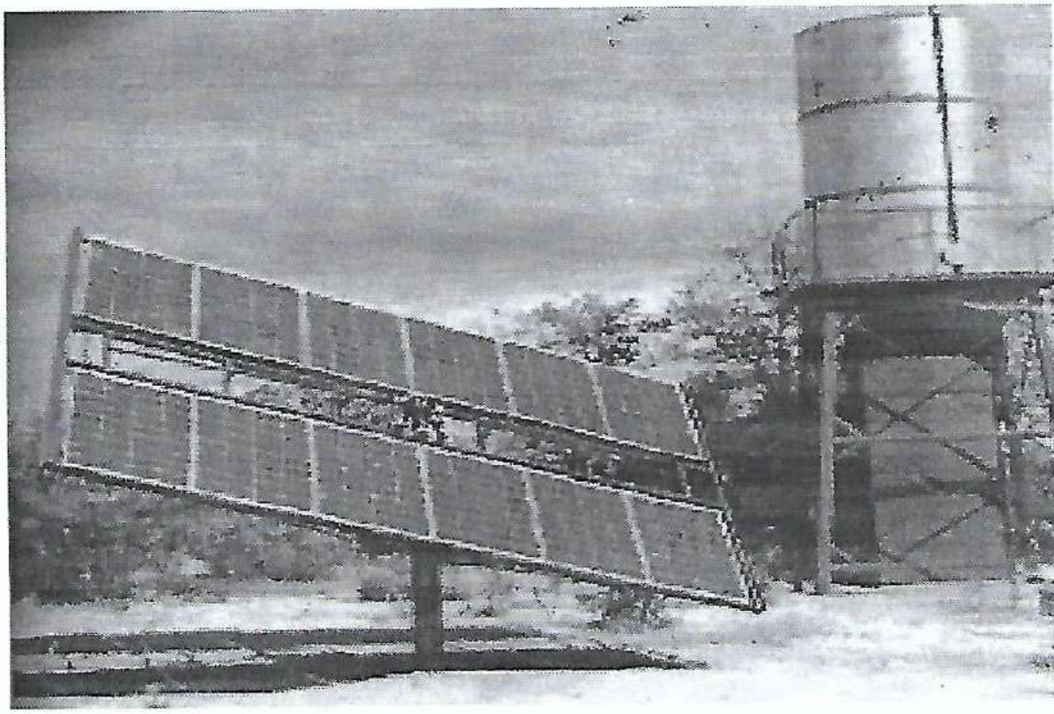

**Figure 1.1: Typical Small Community Water Supply System Powered by Twelve Solar Modules with Cylindrical Overhead Water Storage Tank.**

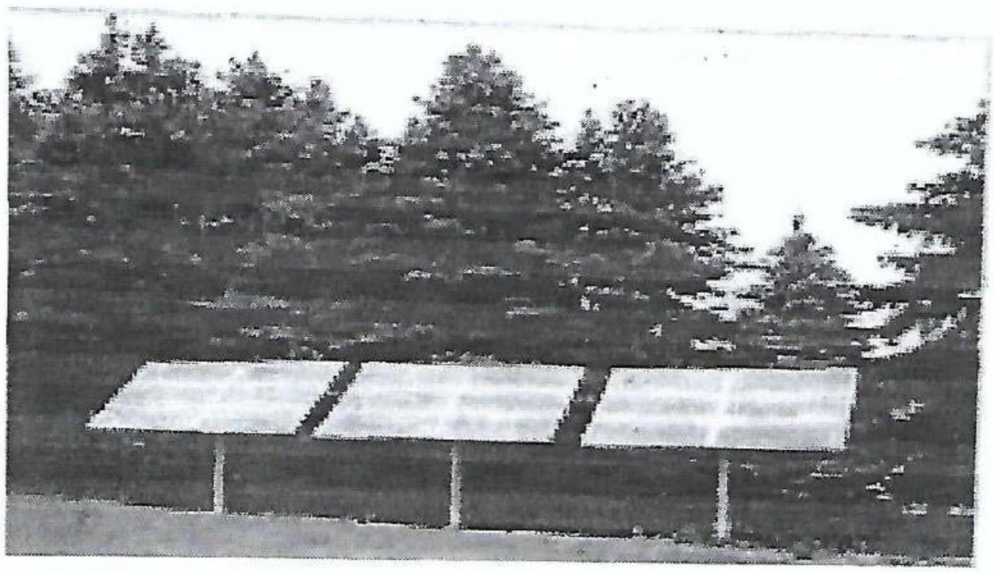

**Figure 1.2: Eighteen Solar Modules Connected & Supported on fixed Racks for a Water Pumping Application**

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 REVIEW OF COMMON MODELS FOR ESTIMATING SOLAR RADIATION DATA PARAMETRES IN NIGERIAN ENVIRONMENT

All the literatures reviewed agreed on the essentiality of knowing the sunshine hours and global solar radiation of any location before the design and installation of solar PV systems could be done. They all differ in one way or another by the methods and parameters they employ in the estimation of these two important variables.

However all these models could be classified into two broad groups based on:

1. The methodology employed in their models
2. The type of data employed in their models.

Based on their methodologies, most common models could further be classified as

1. Empirical Regression Models i.e. models based on regression of one or more parameters or ratios and picking model with best fit and least errors values.
2. Fourier Series Models i.e models based on analysis of modeling parameter with time.
3. Artificial Neural Network Models i.e. models based on analysis of several parameters.

The third group is the latest of the group and it tends to be more relatively robust but could only be developed with a computer and by a highly- trained personnel. Works on the second are sparse while the first (regression method) is the most common and easy to develop model.
On the other hand based on da {a. type Used in most common models could also be further classified as

1. Ground Data Models ie. models teased on ground data collected by ground based meteorological and/or weather" instruments.
2. Satellite Data Models i.e. models based on geo-synchronous satellite collected data, which could either be corrected/and or adjusted by ground data or not.

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The first method presupposes the measurement of weather data on the ground.
In developing these models, the measured data includes: daily sunshine duration hour (measured with a Campbell-Stokes Sunshine paper recorder).; Global or total solar radiation (measured with a pyrrheliometers or radiometer); Diffuse solar radiation (measured with a radiometer); Direct solar radiation (measured with a pyrrheliometers); Daily temperatures; Solar declination; Latitude; Longitude; Rainfall level (measured with rain gauge); Relative humidity (measured with hydrometer); Atmospheric air pressures etc.

The daily readings of these data are usually averaged for each of the twelve months to finally arrive at monthly averaged values of the parameters, which are subsequently used in the modeling.

Ratios of some of these parameters are also used in the analysis such as:

1. Clearness index: ratio of monthly averaged global solar radiation to monthly averaged extraterrestrial radiation
2. Cloudiness index: ratio of monthly averaged sunshine hour to monthly averaged maximum possible sunshine hour in a month

As mentioned earlier, the regression method (either for ground based data or satellite data) is the most common and easy to develop model. It could however be based on linear, quadratic, or even a polynomial regression of global solar radiation (or clearness index) to other parameters or cloudiness index. The foregoing are some of the common solar parameter models for Nigeria and other regions.

## 2.2 EMPIRICAL REGRESSION MODELS

Again these models could be classified as:

i. Empirical Regression Models for Nigerian Locations; and
ii. Empirical Regression Models For other locations outside Nigeria.
iii. Empirical Regression Models For Nigerian Locations

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### 2.2.1 Udol & 2 MODELS:

According to. Udo (2002), both linear and quadratic regressions exist between global solar radiation' and sunshine hours for Ilorin, a tropical region in Nigeria.. The regression models were called ANGSTROM-PRESCOT BASED MODELS because they involved regressing clearness index to cloudiness index. Monthly averaged daily values of clearness index and cloudiness index for a period of two years were used to develop two equations one linear, one quadratic. The predictive efficiencies of the two models were judged in terms of their Mean Bias Error (MBE), Mean Absolute Bias Error (MABE) and Root Mean Square Error (RMSE). These are compared with error values of other common models.

The equations and error values are:

$K_T$ = $0.23+0.48K$, r = 95.89%. (Linear Udo model).......................2.1

$K_T$ = $0.053 + 1.28K - 0.83k^2$, r=96.97%, (Quadratic Udo model)........2.2

He compared the models with some other models for the region and concluded that they could be used for estimating global solar radiation for other locations with similar geographical attributes with Ilorin.

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$K_T = 0.23+0.48K$, r = 95.89%. (Linear Udo model)............................2.1

$K_T = 0.053 +1.28K-0.83k^2$, r = 96.97%, (Quadratic Udo model)........2.2

He compared the models with some other models for the region and concluded that they could be used for estimating global solar radiation for other locations with similar geographical attributes with llorin.

### 2.2.2 Fagbenle 1& 2 Models:

Fagbenle, in Fagbenle (1991), developed two models, one linear one quadratic for three locations (Benin, Ibadan and Samaru) in Nigeria and reported the following equations and error values.

$K_T = 0.212+0.556K$, (Linear Fagbenle model)............................2.3

$K_T=0.375+0.128K+0.660K^2$, (Quadratic Fagbenle model)..........2.4

### 2.2.3 Akpabio-Etuk model:

In *Akpabio et al (2003),* the authors established Angstrom-type regression between measurements of global solar radiation and sunshine duration data during the period from 1981 to 1999 at Onne, which lies between the rainforest climatic zones of southeastern Nigeria.

They compared the predictive performance values (%MBE, %RMSE and r) of the model with that of five other models applicable to the region and recommended that tine model is better; suitable for the region and could also be used to estimate the global solar radiation of other region with similar geographical and climatic characteristics with Onne. The equation and error values are given as follows.

$K_T= 0.23+0.38K$, r=0.80 (Linear Akpabio-Etuk model)............... .2.5

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### 2.2.4 Ododo's 5 Reviewed Angstrom-Prescott-Page Models:

*Ododo et al (2005),* while investigating the applicability of Swartman-Ogunlade equations to Nigerian Stations collected meteorological data for 24 stations located in different geographical and climatic zones in Nigeria and analyzed both the original 'Swartman-Ogunlade equations and their modified forms; the Angstrom-Prescott equation and an equation that uses both the relative sunshine duration and maximum air temperature.

They showed that the original Angstrom-Prescott-Page equation is in the form:

$K_T = H/Ho; H/Ho = a0 + a1\ (n/N)$ ......... .. ........................... 2.6

Where

$K_T = H/Ho$ and $K = n/N$.

The original Swartman-Ogunlade equations are:

$H = b0 * (n/N)^{b1} * R^{b2}$ ............................................ 2.7

And $H = c0 + c1 * (n/N) + c2 * R$ .......................................... 2.8

Where $K_T$ -clearness index, K=cloudiness index, n=sunshine duration hour, N=maximum possible sunshine hour, H=global solar radiation, Ho=extraterrestrial solar radiation, R =relative humidity.

The original Angstrom-Prescott-Page equation is represented in a better form as:

$YOl = H/Ho$; $H/Ho = a0 + al\ (n/N)$. (Ododo 1) ......................... 2.9

The modified Swartman-Ogunlade equations are:

$Y * Hol3 = H$; $H = a0 * (n/N)_{a1} * R^{a2}$ (Ododo 2) ................................ 2.10

And $Y * Hol3 = H$; $H = a0 + al * (n/N) + a3 * R$. (Ododo 3) ........... 2.11

Introducing maximum air temperature Tm into the original equation did the modification of' the Angstrom-Prescott equation. Simply replacing H by H/Ho did the modification of the Swartman-Ogunlade equations:

Y013= H/Ho; H/Ho =a0 * (n/N) $^{al}$ * R $^{a2}$ (Ododo 4) modified Swartman-Ogunlade modell ............................................. 2.12

Y 013= H/Ho;

H/Ho =a0 + al* (n/N) + a3 *R. (Ododo 5) modified Swartman-Ogunlade Model.................................................................................................... 1.2.13

And Y 012 = H/Ho; H/Ho=a0 + al*(n/N) + *a2* * Tm. (Ododo 6) modified Angstrom-Prescott Equation .................................................. 2.14

The above six equations were analyzed in turn for 24 Nigerian locations and their "efficiencies" as indicated by a number of goodness-of-fit indices compared.

They concluded that the modified Swartman-Ogunlade equations give better fits than the Angstrom-Prescott equation; while for a majority of stations the best fit is given by the equation involving both sunshine duration and maximum relative temperature (i.e. modified Angstrom-Prescott equation, Ododo6).

ii. Empirical Regression Models for Other Locations outside Nigeria.

**2.2.5 Rierveld Model:**

Rietveld, in Rietveld (1978), developed a linear model, which is believed to applicable to all regions in the world and yields superior results for cloudy conditions for K<0.4.

The model and its error values are: $K_T$=0.18+0.62K, (Linear Rietveld model)........................2.15

**2.2.6 Glover Model:**

Glover and McCulloch, in Glover *et al.,* (1958), developed[7] empirical regression models with latitude dependency introduced to the linear model. The equation and error values are given as follows.

$K_T$=0.29 cos (K)+0.52K, k<60° (Linear Glover model)......................2.16 '

### 2.2.7 Ogelman Quadratic Model:

Ogelnian, Ecevit and Tasdemiroglo, in Ogelman *et al* (1981), proposed the use of a correlation which relates the global solar radiation for Ankara and Adana in Turkey, to K in a quadratic form with error values.

$K_T$ = 0.195+0.675K-0.142K2, (Quadratic Ogelman model)..................2.17.

### 2.2.8 Akioglu and Ecevit model:

Akioglu and Ecevit, in Akioglu *et al* (1993), proposed a model for estimating global solar radiation for 58 different locations in several countries in quadratic form with the following error values.

$K_T$=0.145+0.845K-0.2SOK2, (Quadratic Akioglu model).................. .2.18

### 2.2.9 Turton Model:

Turton, in Turton (1987), developed a linear Angstrom based model applicable for the humid tropical countries with following equation and error values.

$K_T$=0.30+0.40K. r=0.82 (Linear Turton model).............................2.19

### 2.2,10 BADESCU'S 5 SIMPLE CLEAR SKY SOLAR RADIATION MODELS:

Badescu in Badescy (19970, reviewed five different models for estimating clear sky irradiance and applicable to Romania. The models aire very simple and the include

#### a. The Danehyar-Paltridge-Proctor Model DPP model:

Io=950.2 *(l-exp (-0.075(PI/2iX>))...........................................2.20a

Do=14.29+21.04*(PI/2-z)...,................................................,.2.20b

Go=Io+ Do.........................................................................2,20c

Where lo is indirect or diffuse radiation in W/m2, Do=direct radiation in W/m2; Go=global solar radiation in W/m2 and z=zenith angle in radians

**b. The Kasten-Czesplak KC Model:**

Go=910 *cos (z-30)..........................................................2.21

**c. The Ilourwitz II Model:**

Go=1098 * cos._(z) * exp (-0.057/cos(z)).......................................2.22.

**d. The Berger-Duffie Model (BD)**

Go =1350*0.70*cos (z)...............................................................2.23

**e. The Adnot-Bourges-Campana-Gicquel ABCG Model:**

Go=951.39*cos $^{(1.15)}$ (z)......'.'.........................................................2.24

## 2.3 FOURIER SERIES MODELS

There is a dearth of literatures on Fourier series modeling of solar parameters I Nigeria. However Fagbenle, in Fagbenle (1995), established that parameters of the first harmonic might be used to estimate the global solar irradiation in Ibadan within 10% of the data for any year. His work was based on application of theory of Fourier series analysis to monthly-averaged daily Climatological series.

## 2.4 ARTIFICIAL NEURAL NETWORK MODELS

Similar to Fourier Series Models, there is also a dearth of literatures on the application of Neural Network to modeling of solar radiation parameters in Nigeria. However, Jiya and Alfa utilized the principle of Artificial Neural Network in estimating global solar radiation for Nigerian locations. Jiya and Alfa ANN model: According to Jiya *et al (2002),* geostationary satellite imageries and artificial neural network could be used for determination and forecasting of global solar radiation conditions even at locations where there is an absence of sufficient network of solar radiation data collection stations. The authors used a multilayer perception neural network for parametizing monthly mean daily values of global solar radiation on horizontal surface. The neural network uses latitude, longitude, altitude, sunshine duration and period number to parameterize solar radiation values. The network consists of 5 inputs, 12 neurons in the one hidden layer and one neuron in the output layer. The latitude, longitude, altitude, sunshine hour and time indicator were used as inputs while the output is the ratio of monthly mean daily values of global solar radiation or KT. The network was done for 24 locations in Nigeria.

## CHAPTER THREE

## MATERIALS AND METHODS

### 3.1 DATA USED IN THE PROJECT WORK AND THEIR SOURCES

The data used in the project work are divided into two broad groups namely:

i. Ground station data values of daily sunshine duration hour, latitude, longitude and altitude were obtained from Nigerian Meteorological Agency Oshodi for twenty-four (24) stations in Nigeria spanning a 10-year period between 1983-1993; and

ii. Satellite data values of monthly averaged global solar radiation H, monthly averaged extraterrestrial solar radiation Ho, monthly averaged Clearness index $K_T$ and monthly averaged maximum possible sunshine hour N, for twenty-four (24) locations in Nigeria were obtained from NASA Surface meteorology and Solar Energy SSE data archive available at http://www.eosweb.larc.nasa.gov/sse.

The data also covers the period 1983-1993.

### 3.1.1 GROUND DATA COLLECTED' FROM NIMET: LATITUDE, LONGITUDE, STATION NUMBER & ALTITUDE

Table 3.1 below shows the latitudes, longitudes, meteorological station numbers and average elevations for twenty-four stations used I this study as collected by NIMET.



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**Table 3.1 Twenty-Four Well-Spread Locations in Nigeria with their Latitudes, Longitudes and Station Numbers**

| S/No | Location | Lat. (°N) | Long. (°E) | Station No | Average Altitude (m) |
|---|---|---|---|---|---|
| 1 | Akure | 7.28 | *~530* | 65232 | 375.0 |
| 2 | Bauchi | 10.28 | 9.82 | 65055 | 609.0 |
| 3 | Benin | 6.32 | 5.10 | 65229 | 77.8 |
| 4 | Bida | 9.10 | 6.02 | 65112 | 144.3 |
| 5 | Calabar | 4.97 | 8.35 | 65264 | 61.9 |
| 6 | Enugu | 6.47 | 7.55 | 65257 | 141.8 |
| 7 | Gusau | 12.17 | 6.70 | 65015 | 463.9 |
| 8 | Ibadan | 7.43 | 3.90 | 65208 | 227.2 |
| 9 | Ikeja | 6.58 | 3.33 | 65201 | 39.4 |
| 10 | Ilorin | 8.48 | 4.58 | 65101 | 307.4 |
| 11 | Jos | 9.87 | 8.90 | 65134 | 472.5 |
| 12 | Kaduna | 10.60 | 7.45 | 65019 | .645.4 |
| 13 - | Kano | 12.05 | 8.20 | 65046 | 472.5 |
| 14 | Lokoja | 7.78 | 6.73 | 65243 | 62.5 |
| 15 | Maiduguri | 11.85 | 13.08 | 65082 | 353.8 |
| 16 | Ogoja | 6.67 | 8.80 | 65275 | 117.0 |
| 17 | Oshogbo | 7.78 | 4.48 | 65215 | 302.0 |
| 18 | P/Harcourt | 4.85 | 7.02 | 65250 | 19.5 |
| 19 | Potiskum | 11.70 | 11.03 | 65073 | 414.8 |
| 20 | Shaki | 8.67 | 3.38 | 65108 | 278.0 |
| 21 | Sokoto | 13.02 | 5.25 | 65010 | 350.8 |
| 22 | Warri | 5.52 | 5.73 | 65236 | 6.1 |
| 23 | Yelwa | 10.88 | 4.75 | 65001 | 2440 |
| 24 | Yola | 9.23 | 12.47 | 65167 | 186.1 |

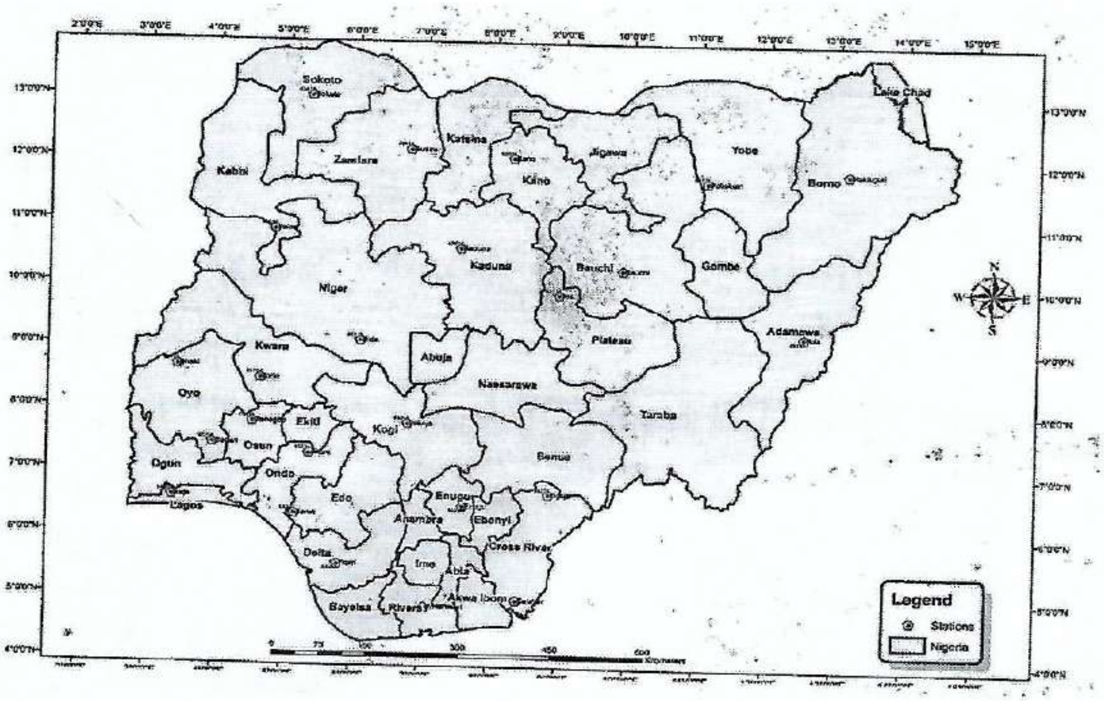


**Figure 3.1 Map of Nigeria Showing the Studied Twenty-Four Locations**

Figure 3.1 above is a map showing the twenty-four locations having consistent daily sunshine hour data with their latitudes and longitudes. The locations are spread across Nigeria and covered twenty-two out of thirty-six states in Nigeria.

### 3.1.2 SSE SATELITE DATA: MONTHLY AVERAGED VALUES OF H, Ho, & N.

The latitudes and longitudes of the twenty-four locations were used in deriving the monthly averaged values of global solar radiation, extraterrestrial solar radiation, and maximum possible sunshine duration for the period 1983-1993 from http://www.eosweb.larc.nasa.gov/sse.

## 3.2 ESTIMATION OF TOTAL YEARLY EXTRATERRESTRIAL SOLAR RADIATON FOR ENTIRE NIGERIAN LANDMASS.

Extraterrestrial Solar radiation Ho, is the amount of solar radiation coming directly from the sun and available beyond the atmosphere. Geosynchronous satellites placed in space easily measure Ho. NASA Surface meteorology and Solar Energy SSE satellites measure several solar radiation parameters on a 1° by 1° (latitude by longitude) grids covering the entire globe. If the total number of grids in which a country falls in is estimated, the sum of all extraterrestrial solar radiation of each grid gives the total extraterrestrial solar radiation of the country

The methodology for estimating the total yearly extraterrestrial solar radiation is as follows:

i. the range of latitude within which Nigeria falls was estimated by subtracting the minimum latitude value of Nigeria from its maximum latitude value.

ii. the range of longitude within which Nigeria falls was also estimated by subtracting its minimum longitude value from its maximum longitude value.

iii. Bearing in mind that the satellite grid size is 1° by 1° (latitude by longitude) all the grids in which Nigeria falls were listed out.

iv. For each grid in which Nigeria falls, the monthly averaged extraterrestrial solar radiation, collected from NASA SSE data, for the twelve months of the year was summed up to derive the total yearly extraterrestrial solar radiation of each grid.

v. the total yearly extraterrestrial solar radiation of ALL the grids in which Nigeria falls as derived in step above was summed up to derive the total yearly extraterrestrial solar radiation of Nigeria.

## 3.3 DEVELOPMENT OF POLYNOMIAL REGRESSION MODELS FOR ESTIMATING CLEARNESS INDICES $K_T$, OF 24 LOCATIONS IN NIGERIA

Firstly, Microsoft Excel spreadsheet was used to derive the monthly averaged values of sunshine duration hour, from the daily values supplied by NIMET.

By definition Clearness index $K_T$ is the ratio of monthly averaged values of global solar radiation and extraterrestrial solar radiation i.e. $K_T$ (=H/Ho).

Similarly, Cloudiness index K is the ratio" of monthly averaged values of sunshine duration hour and maximum possible sunshine duration hour i.e. K (=n/N).

Thus, Clearness Index $K_T$ (=H/Ho) and Cloudiness Index K (=n/N) were obtained for the 24 locations in Nigeria from the values of H, Ho, n and N. $K_T$ is also, available directly from NASA SSE geo-synchronous satellites dataset at http://www.eosweb.larc.nasa.gov/sse. Verifications were however made for the two modes of obtaining $K_T$; its values were found to be virtually the same.

The methodology followed in the development of ANGSTROM-PRESCOTT regression models is as follows:

i. Using Microsoft Excel spreadsheet, the twelve pairs of monthly averaged values of $K_T$ and K were estimated for each of the twenty-four locations.

ii. Using the curve estimation and regression tools in SPSS statistical package, ten polynomial ANGSTROM-PRESCOTT regression models were developed for the twelve-pairs of $K_T$ and K for each of the twenty-four locations. The ten polynomials are as follows:

a. Linear Function: y""= a + b*x................................3.1
b. Quadratic Function: y= a + bx =cx$^2$.......................3.2
c. Compound function: y= a*b$^x$...............................3.3
d. Growth function: ln y= a+ b*x...............................3.4
e. Logarithmic function: In y=a +b* In x.................3.5
f. Cubic function: y=a +b*x=c*x$^2$+d*x$^3$.........................3.6

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g. S function: $y = \exp(a + b/x)$....................................3.7

h. Exponential function: $y = a * (\exp b*x)$................3.8

i. Inverse function: $y=a + b/x$....................................3.9

j. Power function: $y=a * x^b$......................................3.10

Note: in these equations y=Kr (Clearness index) and x=K (Cloudiness index).

iii. Examine the $R^2$ values of the ten ANGSTROM-PRESCOTT polynomial REGRESSION models. There were two hundred and forty models in all. Twenty-four of these models with the highest $R^2$ values are recommended as the ANGSTROM-PRESCOTT polynomial regression models. The resulting 24 equations are the preliminary best models for predicting $K_T$ from K for any locations in Nigeria.

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## CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

### 4.1 TOTAL YEARLY EXTRATERESTRIAL SOLAR RADIATION FOR NIGERIA

From data collected from NIMET OSHODI, Nigeria falls within the latitude range of 4°N and 14 °N (i.e. a latitude range of 12° =14°-4°). It also falls within longitude range of 3 °E and 15 °E (i.e. longitude of 12° =15°-3°).

NASA SSE Satellites have grids with size of 1° by 1°. Therefore Nigeria has 12*12=144 grids.

Lastly, summing up the monthly averaged extraterrestrial solar radiation obtained from NASA SSE archived data for each month for each of the 144 grids encompassing Nigeria, the total yearly averaged extraterrestrial solar radiation incident on the whole Nigeria as $10.3831*10^{12}$ MW-hr/day.

### 4.2 MONTHLY AVERAGED. SUNSHINE DURATION HOURS FOR 24 NIGERIAN LOCATIONS.

Microsoft Excel Spreadsheet was used to evaluate the monthly averaged values of sunshine duration hour for the twenty-four locations from the daily values available from NIMET Oshodi.

Table 4.1 below, gives the result of averaging of values of daily sunshine duration hours of the twenty-four locations used in the study on a monthly basis over the period 1983-1993.

**Table 4.1: Monthly Sunshine Duration Hour, of daily values collected by NIMET averaged between 1983-1993 for 24 different locations in Nigeria**

| S/no | Location | Monthly Sunshine Duration Hours, n averaged between 1983-1993 as collected by NIMET | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Yearly Average |
| 1 | Akure | 5.80 | 6.28 | 5.72 | 5.92 | 5.88 | 4.89 | 3.20 | 3.07 | 3.60 | 5.23 | 6.79 | 5.68 | 5.17 |
| 2 | Bauchi | 7.52 | 7.55 | 6.88 | 6.60. | 7.37 | 6.98 | 5.60 | 6.30 | 6.23 | 7.34 | 8.20 | 7.96 | 7.04 |
| 3 | Benin | 5,10 | 5.43 | 5.20 | 5.75 | 5.79 | 4.51 | 2.96 | 2.51 | 3.04 | 4.61 | 6.17 | 5.79 | 4.74 |
| 4 | Bida | 5:8S | 7.20 | 6.21 | 7.01 | 7.02 | 5,52 | 4.67 | 4.58 | 5.64 | 7.16 | 8.16 | 7.08 | 6.34 |
| 5 | Calabar | 4.91 | 4.75 | 4.05 | 4.48 | 4.50 | 3.72 | 2.29 | 1.80 | 2.63 | 3.10 | 4.42 | 5.10 | 3.81 |
| 6 | Eroigu | 6.08 | 6.18 | 5.80 | 6.07 | 6.01 | 5.27 | 3.86 | 3.54 | 4.04 | 5.48 | 7.11 | 7.01 | 5.54 |
| 7 | Gusau | 6.37 | 6.68 | 6.05 | 6.08 | 6.37 | 5.24 | 5.55 | 5.88 | 6.81 | 7.68 | 7.62 | 6.29 | 6.39 |
| 8 | Ibadan | 6.25 | 6.52 | 6.24 | 5.77 | 6.22 | 4.97 | 3.71 | 3.86 | 4.41 | 4.92 | 6.80 | 6.63 | 5.53 |
| 9 | Ikeja | 5.56 | 6.18 | 5.82 | 5.88 | 5.64 | 3.74 | 2.99 | 3,38 | 3.54 | 5.29 | 6.18 | 6.20 | 5.03 |
| 10 | Ilorin | S .20 | 7.72 | 7.10 | 6.76 | 7.01 | 6.42 | 4.47 | 3.67 | 4.32 | 6.42 | 7.54 | 7.60 | 6.35 |
| 11 | Jos | 9.32 | 9.08 | 7.91 | 6.87 | 6.74 | 6.74 | 4.87 | 4.37 | 5.84 | 7.57 | 8.98 | 9.19 | 7.29 |
| 12 | Kaduna | 7.91 | 8.50 | 7.55 | 8.08 | 7.57 | 7.52 | 6.09 | 5.67 | 6.30 | 7.84 | 9.12 | 8.28 | 7.54 |
| 13 | Kano | 7.31 | 7.42 | 6.88 | 6.98 | 6:00 | 8.10 | 7.15 | 7.02 | 7.74 | 7.43 | 8.07 | 7.74 | 7.49 |
| 14 | Lokoja | 7.42 | 7.36 | 6.68 | 6.79 | 6.79 | 6.13 | 5.26 | 4.46 | 5.22 | 6.73 | 8.19 | 7.55 | 6.55 |
| 15 | Maiduguri | 8.80 | 9.16 | 8.50 | 7.94 | 8.47 | 8.17 | 7.01 | 6.47 | 7.61 | 9.13 | 9.37 | 8.88 | 8.29 |
| 16 | Ogoja | 6.46 | 6.70 | 5.70 | 6.47 | 6.61 | 5.71 | 3.91 | 3.55 | 4.53 | 5.85 | 7.08 | 7.17 | 5.81 |
| 17 | Oshogbo | 6.10 | 6.68 | 6.37 | 6.31 | 6.16 | 5.58 | 3.51 | 2.58 | 3.41 | 5.42 | 7.12 | 6.90 | 5.51 |
| 18 | P/Harcourt | 4.54 | 4.39 | 3.70 | 4.39 | 4.60 | 3.16 | 2.33 | 2.33 | 2.36 | 3.30 | 4.30 | 4.60 | 3.67 |
| 19 | Potiskum | 8.65 | 8.51 | 8.10 | 6.99 | 8.01 | 8.32 | 7.26 | 7.09 | 7.80 | 8.88 | 9.05 | 8.77 | 8.12 |
| 20 | Shaki | 7.26 | 7.25 | 7.06 | 7.16 | 7.23 | 6.07 | 3.97 | 3.91 | 4.06 | 6.25 | 7.78 | 6.91 | 6.24 |
| 21 | Sokoto | 8.04 | 8.05 | 7.24 | 7.32 | 7.44 | 7.60 | 6.96 | 6.07 | 7.91 | 8.41 | 8.66 | 8.01 | 7.64 |
| 22 | Warri | 5.04 | 5.15 | 4.56 | 5.00 | 5.05 | 3.94 | 2.24 | 2.18 | 2.78 | 4.11 | 5.57 | 5.57 | 4.27 |
| 23 | Yelwa | 7.62 | 7.71 | 7.02 | 7.27 | 7.65 | 7.91 | 6.34 | 5.53 | 6.93 | 8.20 | 8.65 | 7.93 | 7.40 |
| 24 | Yola | 8.24 | 8.45 | 7.57 | 7.57 | 7.85 | 7.49 | 6.57 | 6.30 | 6.84 | 8.39 | 9.30 | 9.03 | 7.80 |

## 4.3 MONTHLY AVERAGED VALUES OF $K_T$ & K FOR 24 NIGERIAN LOCATIONS.

Monthly averaged values of H, Ho, and N for the twenty-four locations obtained from NASA SSE website are summarized in Tables 4.2-4.

The results of the use of Microsoft-Excel Spreadsheet to evaluate the monthly averaged values of Clearness Index and Cloudiness Index from the monthly averaged values of H, Ho, N given by NASA SSE data, and n available from processing of NIMET data for each of the twenty-four locations are also summarized in Tables 4.5 and 4.6.

**Table 4.2: Monthly Global Solar Radiation, H, averaged between 1983-1993 as collected by NASA Surface Meteorology & Solar Energy SSE Satellites for 24 different locations in Nigeria**

| S/no | Location | Monthly Global Solar Radiation, H, averaged between 1983-1993 as collected by NASA Surface meteorology & Solar Energy SSE Satellites | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Yearly Average |
| 1 | Akure | 5.84 | 6.13 | 5.85 | 5.64 | 5.14 | 4.83 | 4.15 | 3.94 | 4.25 | 4.87 | 5.33 | 5.52 | 5.12 |
| 2 | Bauchi | 5.79 | 6;35 | 6.48 | 630 | 6.02 | 5.98 | 5.49 | 5.24 | 5.60 | 5.85 | 5.74 | 5.53 | 5.86 |
| 3 | Benin | 5:67 | 5.80 | 5.58 | 5.38 | 4.88 | 4.47 | 3.73 | 3.68 | 4.01 | 4.71 | 5.19 | 5.32 | 4.87 |
| 4 | Bida | 5.89 | 6.36 | 6.36 | 6.34 | 5.85 | 5.36 | 4.86 | 4.58 | 5.07 | 5.62 | 5.81 | 5.65 | 5.65 |
| 5 | Calabar | 5.64 | 5.77 | 5.03 | 4.75 | 4.38 | 3.92 | 3.29 | 3.17 | 3.39 | 3.67 | 4.48 | 5.20 | 4.39 |
| 6 | Enugu | 5.88 | 5.99 | 5.70 | 5.49 | 5.01 | 4.73 | 4.30 | 4.07 | 4.34 | 4.76 | 5.25 | 5.51 | 5.09 |
| 7. | Gus'au | 5.50 | 6.49 | 6.90 | 7.04 | 7.06 | 6.86 | 6.07 | 5.75 | 5.88 | 5.98 | 5.60 | 4.97 | 6.18 |
| 8. | Ibadan | 5.77 | 6.08 | 5.89 | 5.68 | 5.35 | 4.90 | 4.22 | 3.90 | 4.34 | 4.88 | 5.26 | 5.48 | 5.15 |
| 9. | Ikeja | 5.55 | 5.83 | 5,64 | 5.50 | 4.97 | 4.38 | 4.03 | 3.97 | 4.17 | 4.71 | 5.01 | 5.25 | 4.92 |
| 10. | Ilorin | 5.88 | 6.26 | 6.24 | 5.95 | 5.52 | 5.08 | 4.44 | 4.15 | 4.62 | 5.09 | 5.55 | 5.68 | 5.37 |
| 11. | Jos | 6.06 | 6.46 | 6.39 | 6.15 | 5.60 | 5.29 | 4.75 | 4.46 | 4.82 | 5.42 | 5.97 | 5.78 | 5.60 |
| 12. | Kaduna | 5.86 | 6.39 | 6.50 | 6.46 | 6.14 | 5.64 | 5.14 | 4.86 | 534 | 5.75 | 5.92 | 5.64 | 5.80 |
| 13. | Kano | 5.58 | 6.60 | 6.89 | 7.09 | 6.98 | 6.83 | 6.16 | 5.84 | 5.91 | 6.06' | 5.62 | 4J& | 6.21 |
| 14. | Lokoja | 6.00 | 6.18 | 5.89 | 5.70 | 5.21 | 4.93 | 4.48 | 4.26 | 4.45 | 5.00 | 5.48 | 5.64 | 5.27 |
| 15. | Maiduguri | 5.79 | 6.61 | 6.89 | 6.79 | 6.42 | 6.37 | 5.73 | 5.54 | 5.84 | 5.98 | 5.68 | 4.95 | 6.08 |
| 16 | Ogoja | 5.92 | 6.10 | 5.78 | 5.58 | 5.12 | 4.80 | 4.42 | 4.21 | 4.49 | 4.94 | 5.34 | 5.60 | 5.19 |
| 17 | Oshogbo | 5.79 | 6.11 | 5.86 | 5.65 | 5.22 | 4.78 | 4.12 | 3.87 | 4.28 | 4.84 | 5.28 | 5.47 | 5.11 |
| 18 | P/Harcourt | 5.58 | 5.40 | 4.88 | 4.67 | 4.30 | 3.79 | 3.16 | 3.43 | 3.45 | 3.74 | 4.45 | 5.09 | 4.33 |
| 19 | Potiskum | 5.84 | 6.69 | 6.86 | 6.91 | 6.59 | 6.53 | 5.98 | 5.68 | 5.92 | 6.01 | 5.71 | 5.20 | 6.16 |
| 20 | Shaki | 5.87 | 6.25 | 6.20 | 5.98 | 5.67 | 5.05 | 4.33 | 3,98. | 4.50 | 4.92 | 5.44 | 5.62 | 5.32 |
| 21 | Sokoto | 5.56 | 6.55 | 7.05 | 7.29 | 7.29 | 7.26 | 6.50 | 6.16 | 6.30 | 6.21 | 5.71 | 5JJ& | 6.41 |
| 22 | Warri | 5.74 | 5.82 | 5:47 | 5.36 | 4.76 | 4.00 | 3.38 | 3.88 | 3.83 | 4.51 | 5.25 | 5.37 | 4.78 |
| 23 | Yelwa | 5.86 | 6.27 | 6.46 | 6.53 | 6.19 | 5.74 | 5.17 | 5.11 | 5.45 | 5.83 | 5.80 | 5.64 | 5.84 |
| 24 | Yola | 5.74 | 6.36 | 6.48 | 6.30 | 5.96 | 5.81 | 5.26 | 5.13 | 5.34 | 5.76 | 5.80 | 5.48 | 5.79 |

**Table 4.3: Monthly Extraterrestrial Solar Radiation, $H_0$/ averaged between 1983-1993 as collected by NASA Surface Q Meteorology Solar Energy SSE Satellites for 24 different locations in Nigeria**

| S/no | Location | Lat. (°N) | Long. (°E) | Station No. | Monthly Extraterrestrial Solar Radiation, $H_0$, averaged between 1983-1993 as collected by NASA Surface meteorology & Solar Energy SSE Satellites | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yearly | | | | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Average |
| 1 | Akure | 7.28 | 5.30 | 65232 | 9.17 | 9.78 | 10.30 | 10.40 | 10:20 | 9.99 | 10.00 | 10.20 | 10.20 | 9.90 | 9.31 | 8.94 | 9.87 |
| 2 | Bauchi | 10.28 | 9.82 | 65055 | 8.78 | 9.51 | 10.10 | 10.40 | 10.30 | 10.20 | 10.20 | 10.30 | 10.20 | 9.69 | 8.97 | 8.53 | 9.77 |
| 3 | Benin | 6.32 | 5.10 | 65229 | 9.28 | 9.86 | 10.30 | 10.30 | 10.10 | 9.90 | 9.94 | 10.10 | 10.20 | 9.97 | .8.42 | 9.07 | 9,87 |
| 4 | Bida | 9.10 | 6.02 | 65112 | 8.92 | 9.61 | 10.20 | 10.40 | 10.30 | 10.10 | 10.10 | 10.30 | 10.20 | 9.77 | 9.08 | 8.67 | 9.80 |
| 5 | Calabar | 4.97 | 8.35 | 65264 | 9.52 | 10.00 | 10.30 | 10.30 | 9.98 | 9.71 | 9.77 | 10.00 | 10.20 | 10.00 | 9.63 | 9.33 | 9.90 |
| 6 | Enugu | 6.47 | 7.55 | 65257 | 9.28 | 9.86 | 10.30 | 10.30 | 10.10 | 9.90 | 9.94 | 10.10 | 10.20 | 9.97 | 9.42 | 9.07 | 9.87 |
| 7 | Gusau, | 12.17 | 6.70 | 65015 | 8.52 | 9.32 | 10.00 | 10.50 | 10.50 | 10.40 | 10.40 | 10.40 | 10.10 | 9.53 | 8.72 | 8.25 | 9.72 |
| 8 | Ibadan | 7.43 r | 3.9C | 65208 | 9.17 | 9.78 | 10.30 | 10.40 | 10.20 | 9.99 | 10.00 | 10.20 | 10.20 | 9.90 | 9.31 | 8.94 | 9.87 |
| 9 | Ikeja | 6.58 | 3.33 | 65201 | 9.28 | 9.86 | 10.30 | 10.30 | 10.10 | 9.90 | 9.94 | 10.10 | 10.20 | 9.97 | 9.42 | 9.07 | 9.87 |
| 10 | Ilorin | 8.48 | 4.58 | 65101 | 9.03 | 9.69 | 10.20 | 10.40 | 10.20 | 10.00 | 10.10 | 10.20 | 10.20 | 9.84 | 9.19 | 8.81 | 9.82 |
| 11 | Jos | 9.87 | 8.90 | 65134 | 8.92 | 9.61 | 10.20 | 10.40 | 10.30 | 10.10 | 10.10 | 10.30 | 10.20 | 9.77 | 9.08 | 8.67 | 9.80 |
| 12 | Kaduna | 10.60 | 7.45 | 65019 | 8.78" | "9.51 | 10.10 | 10.40 | 10.30 | 10.20 | 10.20 | 10.30 | 10.20 | 9.69 | 8.97 | 8.53 | 9.77 |
| 13 | Kano | 12.05 | 8.20 | 65046 | 8.52 | 9.32 | 10.00 | 10.50 | 10.50 | 10.40 | 10.40 | 10.40 | 10.10 | 9.53 | 8.72 | 8.25 | 9.72 |
| 14 | Lokoja | 7.78 | 6.73 | 65243 | 9.17 | 9.78 | 10.30 | 10.40 | 10.20 | 9.99 | 10.00 | 10.20 | 10.20 | 9.90 | 9.31 | 8.94 | 9.87 |
| 15 | Maiduguri | 11.85 | 13.08 | 65082 | 8.66 | 9.41 | 10.10 | 10.40 | 10.40 | 10.30 | 10.30 | 10.30 | 10.20 | 9.61 | 8.85 | 8.40 | 9.74 |
| 16 | Ogoja | 6.67 | 8.80 | 65275 | 9.28 | 9.86 | 10.30 | 10.30 | 10.10 | 9.90 | 9.94 | 10.10 | 10.20 | 9.97 | 9.42 | 9.07 | 9.87 |
| 17 | Oshogbo | 7.78 | 4.48 | 65215 | 9.17 | 9.78 | 10.30 | 10.40 | 10.20 | 9.99 | 10.00 | 10.20 | 10.20 | 9.90 | 9.31 | 8.94 | 9.87 |
| 18 | P/Harcourt | 4.85 | 7.02 | 65250 | 9.52 | 10.00 | 10.30 | 10.30 | 9.98 | 9.71 | 9.77 | 10.00 | 10.20 | 10.00 | 9,63 | 9.33 | 9.90 |
| 19 | Potiskum | 11.70 | 11.03 | 65073 | 8.66 | 9.41 | 10.10 | 10.40 | 10.40 | 10.30 | 10.30 | 10.30 | 10.20 | 9.61 | 8.85 | 8.40 | 9.74 |
| 20 | Shaki | 8.67 | 3.38 | 65108 | 9.03 | 9.69 | 10.20 | 10.40 | 10.20 | 10.00 | 10.10 | 10.20 | 10.20 | 9.84 | 9.19 | 8.81 | 9.82 |
| 21 | Sokoto | 13.02 | 5.25 | 65010 | 8.39 | 9.21 | 10.00 | 10.50 | 10.50 | 10.40 | 10.40 | 10.40 | 10.10 | 9.46 | 8.60 | 8.11 | 9.67 |
| 22 | Warri | 5.52 | 5.73 | 65236 | 9.41 | 9.94 | 10.30 | 10.30 | 10.00 | 9.81 | 9.86 | 10.10 | 10.20 | 10.00 | 9.52 | 9.19 | 9.89 |
| 23 | Yelwa | 10.88 | 4.75 | 65001 | 8.78 | 9.51 | 10.10 | 10.40 | 10.30 | 10.20 | 10.20 | 10.30 | 10.20 | 9.69 | 8.97 | 8.53 | 9.77 |
| 24 | Yola | 9.23 | 12.47 | 65167 | 8.92 | 9.61 | 10.20 | 10.40 | 10.30 | 10.10 | 10.10 | 10.30 | 10.20 | 9.77 | 9.08 | 8.67 | 9.80 |

**Table 4.4: Monthly Maximum Possible Sunshine Duration Hour, N, averaged between. 1983-1993 as collected by NASA Surface meteorology & Solar Energy SSE Satellites for 24 different locations in Nigeria.**

| S/no | Location | Monthly Maximum Possible Sunshine Duration Hour, N, averaged between 1983-1993 by NASA as collected Surface meteorology & Solar Energy SSE Satellites | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Yearly Average |
| 1 | Akure | 11.70 | 11.90 | 12.00 | 12.20 | 12.40 | 12.50 | 12.50 | 12.30 | 12.10 | 11.90 | 11.80 | 11.70 | 12.08 |
| 2 | Bauchi | 11.60 | 11.80 | 12.00 | 12.30 | 12.60 | 12.70 | 12.60 | 12.40 | 12.20 | 11.90 | 11.60 | 11.50 | 12.1 |
| 3 | Benin | 11.80 | 11.90 | 12.00 | 12.20 | 12.40 | 12.40 | 12.40 | 12.30 | 12.10 | 11.90 | 11.80 | 11.70 | 12.08 |
| 4 | Bida | 11.60 | 11.80 | 12.00 | 12.30 | 12.50 | 12.60 | 12.60 | 12.40 | 12.10 | 11.90 | 11.70 | 11.50 | 12.08 |
| 5 | Calabar | 11.80 | 11.90 | 12.00 | 12.20 | 12.30 | 12.30 | 12.30 | 12.20 | 12.10 | 12.00 | 11.90 | 11.80 | 12.07 |
| 6 | Enugu | 11.80 | 11.90 | 12.00 | 12.20 | .12.40 | 12.40 | 12.40 | 12.30 | 12.10 | 11.90 | 11.80 | 11.70 | 12.08 |
| 7 | Gusau | 11.50 | 11.70 | 12.00 | 12.40 | 12.60 | 12.80 | 12.70 | 12.50 | 12.20 | 11.80 | 11.50 | 11.40 | 12.09 |
| 8 | Ibadan | 11.70 | 11.90 | 12.00 | 12.20 | 12.40 | 12.50 | 12.50 | 12.30 | 12.10 | 11.90 | 11.80 | 11.70 | 12.08 |
| 9 | Ikeja | 11.70 | 11.90 | 12.00 | 12.20 | 12.40 | 12.50 | 12.40 | 12.30 | 12.10 | 11.90 | 11.80 | 11.70 | 12.08 |
| 10 | Ilorin | 11.70 | 11.80 | 12.00 | 12.30 | 12.50 | 12.60 | 12.50 | 12.30 | 12.10 | 11.90 | 11.70 | 11.60 | 12.08 |
| 11 | Jos | 11,60 | 11.80 | 12.00 | 12.30 | 12.50 | 12.60 | 12.60 | 12.40 | 12.10 | 11.90 | 11.70 | 11.50 | 12.08 |
| 12 | Kaduna | 11.50 | 11.80 | 12.00 | 12.30 | 12.60 | 12.70 | 12.60 | 12.40 | 12.20 | 11.90 | 11.60 | 11.50 | 12.09 |
| 13 | Kano | 11.50 | 11.70 | 12.00 | 12.30 | 12.60 | 12.80 | 12.70 | 12.50 | 12.20 | 11.80 | 1 1.50 | 11.40 | 12.08 |
| 14 | Lokoja | 11.70 | 11.90 | 12.00 | 12.20 | 12.40 | 12.50 | 12.40 | 12.30 | 12.10 | 11.90 | 11.50 | 11.70 | 12.08 |
| 15 | Maiduguri | 11.50 | 11.70 | 12.00 | 12.30 | 12.60 | 12.70 | 12.70 | 12.50 | 12.10 | 11.80 | 11.60 | 11.40 | 12.08 |
| 16 | Ogoja | 11.80 | 11.90 | 12.00 | 12.20 | 12.40 | 12.40 | 12.40 | 12.30 | 12.10 | 11.90 | 11.80 | 11.70 | 12:08 |
| 17 | Oshogbo | 11.70 | 11.90 | 12.00 | 12.20 | 12.40 | 12.50 | 12.50 | 12.30 | 12.10 | 11.90 | 11.80 | 11.70 | 12.08 |
| 18 | P/Harcourt | 11.90 | 11.90 | 12.10 | 12.20 | 12.30 | 12.30 | 12.30 | 12.20 | 12.10 | 12.00 | 11.90 | 11.80 | 12.08 |
| 19 | Potiskum | 11.50 | 11.70 | 12.00 | 12.30 | 12.60 | 12.80 | 12.70 | 12.50 | 12.20 | 11.80 | 11.60 | 11.40 | 12.09 |
| 20 | Shaki | 11.60 | 11.80 | 12.00 | 12.30 | 12.50 | 12.60 | 12.50 | 12.40 | 12.10 | 11.90 | 11.70 | 11.60 | 12.08 |
| 21 | Sokoto | 11.40 | 11.70 | 12.00 | 12.40 | 12.70 | 12.80 | 12.80 | 12.50 | 12.20 | 11.80 | 11.50 | 11.30 | 12.09 |
| 22 | Warri | 11.80 | 11.90 | 12.00 | 12.20 | 12.30 | 12.40 | 12.40 | 12.30 | 12.10 | 12.00 | 11.80 | 11.80 | 12.08 |
| 23 | Yelwa | 11.50 | 11.80 | 12.00 | 12.30 | 12.60 | 12.70 | 12.60 | 12.40 | 12.20 | 11.90 | 11.60 | 11.50 | 12.09 |
| 24 | Yola | 11.60 | 11.80 | 12.00 | 12.30 | 12.50 | 12.60 | 12.60 | 12.40 | 12.10 | 11.90 | 11.70 | 11.60 | 12.09 |



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**Table 4.5 Monthly Clearness Index, $K_T$, for 24 studied locations in Nigeria.**

| S/no | Location | Monthly Clearness Index, $K_T$, | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Yearly Average |
| 1 | Akure | 0.64 | 0.63 | 0.57 | 0.54 | 0.50 | 0.48 | 0.42 | 0.39 | 0.42 | 0.49 | 0.57 | 0.62 | 0.52 |
| 2 | Bauchi | 0.66 | 0.67 | 0.64 | 0.61 | 0.58 | 0.59 | 0.54 | 0.51 | 0.55 | 0.60 | 0.64 | 0.65 | 0.6 |
| 3 | Benin | 0.61 | 0.59 | 0.54 | 0.52 | 0.48 | 0.45 | 0.38 | 0.36 | 0.39 | 0.47 | 0.55 | 0.59 | 0.49 |
| 4 | Bida | 0.66 | 0.66 | 0.62 | 0.61 | 0.57 | 0.53 | 0.48 | 0.44 | 0.50 | 0.58 | 0.64 | 0.65 | 0.58 |
| 5 | Calabar | 0.59 | 0.58 | 0.49 | 0.46 | 0.44 | 0.40 | 0.34 | 0.32 | 0.33 | 0.37 | 0.47 | 0.56 | 0.44 |
| 6. | Enugu | 0.63 | 0.61 | 0.55 | 0.53 | 0.50 | 0.48 | 0.43 | 0.40 | 0.43 | 0.48 | 0.56 | 0.61 | 0.52 |
| 7 | Gusau | 0:65 | 0.70 | 0.69' | 0.67 | 0.67 | 0.66 | 0.58 | 0.55 | 0.58 | 0.63 | 0.64 | 0.60 | 0.64 |
| 8 | Ibadan | 0.63 | 0.62 | 0.57 | 0.55 | 0.52 | 0.49 | 0.42 | 0.38 | 0.43 | 0.50 | 0.56 | 0.61 | 0.52 |
| 9 | Ikeja | 0.60 | 0.59 | 0.55 | 0.53 | 0.49 | 0.44 | 0.41 | 0.39 | 0.41 | 0.47 | 0.53 | 0.58 | 0.5 |
| 10 | Ilorin | 0.65 | 0.65 | 0.61 | 0.57 | 0.54 | 0.51 | 0.44 | 0.41 | 0.45 | 0.52 | 0.60 | 0.64 | 0.55 |
| 11 | Jos | 0.68 | .0.67 | 0.63 | 0.59 | 0.54 | 0.52 | 0.47 | 0.43 | 0.47 | 0.55 | 0.66 | 0.67 | 0.57 |
| 12 | Kaduna | 0.67 | 0.67 | 0.64 | 0.62 | 0.60 | 0.55 | 0.50 | 0.47 | 0.52 | 0.59 | 0.66 | 0.66 | 0.59 |
| 13 | Kano | 0.65 | 0.71 | 0.69 | 0.68 | 0.66 | 0.66 | 0.59 | 0.56 | 0.59 | 0.64 | 0.64 | 0.60 | 0.64 |
| 14 | Lokoja | 0.65 | 0,63 | 0.57 | 0.55 | 0.51 | 0.49 | 0.45 | 0.42 | 0.44 | 0.51 | 0.59 | 0.63 | 0.53 |
| 15 | Maiduguri | 0.67 | 0.70 | 0.68 | 0.65 | 0.62 | 0.62 | 0.56 | 0.54 | 0.57 | 0.62 | 0.64 | 0.63 | 0.62 |
| 16 | Ogoja | 0.64 | 0.62 | 0.56 | 0.54 | 0.51 | 0.48 | 0.44 | 0.4.2 | 0.44 | 0.50 | 0.57 | 0.62 | 0.53 |
| 17 | Oshogbo | 0.64 | 0.62 | 0.57 | 0.54 | 0.51 | 0.48 | 0.41 | 0.38 | 0.42 | 0.49, | 0.57 | 0.61 | 0.52 |
| 18 | P/Harcourt | 0.59 | 0.54 | 0.47 | 0.45 | 0.43 | 0.39 | 0-32. | 0.34 | 0.34 | 0,38 | 0.46 | 0.55 | 0.44 |
| 19 | Potiskum | 0.67 | 0.71 | 0.68 | 0.66 | 0.63 | 0.63 | 0.58 | 0.55 | 0.58 | 0.63 | 0.65 | 0.62 | 0.63 |
| 20 | Shaki | 0.65 | 0.64 | 0.61 | 0.58 | 0.56 | 0.51 | 0.43 | 0.39 | 0.44 | 0.50 | 0.59 | 0.64 | 0.54 |
| 21 | Sokoto | 0.66 | 0.71 | 0.71 | 0.69 | 0.69 | 0.70 | 0.63 | 0.59 | 0.62 | 0.66 | 0.66 | 0.63 | 0.66 |
| 22 | Warn | 0.61 | 0.59 | 0.53 | 0.52 | 0.48 | 0.41 | 0.34. | 0.38 | 0.38 | 0.45 | 0.55 | 0.58 | 0.48 |
| 23 | Yelwa | 0.67 | 0.66 | 0.64 | 0.63 | 0.60 | 0.56 | 10.51 | 0.50 | 0.53 | 0.60 | 0.65 | 0.66 | 0.60 |
| 24 | Yola | 0.'64 | O.G6 | 0.64 | 0.61 | 0.58 | 0.58 | 0.52 | 0.5 | 0.52 | 0.59 | 0.64 | 0.63 | 0.59 |

**Table 4.6: Monthly Cloudiness Index K averaged between 1983-1993 for 24 different locations in Nigeria.**

| S/no | Location | | | Monthly Cloudiness Index, K, averaged | | | | | | between 1983-1 993 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Yearly Average |
| 1 | Akure | 0.50 | 0.53 | 0.48 | 0.49 | 0.47 | 0.39. | 0.26 | 0.25. | 0.30 | 0.44 | 0.58 | 0.49 | 0.43 |
| 2 | Bauchi | 0.65 | 0.64 | 0.57 | 0.54 | 0.58 | 0.55 | 0.44 | 0.51 | 0.51 | 0.62 | 0.71 | 0.69 | 0.58 |
| 3 | Benin | 0.43 | 0.46 | 0.43 | 0.47 | 0.47 | 0.36 | 0.24 | 0.20 | 0.25 | 0.39 | 0.52 | 0.49 | 0.39 |
| 4 | Bida | 0.51 | 0.61 | 0.52 | 0.57 | 0.56 | 0.44 | 0.37 | 0.37 | 0.47 | 0.60 | 0.70 | 0.62 | 0.52 |
| 5 | Calabar | 0.42 | 0.40 | 0.34 | 0.37 | 0.37 | 0.30 | 0.19 | 0.15 | 0.22 | 0.26 | 0.37 | 0.43 | 0.32 |
| 6 | Enugu | 0.52 | 0.52 | 0.48 | 0.50 | 0.48 | 0.43 | 0.31 | 0.29 | 0.33 | 0.46 | 0.60 | 0.60 | 0.46 |
| 7 | Gusau | 0.55 | 0.57 | 0.50 | 0.49 | 0.51 | 0.41 | 0.44 | 0.47 | 0.56 | 0.65 | 0.66 | 0.55 | 0.53 |
| 8 | Ibadan | 0.53 | 0.55 | 0.52 | 0.47 | 0.50 | 0.40 | 0.30 | 0.31 | 0.36 | 0.41 | 0.58 | 0.57 | 0.46 |
| 9 | Ikeja | 0.48 | 0.52 | 0.49 | 0.48 | 0.45 | 0.30 | 0.24" | 0.27 | 0.29 | 0.44 | 0.52 | 0.53 | 0.42 |
| 10 | Hcrin | 0.62 | 0.65 | 0.59 | 0.55 | 0.56 | 0.51 | 0.36 | 0.30 | 0.36 | 0.54 | 0.64 | 0.66 | 0.53 |
| 11 | Jos | 0.8 | 0.77 | 0.66 | 0.56' | 0.54 | 0.53 | 0.39 | 0.35 | 0.48 | 0.64 | 0.77 | 0.80 | 0.60 |
| 12 | Kaduna | 0.69 | 0.72 | 0.63 | 0.66 | 0.60 | 0.59 | 0.48 | 0.46 | 0.52 | 0.66 | 0.79 | 0.72 | 0.62 |
| 13 | Kano | 0.64 | 0.63 | 0.57 | 0.57 | 0.63 | 0.63 | 0.56 | 0.56 | 0.63 | 0.63 | 0.70 | 0.68 | 0.62 |
| 14 | Lokoja | 0.63 | 0.62 | 3.56 | 0.56 | 0.55 | 0.49 | 0.42 | 0.36 | 0.43 | 0.57 | 0.69 | 0.65 | 0.54 |
| 15 | Maiduguri | 0.77 | 0.78 | 0.71 | 0.65 | 0.67 | 0.64 | 0.55 | 0.52 | 0.63 | 0.77 | 0.81 | 0.78 | 0.69 |
| 16 | Ogoja | 0.55 | 0.56 | 0.48 | 0.53 | 0.53 | 0.46 | 0.32 | 0.29 | 0.37 | 0.49 | 0.60 | 0.61 | 0.48 |
| 17 | Oshogbo | 0.52 | 0.56 | 0.53 | 0.52 | 0.50 | 0.45 | 0.28 | 0.21 | 0.28 | 0.46 | 0.60- | 0.59 | 0.46 |
| 18 | P/Harcourt | 0.38 | 0.37 | 0.31 | 0.36 | 0.37 | 0.26 | 0.19 | 0.19 | 0.20 | 0.28 | 0.36 | 0.39 | 0.3 |
| 19 | Potiskum | 0.75 | 0.73 | 0.68 | •0.57 | 0.64 | 0.65 | 0.57 | 0.57 | 0.64 | 0.75 | 0.78 | 0.77 | 0.67 |
| 20 | Shaki | 0.63 | 0.61 | 0.59 | 0.58 | 0.58 | 0.48 | 0.32 | 0.32 | 0.34 | 0.53 | 0.66 | 0.60 | 0.52 |
| 21 | Sokoto | 0.71 | 0.69 | 0.60 | 0.59 | 0.59 | 0.59 | 0.54 | 0.49 | 0.65 | 0.71 | 0.75 | 0.71 | 0.63 |
| 22 | Warri | 0.43 | 0.43 | 0.38 | 0.41 | 0.41 | 0.32 | 0.18 | 0.18 | 0.23 | 0.34 | 0.47 | 0.47 | 0.35 |
| 23 | Yelwa | 0.66 | 0.65 | 0.59 | 0.59 | U61 | 0.62 | 0.50 | 0.45 | 0.57 | 0.69 | 0.75 | 0.69 | 0.61 |
| 24 | Yola | 0.71 | 0.72 | 0.63 | 0.62 | 0.63 | 0.59 | 0.52 | 0.54 | 0.57 | 0.71 | 0.79 | 0.78 | 0.65 |

### 4.4 POLYNOMIAL ANGSTROM-PRESCOTT REGRESSION MODELS OF CLEARNESS INDEX $K_T$, AGAINST CLOUDINESS INDEX K, FOR 24 LOCATIONS IN NIGERIA

The result of the use of ten polynomial functions (Linear, Quadratic, Compound, Growth, Logarithm, Cubic, S, Exponent, Inverse and Power functions) available in the SPSS 10.0 Statistical package to empirically regress the monthly averaged values of Clearness Index and Cloudiness Index for each of the twenty-four locations is summarized in Table 4.7.

Table 4.7 shows only the model (out of the ten models for each location) with the highest coefficient of correlation ($R^2$) values.

**Table 4.7 Best Angstrom-Prescott Polynomial Regression Models of Clearness Index Kr and Cloudiness Index K for each of the 24 different locations in Nigeria**

| Location | Best Angstrom-Prescott Polynomial Regression Models of Clearness Index Kr and Cloudiness Index K for each of the 24 different locations in Nigeria | $R^2$ %for the best Model of each location |
|---|---|---|
| Akure | Exponential Function: $K_T = 0.280013 * \exp 0.280013 * K$ | 82.055 |
| Bauchi | Cubic Function: $K_T = 0.077496 * 1.105182\, K - 0.571223\, K^3$ | 67.202 |
| Benin | Power Function: $K_T = 0.806756 * K^{0.516636}$ | 82.220 |
| Bida | S Function $K_T = \exp(0.005341 - 0.285629/K)$ | 75.712 |
| Calabar | Cubic Function: $K_T = 0.335530 - 0.288761\, K + 0.893251\, K^2 + 2.645031\, K^3$ | 91.550 |
| Enugu | Power Function: $K_T = 0.802091 * K^{0.558956}$ | 82.315 |
| Gusau | Cubic Function: $K_T = 0.462247 + 0.459259\, K - 0.448856\, K^3$ | 1.836 |
| Ibadan | Power Function: $K_T = 0.880765 * K^{0.662432}$ | 88.695 |
| Ikeja | Exponential Function: $K_T = 0.266471 * (\exp 1.304685\, K)$ | 86.906 |
| Ilorin | Exponential Function: $K_T = 0.279099 * (\exp 1.259402\, K)$ | 94.286 |
| Jos | Cubic Function: $K_T = 0.238755 + 0.55384\, K\ \ 0.007105\, K^3$ | 93.208 |
| Kaduna | S Function: $K_T = \exp(0.148467 - 0.410958/K)$ | 91.366 |
| Kano | Cubic Function: $K_T = 2.329518 + 9.524852\, K = 7.6014479\, K^2$ | 12.611 |
| Lokoja | Exponential Function: $K_T = 0.251885 * (\exp 1.371504\, K)$ | 86.363 |
| Maiduguri | Cubic Function: $K_T\ 0.212285 + 1.688323\, k - 0.948334.K^3$ | 68.698 |
| Ogoja | Exponential function: $K_T = 0.288794 * (\exp 1.232139 K)$ | 80.556 |
| Oshogbo | Exponential Function: $K_T = 0.291279 * (\exp 1.235509\, K)$ | 87.693 |
| P/Harcourt | Exponential Function: $K_T 0.209507 * (\exp 2.359025\, K)$ | 83.573 |
| Potiskum | Cubic Function: $K_T = 0.361094 + 2.097927\, K\ \ 1.3228221 K^2$ | 28.072 |
| Shaki | Exponential Function: $K_T = 0.272260 * (\exp 1.309150 K)$ | 89.550 |
| Sokoto | Quadratic Function: $K_T = 0.996809 + 5.283228\, K\ \ 4.144394\, K^2$ | 42.724 |
| Warri | Exponential Function: $K_T = \exp(0.26557 * (1.749061 K)$ | 87.885 |
| Yelwa | S Function: $K_T = \exp(0.064105 - 0.348807/K)$ | 66.991 |
| Yola | Quadratic Function $K_T = 0.684518 + 3.50334K - 2.320966\, K^2$ | 80.379 |

**Note: Locations shown in bold texts have very low regression coefficients $R^2$, and are therefore not recommended for estimating $K_T$ and/or H from K for Nigeria*

Table 4.8 below, is a summary showing the $R^2$ values as well as the coefficients of regression of ALL the ten polynomial functions for each of the twenty-four locations.

For purpose of convenience and to ensure clarity of results, the twenty-four locations were broken down into three groups. Figures 4.1-3 are graphs showing the trends of clearness index values for the first, second and third groups with the months of the year for the period of study 1983-1993.

Similarly figures 4.4-4.15 are solar maps showing the monthly averaged clearness index values for the period 1983-1993 on a monthly basis for the 24 locations studied in Nigeria

The result of an analysis of the best models for the studied locations also showed that exponent functions have best predictive efficiencies in terms of R2 values at nine out of the twenty-four locations (i.e. 87.50%); cubic function predicted best at six locations (i.e. 25.00%); while quadratic, power and S functions predicted best at three locations each. (i.e. 12.5%). This result is shown in Table 4.9 below.

Furthermore, the result of substitution of Cloudiness index values (and indirectly average monthly sunshine duration values as K=n/N) into the developed mode's is shown in Table 4.10. The table gives the predicted values of monthly averaged Clearness index values of twenty-four of Nigerian locations.



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**Table 4.8: Ten polynomial functions with their $R^2$ values for each of the twenty-four locations.**

| No | Location | $R^2$ Values of Polynomial Functions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10 |
| 1 | Akure | 0.7796 | 0.7725 | 0.7483 | 0.7807 | 0.7819 | 0.8210 | 0.8192 | 0.7996 | 0.8206 | 0.8206 |
| 2 | Bauchi | 0.6558 | 0.6632 | 0.6600 | 0.6692 | 0.6720 | 0.6511 | 0.6596 | 0.6576 | 0.6511 | 0.611 |
| 3 | Benin | 0.7671 | 0.7703 | 0.7515 | 0.7749 | 0.7770 | 0.8132 | 0.8223 | 0.8082 | 0.8132 | 0.8132 |
| 4 | Bida | 0.6778 | 0.7141 | 0.7359 | 0.7482 | 0.7482 | 0.6903 | 0.7311 | 0.7571 | 0.6903 | 0.6903 |
| 5 | Calabar | 0.8632 | 0.7932 | 0.6976 | 0.9153 | 0.9155 | 0.9047 | 0.8470 | 0.7587 | 0.9047 | 0.9047 |
| 6" | Enugu | 0.7848 | 0.7837 | 0.7650 | 0.7883 | 0.7896 | 0.8175 | 0.8230 | 0.8101 | 0.8175 | 0.8175 |
| 7 | Gusau | 0.0095 | 0.0107 | 0.0114 | 0.0174 | 0.0184 | 0.0120 | 0.1141 | 0.0136 | 0.0120 | 0.0120 |
| 8 | Ibadan | 0.8653 | 0.8734 | 0.8661 | 0.8765 | 0.8781 | 0.8717 | 0.8869 | 0.8867 | 0.8717 | 0.8717 |
| 9 | Ikeja | 0.8438 | 0.8216 | 0.7902 | 0.8592 | 0.8585 | 0.8691 | 0.8500 | 0.8209 | 0.8691 | 0.8691 |
| 10 | Ilorin | 0.9200 | 0.8881 | 0.8438 | 0.9383 | 0.9383 | 0.9429 | 0.9204 | 0.8843 | 0.9429 | 0.9429 |
| 11 | Jos | 0.9321 | 0.9176 | 0.8735 | 0.9321 | 0.9321 | 0.9275 | 0.9262 | 0,8952 | 0.9275 | 0.9275 |
| 12 | Kaduna | 0.8744 | 0.8951 | 0.9031 | 0.9089 | 0.9106 | 0.8746 | 0.9004 | 0.9137 | 0.8746 | 0.8746 |
| 13 | Kano | 0.0054 | 0.0075 | 0.0098 | 0.1261 | 0.1261 | 0.0084 | 0.0110 | 0.0138 | 0.0084 | 0.0084 |
| 14 | Lokoja | 0.8374 | 0.8262 | 0.7983 | 0.8374 | 0.8375 | 0.9293 | 0.8588 | 0.8366 | 0.8636 | 0.9293 |
| 15 | Maiduguri | 0.5954 | 0.6212 | 0.6416 | 0.6836 | 0.6870 | 0.6123 | 0.6402 | 0.6626 | 0.6123 | 0.6123 |
| 16 | Ogoja | 0.7699 | 0.7436 | 0.7043 | 0.7798 | 0.7798 | 0.8056 | 0.7843 | 0.7486 | 0.8056 | 0.8056 |
| 17 | Oshogbo | 0.8341 | 0.8041 | 0.7522 | 0.8396 | 0.8466 | 0.8769 | 0.8556 | 0.8101 | 0.8769 | 0.8769 |
| 18 | P/Harcourt | 0.7867 | 0.7635 | 0.7322 | 0.8038 | 0.8056 | 0.8357 | 0.8203 | 0.7954 | 0.8357 | 0.8357 |
| 19 | Potiskum | 0.2706 | 0.2807 | 0.2891 | 0.3345 | 0.3388 | 0.2807 | 0.2910 | 0.2997 | 0.2807 | 0.2807 |
| 20 | Shaki | 0.8748 | 0.8633 | 0.8437 | 0.8761 | 0.8761 | 0.8955 | 0.8897 | 0.8752 | 0.8955 | 08955 |
| 21 | Sokoto | 0.0376 | 0.0543 | 0.0750 | 0.4272 | 0.4272 | 0.0446 | 0.0627 | 0.0849 | 0.0445 | 0.0446 |
| 22 | Warri | 0.8485 | 0.8100 | 0.7521 | 0.8594 | 0.8602 | 0.8789 | 0.8492 | 0.7979 | 0.8789 | 0.8789 |
| 23 | Yelwa | 0.6226 | 0.6419 | 0.6505 | 0.6600 | 0.6624 | 0.6370 | 0.6589 | 0.6699 | 0.6370 | 0.6370 |
| 24 | Yola | 0.6936 | 0.7266 | 0.7538 ' | O.S038 | 0.8041 | 0.6953 | 0.7304 | 0.7597 | 0.6953 | 0.6953 |

Note: the numbering of the functions follows that shown in section 3.3.ii

Table 4.9 **Best Model, Their Frequencies and Percentage of Occurrence**

| S/No | Best Polynomial Function for Predicting $K_t$ | Locations of occurrence | Frequency of occurrence | Percentage of occurrence |
|---|---|---|---|---|
| 1. | Exponent function | Akure, Ikeja, Ilorin, Lokoja, Ogoja, Oshogbo, Port Harcourt, Shaki Warri | 9 | 37.50% |
| 2 | Cubic function | Bauchi, Calabar, Jos, Maiduguri | 6 | 25.00% |
| 3 | Quadratic function | Yola | 3 | 12.50% |
| 4 | Power function | Benin, Enugu, Ibada | 3 | 12.50% |
| 5 | S function | Bida, Kaduna, Yelwa | 3 | 12.50% |

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**Table 4.10 Predicted Values of Clearness Index $K_T$ Based On Developed Empirical Regression Models And Substitution Of K-values (n/N).**

| S/no | Location | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Best Model |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Akure | 0.5682 | 0.5928 | 0.5593 | 0.5602 | 0.5446 | 0.4863 | 0.4046 | 0.3989 | 0.4281 | 0.5219 | 0.6363 | 0.5602 | | Exponent |
| 2. | Bauchi | 0.639 | 0.6351 | 0.6017 | 0.5843 | 0.607 | 0.5903 | 0.5151 | 0.5654 | 0.5654 | 0.6266 | 0.6577 | 0.6524 | | Cubic |
| 3. | Benin | 0.5216 | 0.5401 | 0.5216 | 0.5462 | 0.5462 | 0.4759 | 0.386 | 0.3513 | 0.3942 | 0.496 | 0.5755 | 0.5581 | | Power |
| 4. | Bida | 0.5742 | 0.6295 | 0.5805 | 0.6091 | 0.6037 | 0.5253 | 0.4646 | 0.4646 | 0.5475 | 0.6246 | 0.6685 | 0.6342 | | S |
| 5. | Calabar | 0.5678 | 0.5322 | 0.4446 | 0.485 | 0.485 | 0.4007 | 0.3311 | 0.3212 | 0.3434 | 0.3673 | 0.485 | 0.5868 | | Cubic |
| 6. | Enugu | 0.5565 | 0.5565 | 0.5322 | 0.5445 | 0.5322 | 0.5004 | 0.4168 | 0.4015 | 0.4316 | 0.5197 | 0.6029 | 0.6029 | | Power |
| 7. | Gusau | 0.6402 | 0.6409 | 0.6358 | 0.6345 | 0.6369 | 0.6196 | 0.6261 | 0.6315 | 0.6406 | 0.6375 | 0.6363 | 0.6402 | | Cubic |
| 8. | Ibadan | 0.5784 | 0.5927 | 0.5711 | 0.5341 | 0.5565 | 0.48 | 0.3967 | 0.4054 | 0.4477 | 0.4879 | 0.614 | 0.6069 | | Power |
| 9. | Ikeja | 0.5359 | 0.5646 | 0.5429 | 0.5359 | 0.5153 | 0.4237 | 0.3918 | 0.4074 | 0.4182 | 0.5086 | 0.5646 | 0.572 | | Exponent |
| 10 | Ilorin | 0.6094 | 0.6328 | 0.5868 | 0.5579 | 0.565 | 0.5305 | 0.439,2 | 0.4072 | 0.4392 | 0.5509 | 0.6249 | 0.649 | | Exponent |
| 11. | Jos | 0.677 | 0.662 | 0.6023 | 0.5477 | 0.5367 | 0.5312 | 0.4543 | 0.4323 | 0.5038 | 0.5914 | 0.662 | 0.677 | | Cubic |
| 12. | Kaduna | 0.6395 | 0.6555 | 0.6042 | 0.6224 | 0.5848 | 0.5781 | 0.4928 | 0.4748 | 0.5263 | 0.6224 | 0.6895 | 0.6555 | | S |
| 13. | Kano | 0.6528 | 0.6541 | 0.6299 | 0.6299 | 0.6541 | 0.6541 | 0.6206 | 0.6206 | 0.6541 | 0.6541- | 0.6132 | 0.6325 | | Quadratic |
| 14. | Lokoja | 0.5977 | 0.5895 | 0.5429 | 0.5429 | 0.5356 | 0.4932 | 0.4481 | 0.4127 | 0.4543 | 0.5504 | 0.6489 | 0.6143 | | Exponent |
| 15. | Maiduguri | 0.6548 | 0.6546 | 0.647 | 0.6247 | 0.6247 | 0.6196 | 0.5585 | 0.5323 | 0.6142 | 0.6548 | 0.6513 | 0.6546 | | Cubic |
| 16. | Ogoja | 0.5687 | 0.5758 | 0.5217 | 0.5549 | 0.5549 | 0.509 | 0.4284 | 0.4128 | 0.4556 | 0.5282 | 0.6049 | 0.6124 | | Exponent |
| 17 | Oshogbo | 0.5538 | 0.5818 | 0.5607 | 0.5538 | 0.5403 | 0.5079 | 0.4117 | 0.3776 | 0.4117 | 0.5142 | 0.6113 | 0.6038 | | Exponent |
| 18 | P/Harcourt | 0.5135 | 0.5015 | 0.4353 | 0.4898 | 0.5015 | 0.3869 | 0.328 | 0.328 | 0.3358 | 0.4056 | 0.4898 | 0.5257 | | Exponent |
| 19 | Potiskum | 0.6543 | 0.6558 | 0.6496 | 0.5897 | 0.6348 | 0.6393 | 0.5897 | 0.5897 | 0.6348 | 0.6543 | 0.6475 | 0.6504 | | Cubic |
| 20 | Shaki | 0.6211 | 0.6051 | 0.5894 | 0.5818 | 0.5818 | 0.5104 | 0.4139 | 0.4139 | 0.4249 | 0.5449 | 0.646 | 0.5972 | | Exponent |
| 21 | Sokoto | 0.6651 | 0.6755 | 0.6811 | 0.6776 | 0.6776 | 0.6776 | 0.6476 | 0.5969 | 0.6863 | 0.6651 | 0.6344 | 0.6651 | | Quadratic |
| 22 | Warri | 0.5443 | 0.5443 | 0.4987 | 0.5256 | 0.5256 | 0.449 | 0.3515 | 0.3515 | 0.3836 | 0.465 | 0.5837 | 0.5837 | | Exponent |
| 23 | Yelwa | 0.6285 | 0.6234 | 0.5903 | 0.5903 | 0.6019 | 0.6074 | 0.5307 | 0.4911 | 0.5782 | 0.6431 | 0.6697 | 0.6431 | | S |
| 24 | Yola | 0.6328 | 0.6347 | 0.6014 | 0.5954 | 0.6014 | 0.5745 | 0.5096 | 0.4985 | 0.5583 | 0.6328 | 0.6346 | 0.636 | | Quadratic |

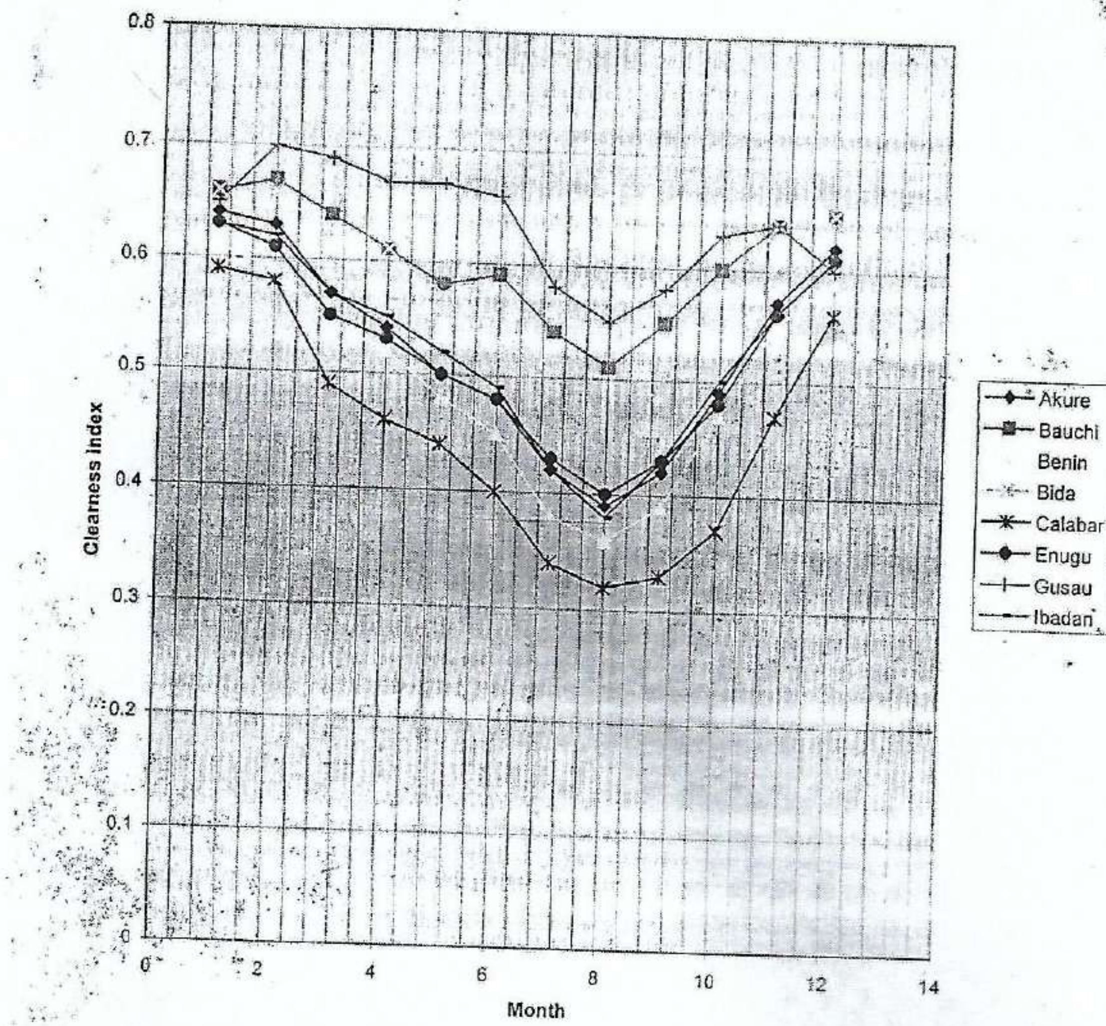


**Figure 4.1: Graph showing trend of clearness index of first 8 location studied with months**

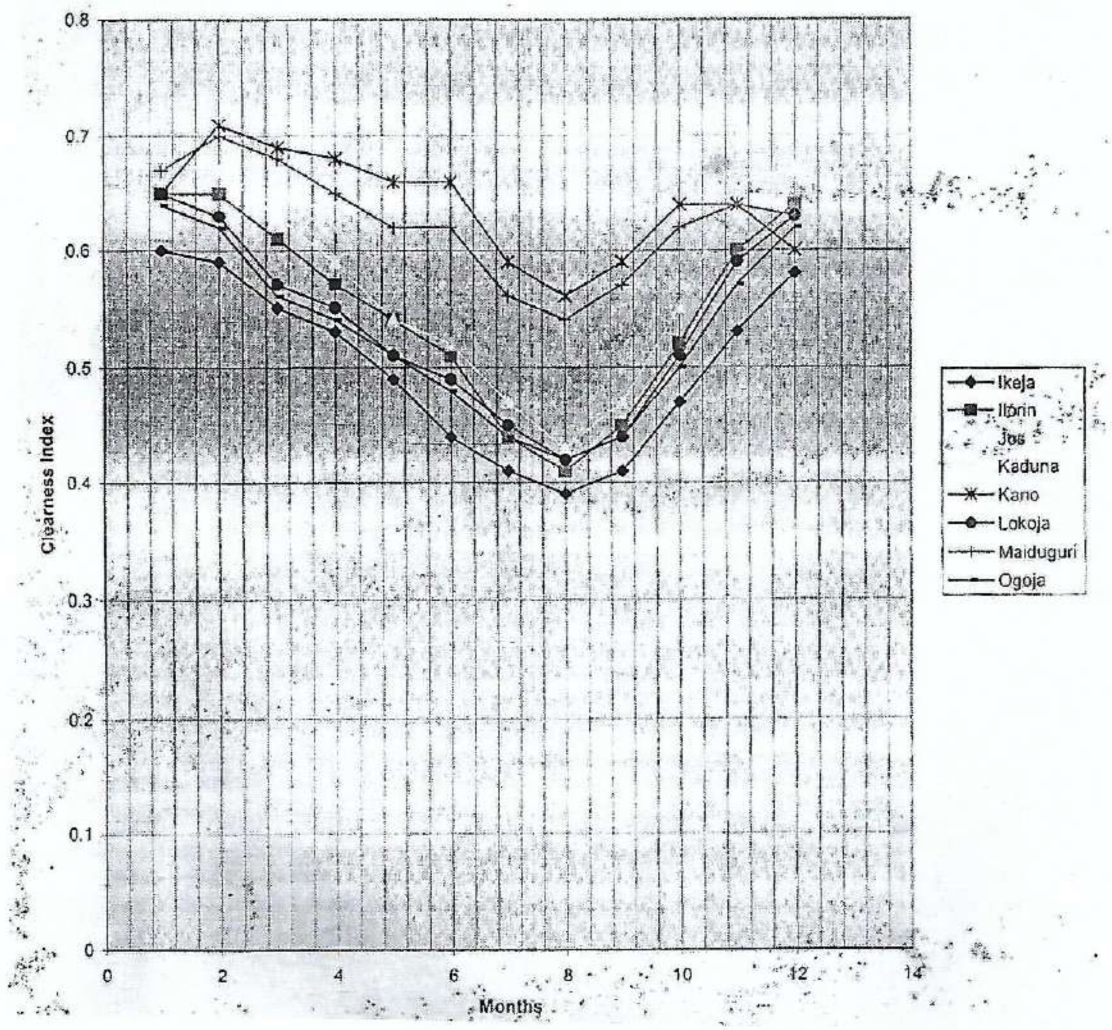


**Figure 4.2: Graph showing Trend of clearness Index of second 8 locations studied with months**

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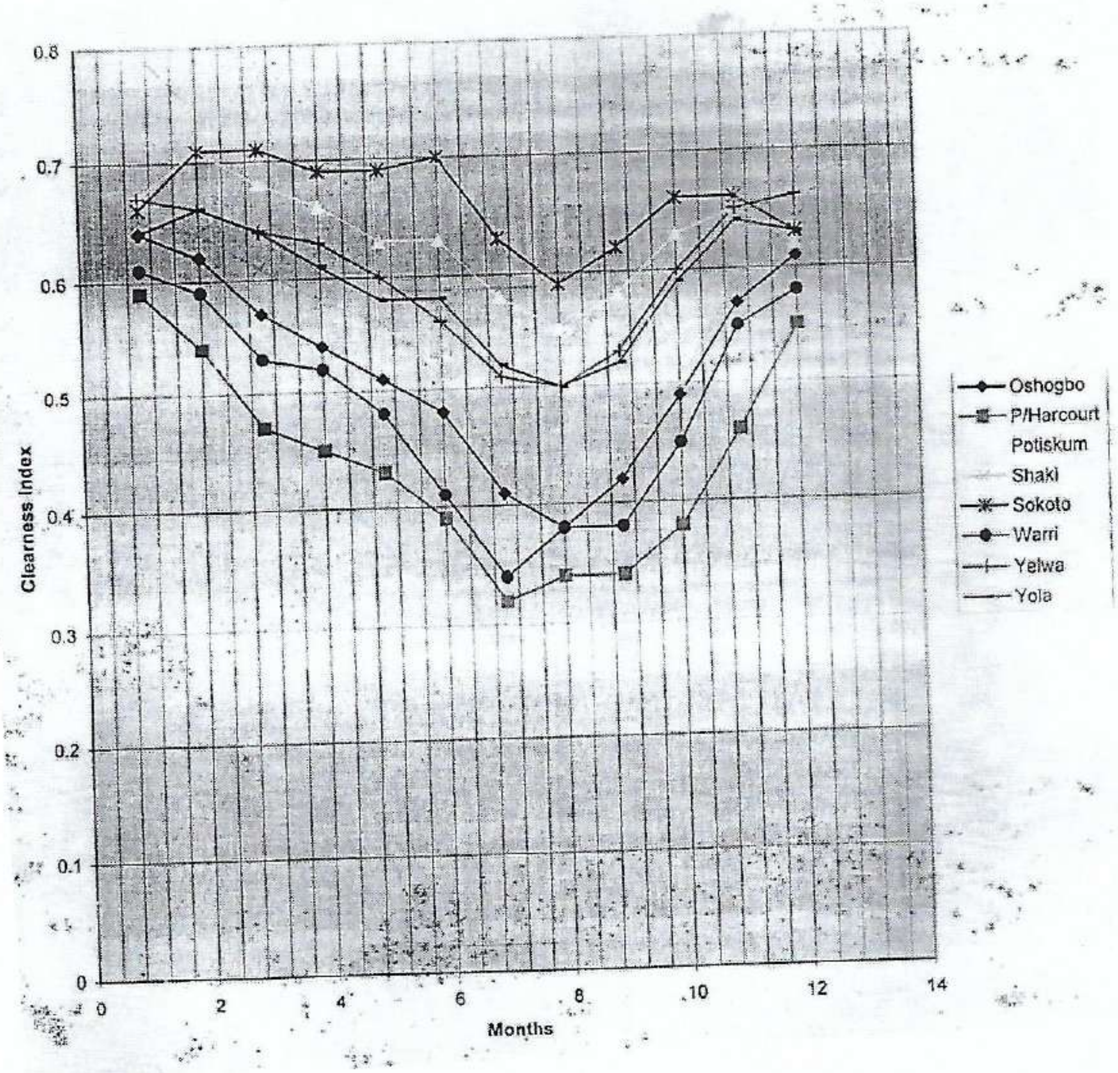


**Figure 4.3: Graph showing Trend of clearness Index of third 8 locations studied with months**

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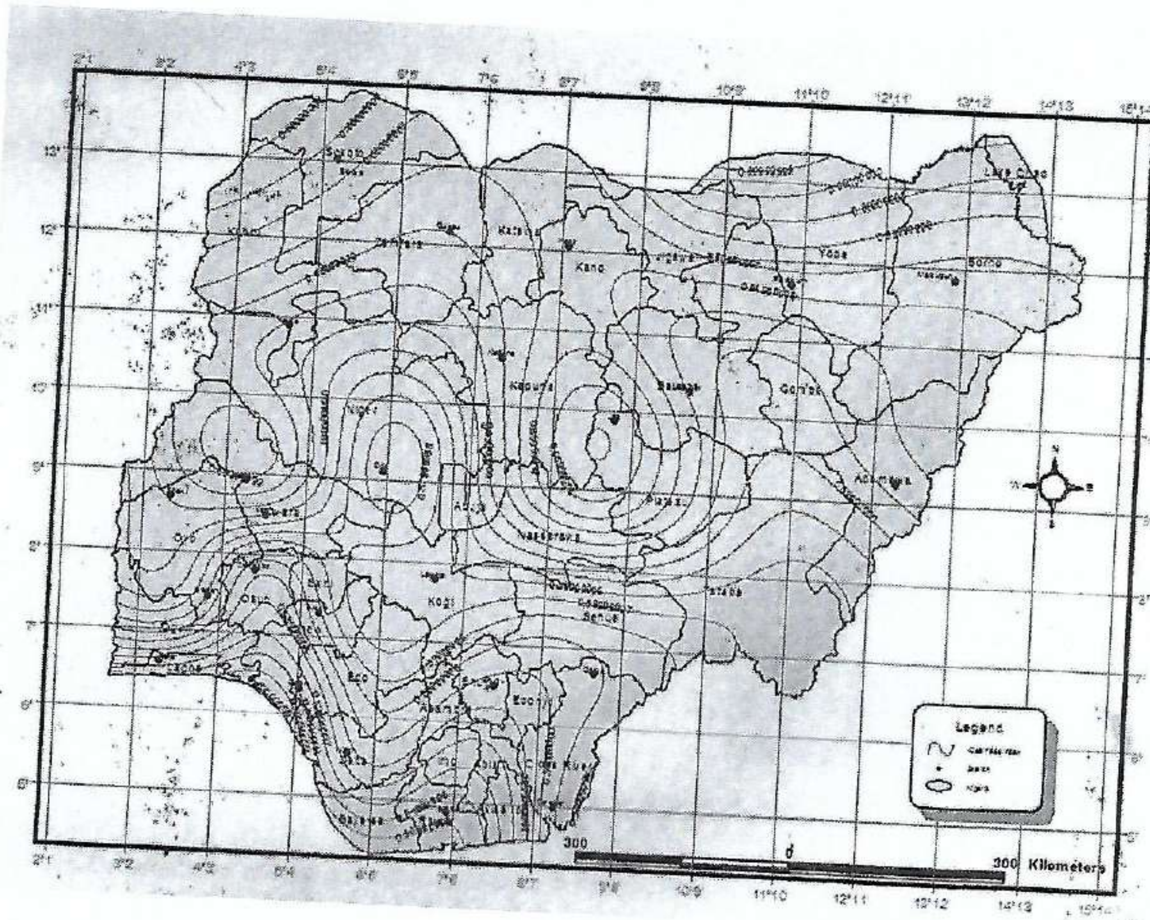


**Fig 4.4 Solar map showing predicted monthly averaged clearness index for January for 24 location in Nigeria**



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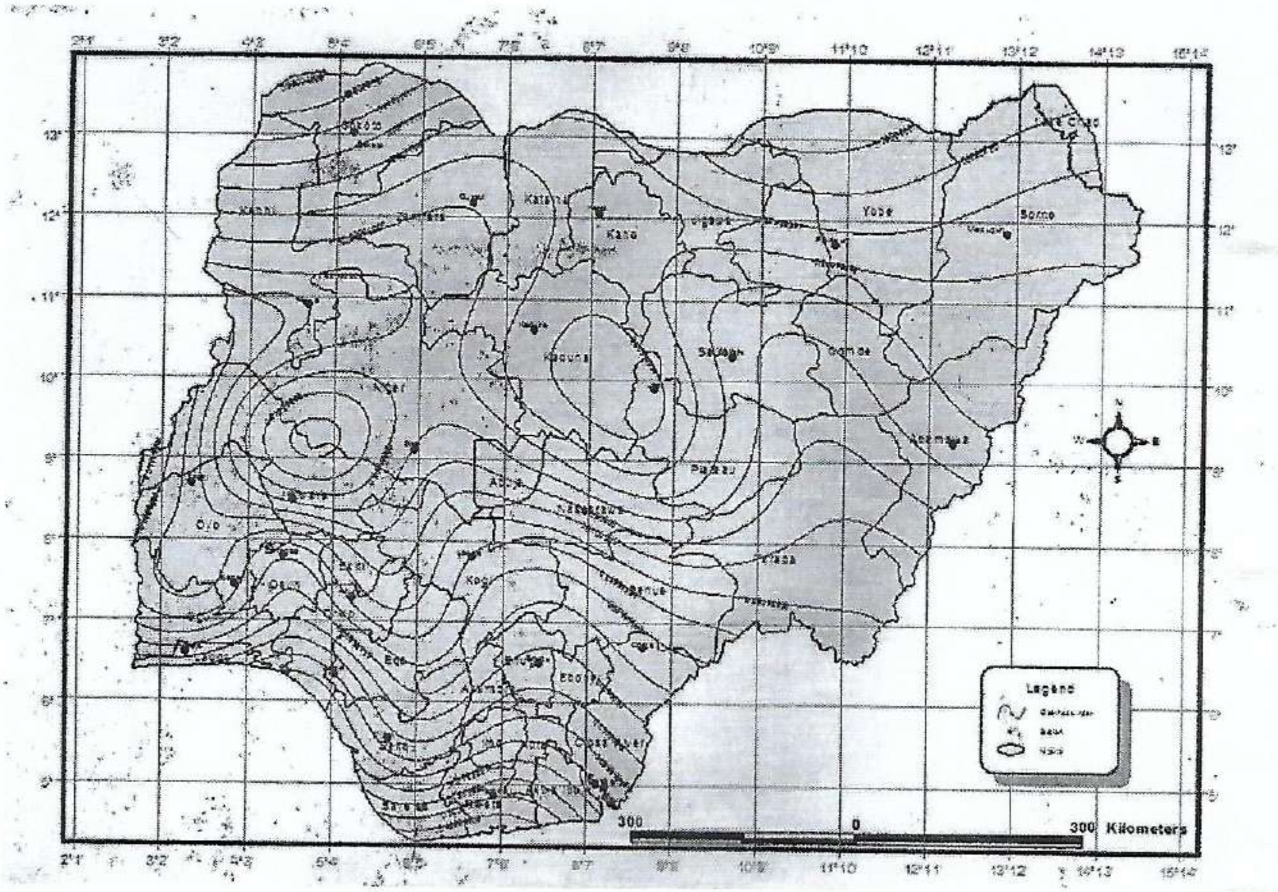


**Fig. 4.5 Solar Map showing predicted monthly averaged clearness index for February for 24 locations in Nigeria**

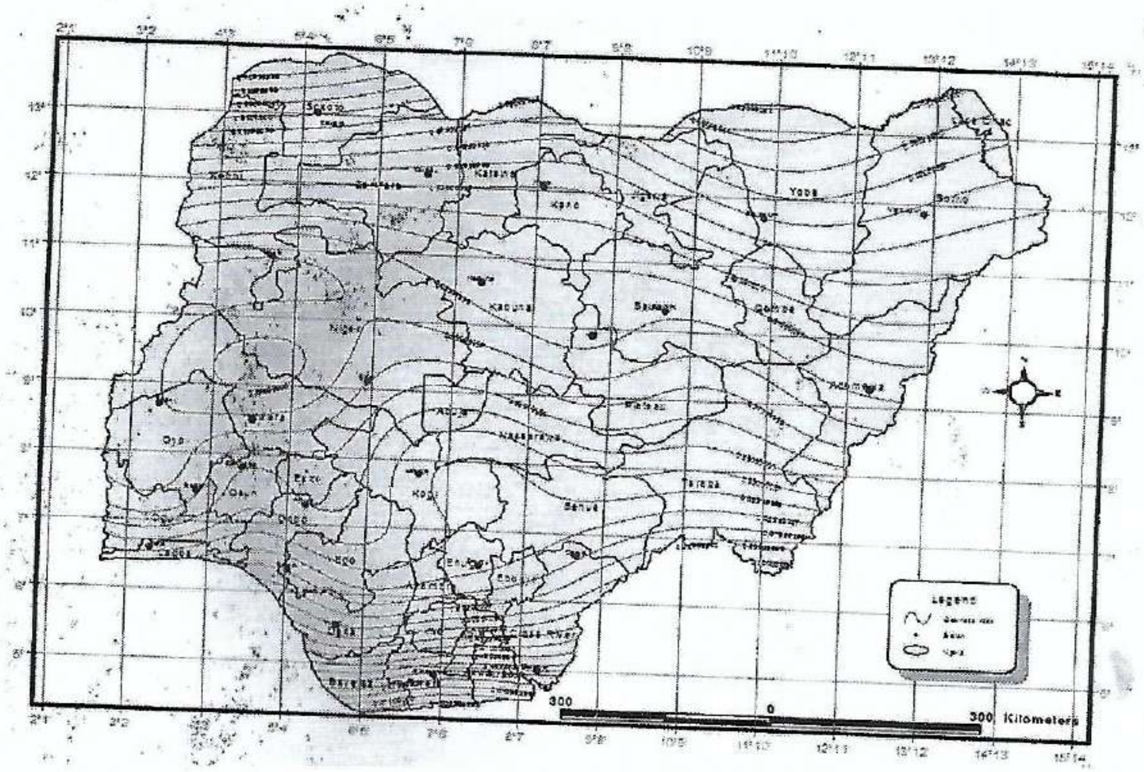


**Fig. 4.6 Solar Map showing predicted monthly averaged clearness index for March for 24 locations in Nigeria**

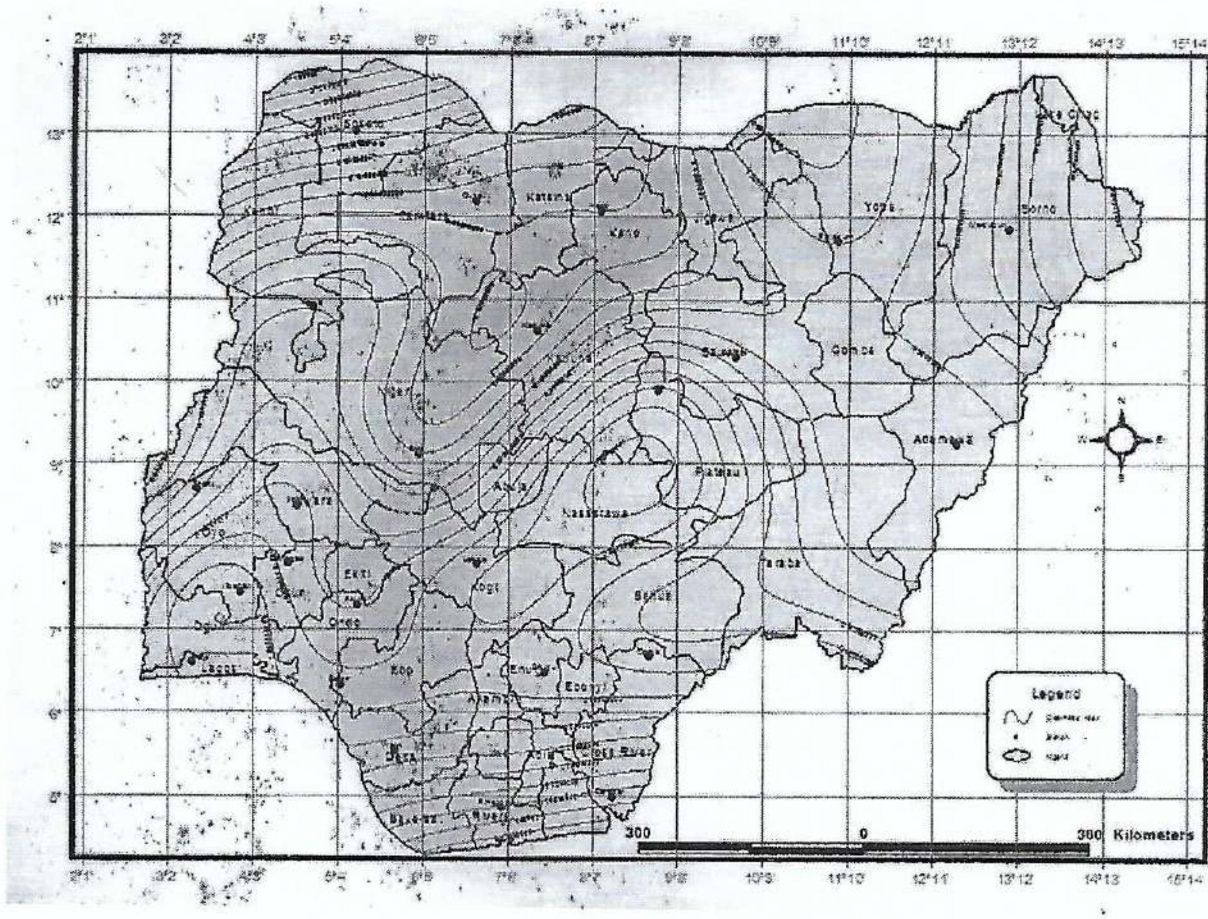


**Fig. 4.7 Solar Map showing predicted monthly averaged clearness index for April for 24 locations in Nigeria**



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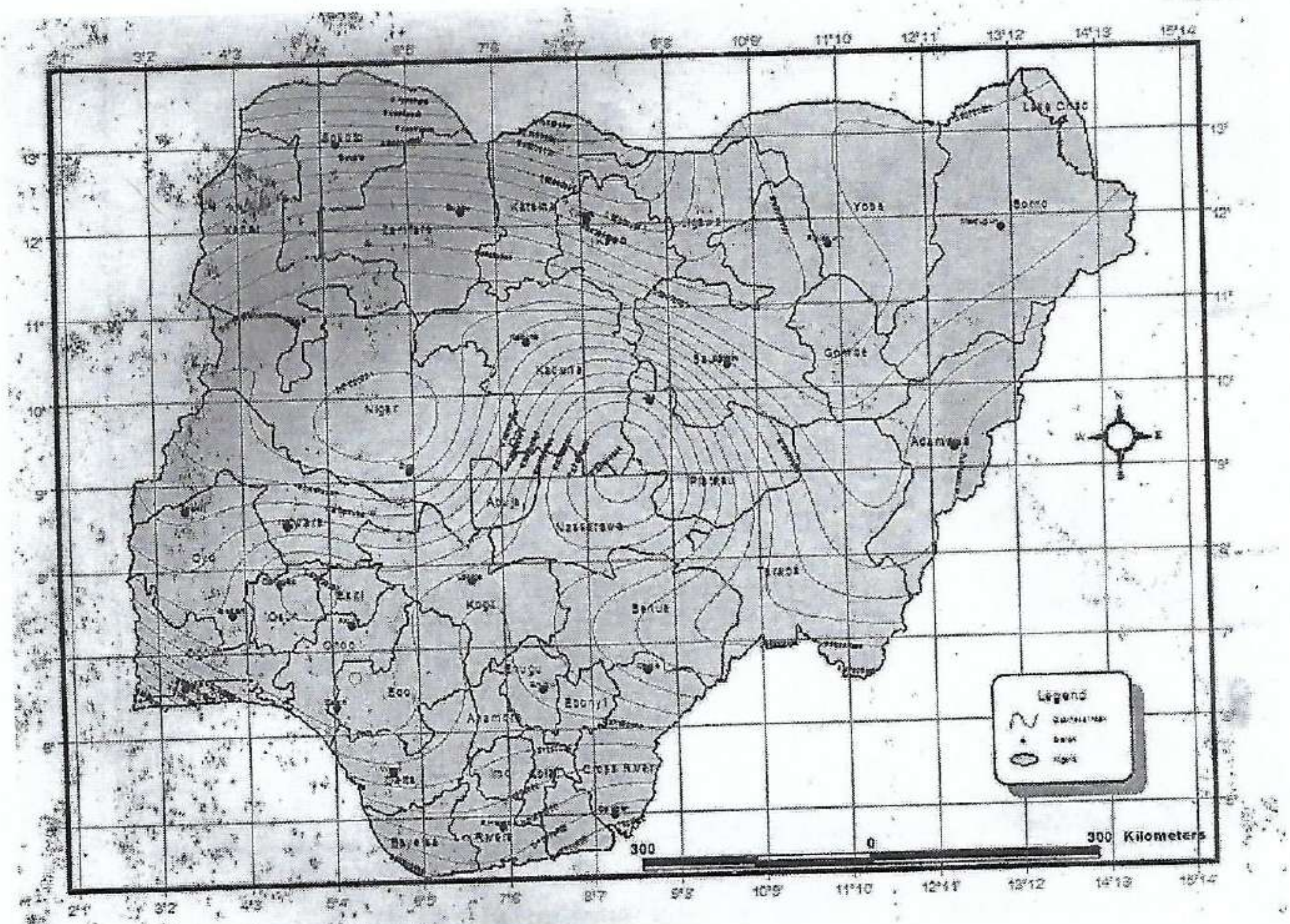


**Fig. 4.8 Solar Map showing predicted monthly averaged clearness index for May for 24 locations in Nigeria**

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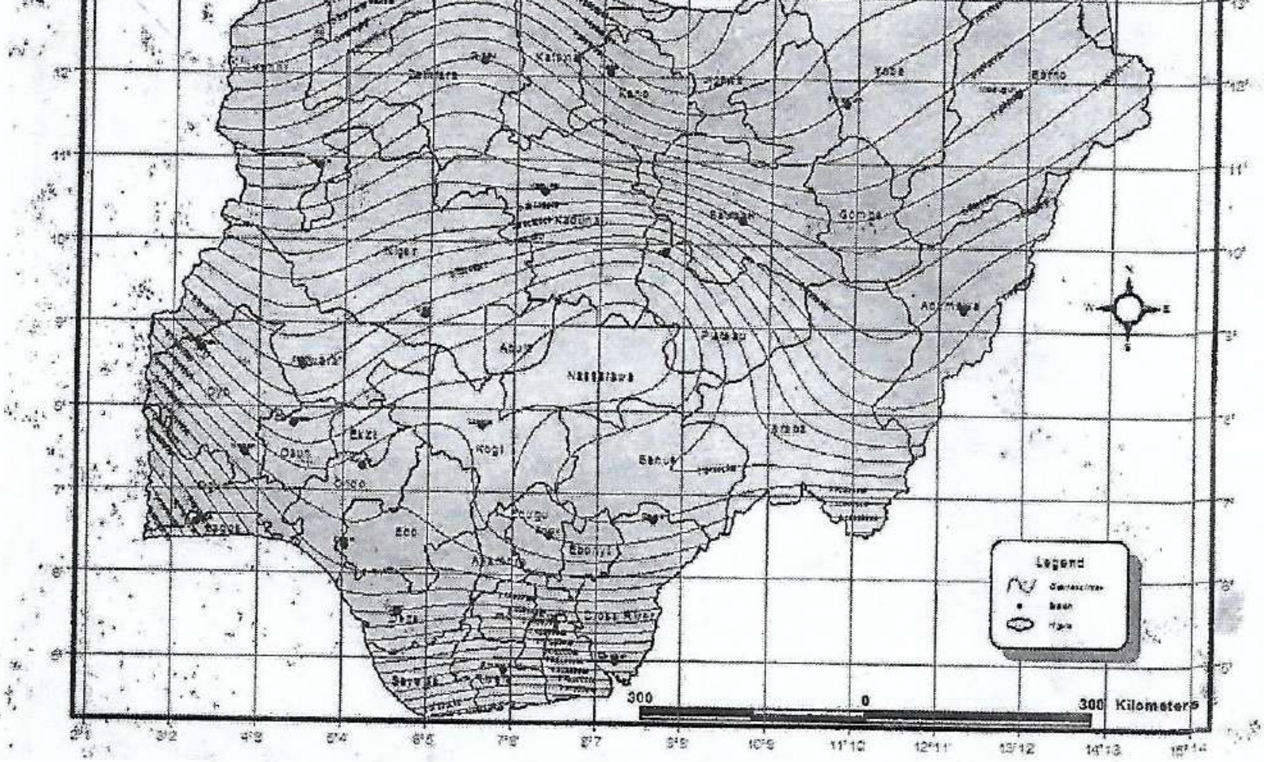


**Fig. 4.9 Solar Map showing predicted monthly averaged clearness index for June for 24 locations in Nigeria**



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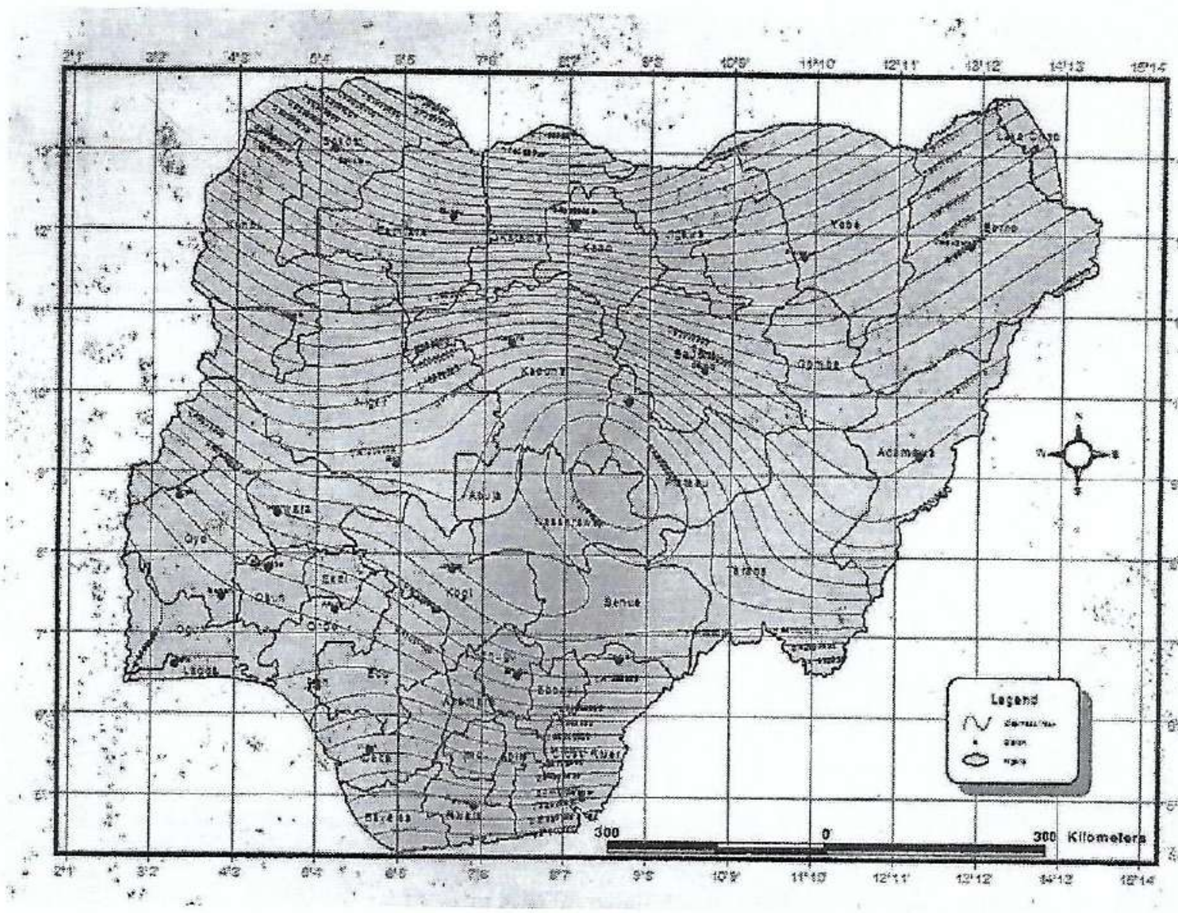

**Fig. 4.10 Solar Map showing predicted monthly averaged clearness index for July for 24 locations in Nigeria**

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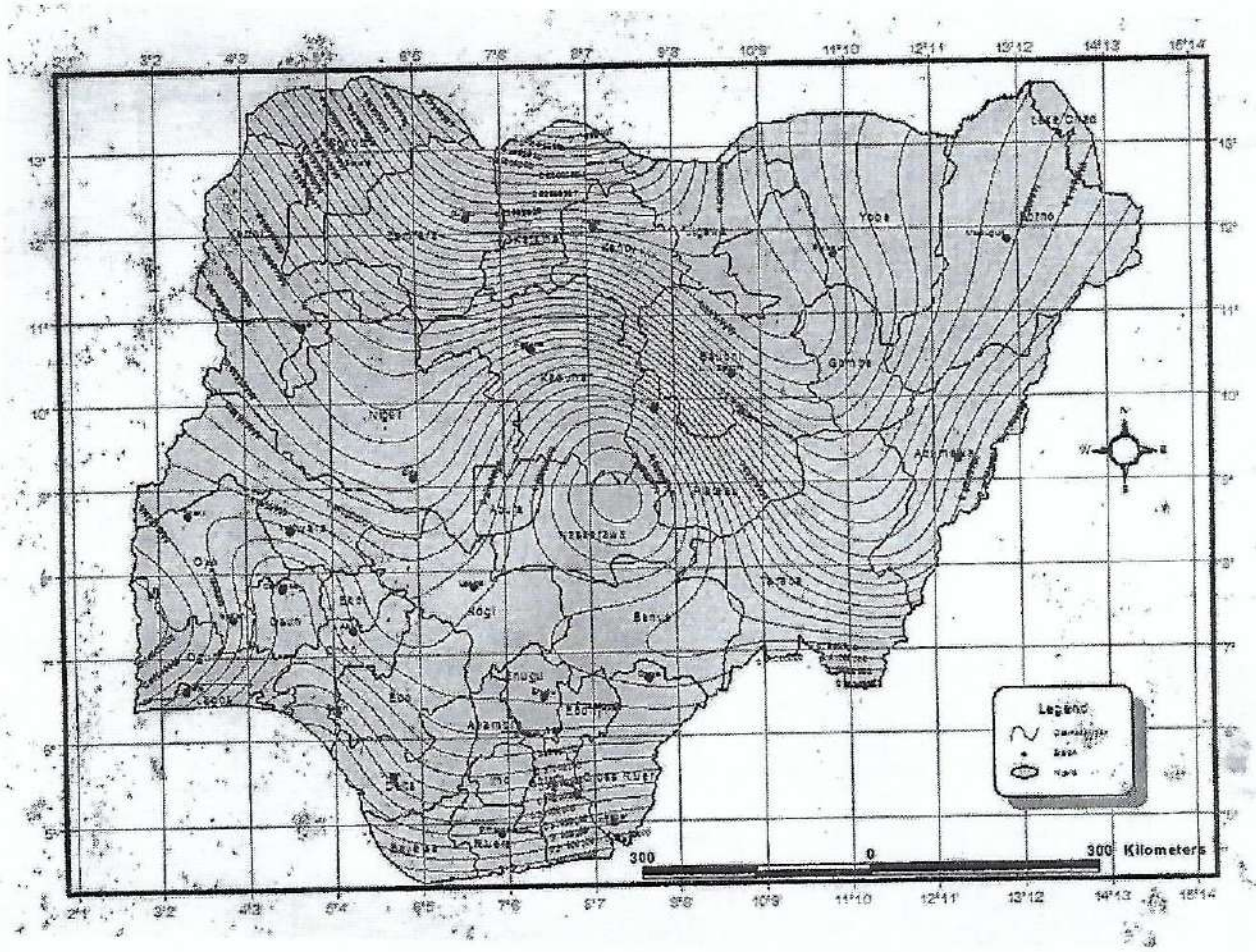


**Fig. 4.11 Solar Map showing predicted monthly averaged clearness index for August for 24 locations in Nigeria**

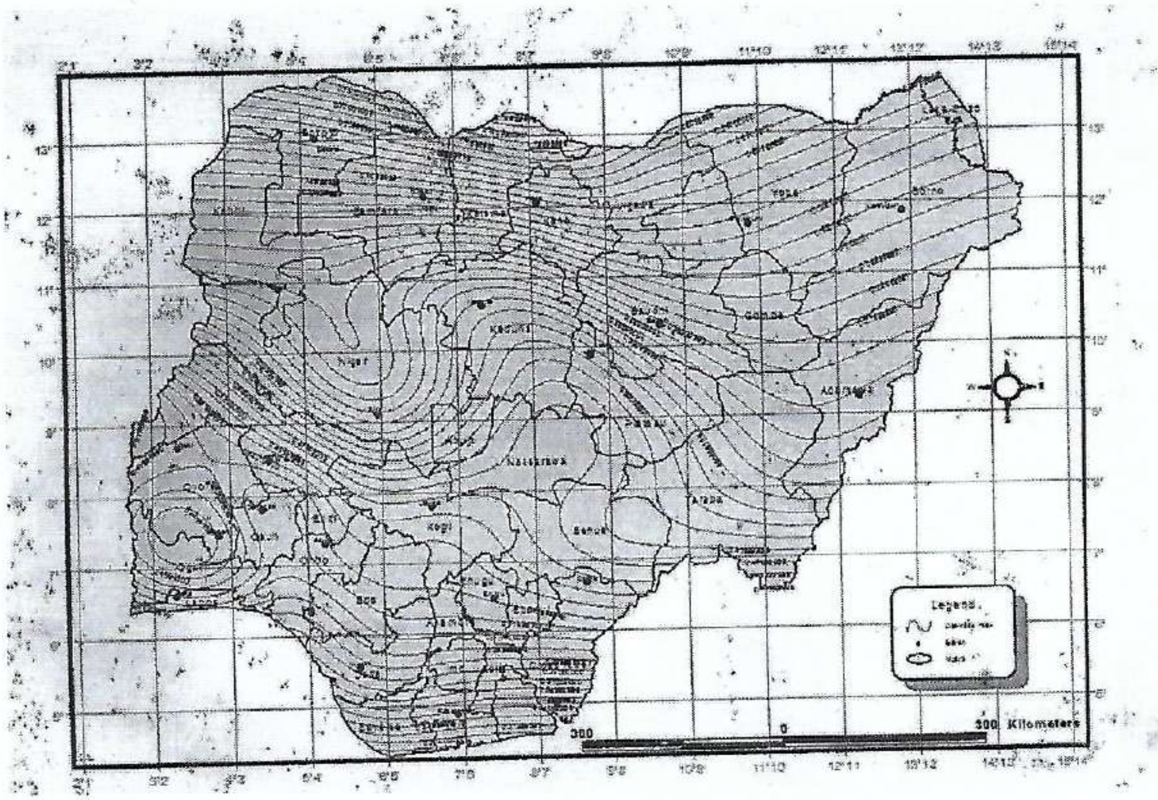


**Fig. 4.12 Solar Map showing predicted monthly averaged clearness index for September for 24 locations in Nigeria**

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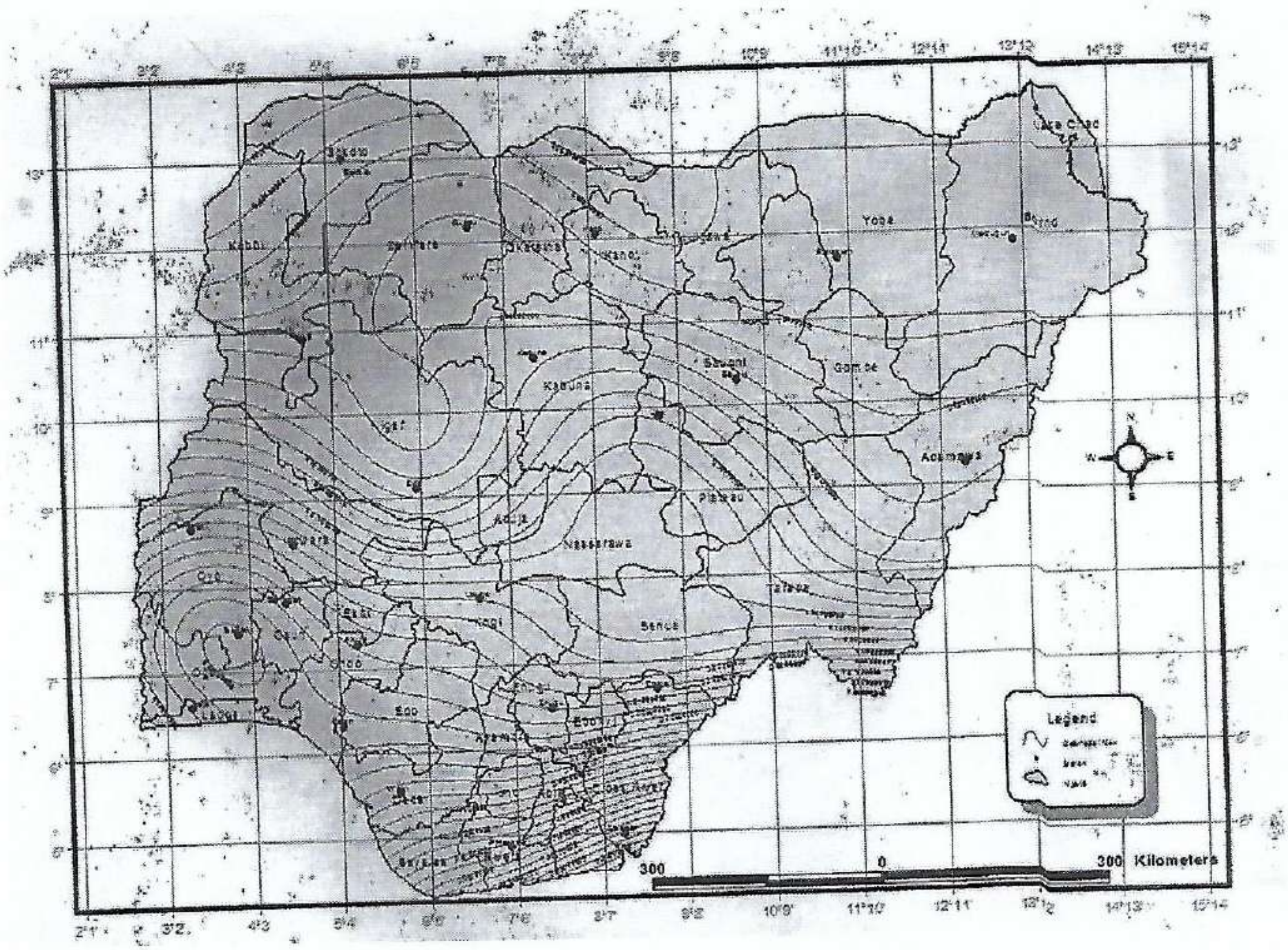


**Fig. 4.13 Solar Map showing predicted monthly averaged clearness index for October for 24 locations in Nigeria**

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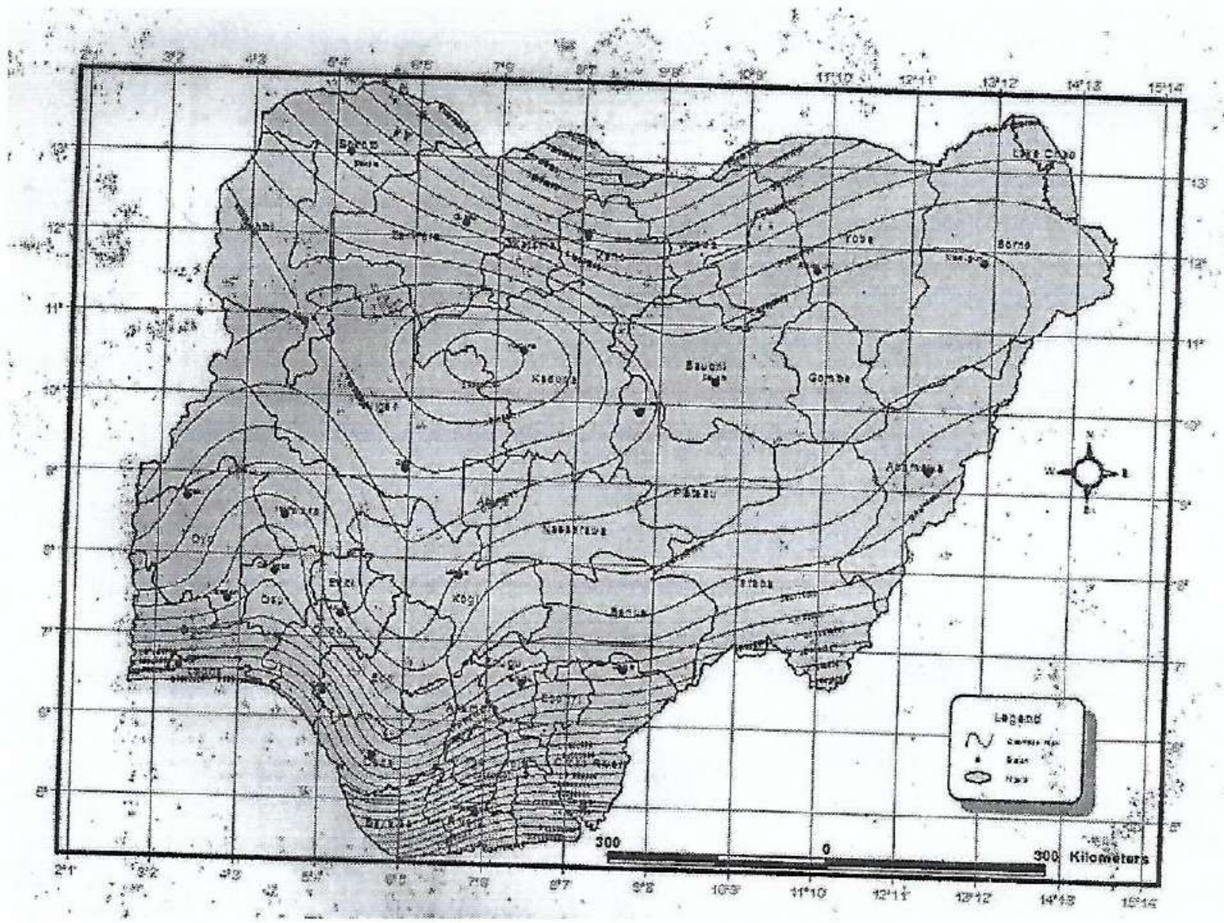


**Fig. 4.14 Solar Map showing predicted monthly averaged clearness index for November for 24 locations in Nigeria**

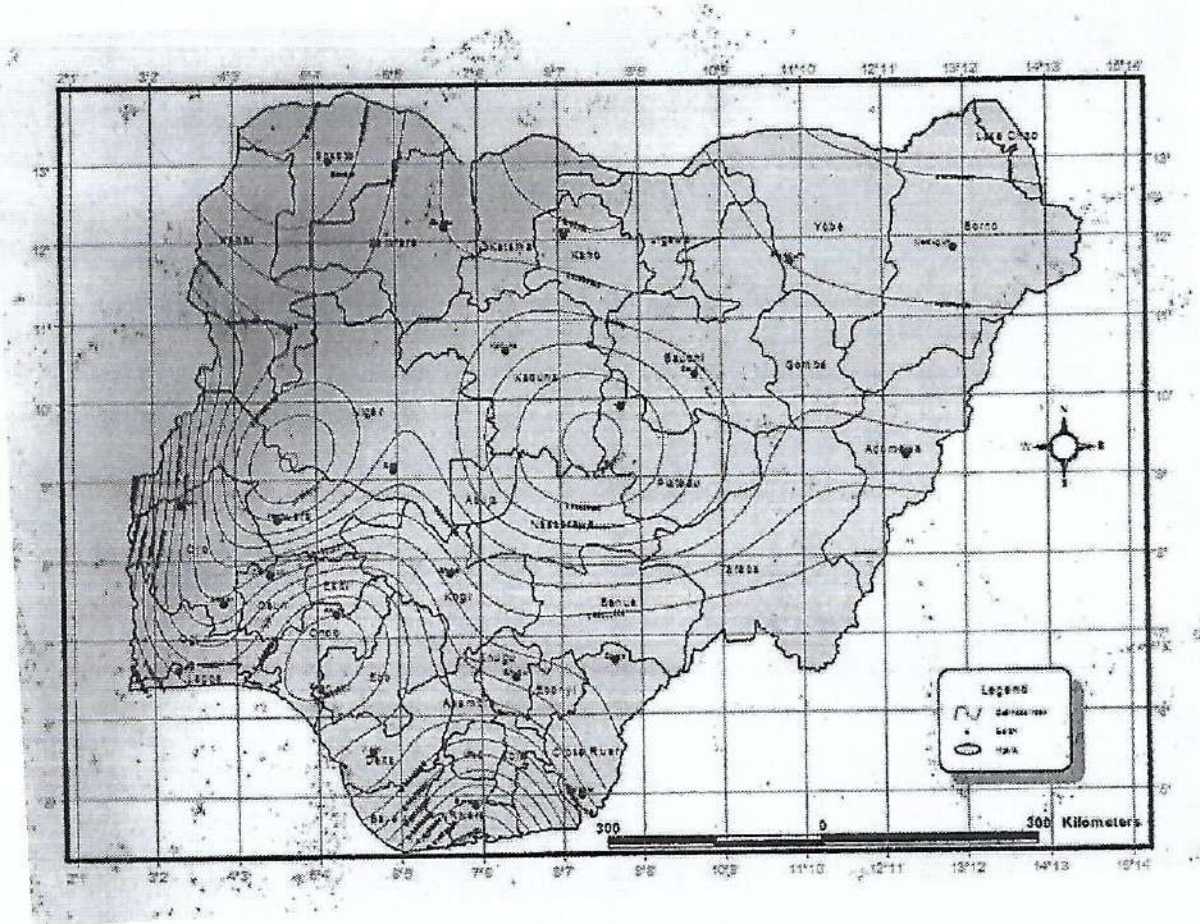


**Fig. 4.15 Solar Map showing predicted monthly averaged clearness index for December for 24 locations in Nigeria**

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CHAPTER FIVE

# 5.0 CONCLUSION AND RECOMMENDATION

## 5.1 IMPORTANT-CONCLUSION

From the foregoing discussion of results it can be concluded that:

1. The total yearly averaged extraterrestrial solar radiation for entire landmass of Nigeria is $10{,}385*10^{12}$. MW-hr /day.
2. Linear and Quadratic functions are not the only functions that could estimate Clearness Index from Cloudiness Index based on ANGSTROM-Prescott Modeling approach for Nigeria; Exponential functions were found to have highest and widest applicability in regressing Clearness index to Cloudiness index for Nigerian locations. The exponent, cubic, quadratic, power and S models found to be best for Nigerian locations were presented in Table 4.7.
3. The general trend of Clearness index values is for $K_T$ to have PEAK values between March and May; rapidly declining values between June and July; rapidly increasing values between September and October and lastly minimum values at August for most of the 24 location studied. However, experience with climate of Nigeria revealed that these observations about the trends of $K_T$ correlate with the seasons of Nigeria. $K_T$ values generally are high during the dry seasons and low during the rainy seasons when clouds prevent the much of solar radiation from reaching the ground.
4. Four out of, the twenty-four ANGSTROM-PRESCOTT models developed in the study for estimating $K_T$ from K have very low values of $R^2$ ranging between 1.836% and 42.724%.
5. With the development of ANGSTROM-PRESCOTT models to estimate $K_T$, sizing and design of solar systems applications could easily be done once values of minimum averaged monthly sunshine duration hour is known for, the location involved. The developed models as well as Table 4.6 having values of maximum possible values of N could be used.

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## 5.2 RECOMMENDATIONS.

As a result of this study I wish to recommend that

1. Efforts be stepped up in the utilization of the very abundant solar radiation potential estimated in this study for Nigerian landmass.
2. The twenty-four models developed for 24 studied Nigerian locations as well as the tables of values of N be used in the sizing of solar energy systems for these locations in Nigeria and for other locations with close values of latitudes and similar meteorological attributes to these locations.
3. That interpolation method could be used on the developed models for the twenty-four studied locations to estimate $K_T$ for other locations with close values of latitudes and similarly meteorological attributes to those locations.
4. That exponent function, which has the highest and widest applicability in Nigeria, might also be used to quickly and roughly estimate the Clearness index values for any locations in Nigeria.

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