ISO-RADIATION MAPS OF ADAMAWA STATE, NIGERIA

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Abstract

Regression coefficients relating solar radiation to latitude were determined for 10 stations in North – East and South – East of Nigeria. These were used to estimate both average annual and average monthly solar radiations for 68 sampled stations in Adamawa state, Nigeria. Iso-radiation maps were drawn using the estimated radiations. The estimated average annual radiations range between 17 MJ/m^{2}day and 23 MJ/m^{2}day while the estimated average monthly radiation values range between 14 MJ/m^{2}day and 24 MJ/m^{2}day. These results have implication for deployment and development of solar technologies in Adamawa state.

Keywords: regression coefficients, solar radiation, iso - radiation maps, sampled stations, implication.

Nomenclature

H	= Mean of daily global (or total) radiation on a horizontal surface (in MJm^{-2}day^{-1})
H_o	= Mean of extra-terrestrial radiation on a horizontal surface (in MJm^{-2}day^{-1}).
S_o	= Mean of day length (in hours).
S	= Mean of daily sunshine hours (in hours).
T_m	= Mean of maximum air temperature (in ^{o}C).
R	= Relative humidity.
Ø	= Latitude for a given area (in degrees).
θ	= Longitude for a given area (in degrees).
ε	= Eccentricity of the earth's orbit
δ	= Declination (in degrees).
I_{sc}	= Solar constant (= 4.8708MJhr^{-1}m^{-2}).
w_{sr}	= Sunrise hour angle (in degrees).
d	= Number of days starting from the beginning of the year (i.e. 1st Jan. to 31st Dec.).

Introduction

Adamawa State is situated between latitude 7^0 and 11^0 North of the equator and between longitude 11^0 and 14^0 East of the Greenwich meridian within the North Eastern part of Nigeria (Adebayo, 1999a). The state has a wide range of climatic variables due to its relatively extensive latitudinal spread. The state, with its well suited positioning with respect to solar energy reception, stands a good chance of gaining from this natural resource especially in technologies such as solar dryers and refrigerators, solar water pumping and rural electrification to mention but a few.

The utilization of solar energy resource requires the knowledge of the amount of solar radiation that is available at a given geographical region for optimum design of solar energy conversion systems. The unavailability of direct solar radiation measuring devices therefore calls for development of models, based on meteorological data, which can be used to estimate solar radiation within some accepted limits of errors. This paper used some of such models from earlier studies by Ododo and Kundwal (2007) to draw both annual and monthly iso-radiation maps for the whole of Adamawa state.

Empirical Formulae

Several formulae relating solar radiation to some climatic factors are in existence. These formulae have been used to analyse solar radiation data for some locations both within and outside Nigeria. Most of the empirical formulae relate solar radiation with various meteorological variables such as sunshine hours, relative humidity and maximum temperature to obtain estimates of solar radiation. A few among these formulae are as follows:

a) Angstrom-Page equation (Page, 1964)

$$\frac{H}{H_0} = \alpha_0 + \alpha_1 \frac{S}{S_0} \qquad (1)$$

where α_0 and α_1 are regression constants and H_0 is mean extraterrestrial radiation on a horizontal surface (see appendix 1).

b) Swartman - Ogunlade equations (Swartman and Ogunlade, 1967)

$$H = b_0 \left(\frac{S}{S_0} \right)^{b_1} R^{b_2} \qquad (2)$$

$$H = c_0 + c_1 \frac{S}{S_0} + c_3 R \qquad (3)$$

where b_0, b_1, b_2, c_0, c_1, c_2 and c_3 are coefficients.

c) The latitude equations proposed by Ododo and Suleiman (1993)

$$H = l_0 + l_1 Ø \qquad (4)$$

where l_0 and l_1 are coefficients determined by linear regression. For stations in the North-East of Nigeria, $l_0 = 6.911$ and $l_1 = 1.436$

$$H/H_0 = 0.1835 + .0425Ø \qquad (5)$$

$$S/S_{0P} = 0.0335 + 0.0617Ø \qquad (6)$$

d) The ST_mR equations proposed by Ododo et al. (1995) namely

$$\frac{H}{H_0} = \sum_{i,j,k=0}^{n} \alpha_{ijk} \left(\frac{S}{S_0} \right)^i T_m^j R^k \qquad (7)$$

or

$$H = \sum_{i,j,k=0}^{n} \alpha_{ijk} \left(\frac{S}{S_0} \right)^i T_m^j R^k \qquad (8)$$

where *i j,k = 0,1............ n*; and *n* is the maximum power desired in any of the equations.

For Adamawa State, values of H (or H/H_0) and S/S_0 for many towns either did not exist or were not readily available. Also, no values of H, T_m and R could be found, even from the records of either Upper Benue River Basin Development Authority (UBRBDA) or Nigerian Meteorological Agency (NIMET) except for two stations (Yola and Ngurore). Therefore, the only way to obtain estimates of H for stations in Adamawa State was to use the latitude, Ø.

Equations (4), (5) and (6) were used to estimate three sets of annual radiation (H_1, H_2 and H_3 respectively) for 68 randomly selected towns and villages. Latitudes of these towns and villages were obtained from Microsoft Encarta Premium Suit (2004). Equation (4) was used to estimate H_1 using coefficients from Table 3. Equation (5) was used to estimate H_2; that is, by multiplying H/H_0 with the calculated values of H_0.

$H_0 = 24/\Pi)(\varepsilon I_{sc})\{(\cos Ø)(\cos\delta)(\sin W_{sr}) + (2\Pi W_{sr}/360)(\sin Ø)(\sin\delta)\}$

where

$\varepsilon = 1 + 0.033\cos(360d/365.25)$

and $W_{sr} = \cos^{-1}(-\tan Ø \tan\delta)$.

Equation (6) was used to estimate values of S/S_0 which were in turn used to estimate solar radiation H_3 using the Angstrom – Page equation (equation 1). The average value of the three estimates was used to plot annual iso-radiation map. For monthly estimates, only equation (4) was used as it was observed that there was no significant difference between the three different values of the annual estimates. Coefficients used for estimating the solar radiations are shown in Table 1 while the latitudes and longitudes of stations studied are shown in Table 2

Basically, the instrument that was used in the measurement of solar irradiance is Eppley Pyranometer, which measures respectively the diffuse, direct and global components of the radiation. Campbell Stoke's Sunshine Recorder gives the number of hours of bright sunshine, between sunrise and sunset.

Table 1: Annual Regression Coefficients of fitted values using equation 8

Intercept I_o *(MJm^{-2}day^{-1})*	*Slope* I_1 *(MJm^{-2}day^{-1} (^{o}N)$^{-1}$)*	*Correlation Coefficients R*
6.911	1.436	0.995

(***Source:*** Ododo and Suleiman (1993))

Table 2: Monthly Regression Coefficients of fitted values using equation 8

Month	*Intercept* I_o *(MJm^{-2}day^{-1})*	*Slope* I_1*(MJm^{-2}day^{-1} (^{o}N)$^{-1}$)*	*Correlation Coefficients R*
Jan.	9.4660	1.0506	0.978
Feb.	9.2440	1.3540	0.975
Mar.	8.4609	1.4718	0.991
Apr.	8.9150	1.4262	0.982
May	7.7305	1.4453	0.975
Jun.	5.8000	1.5008	0.984
Jul.	3.1672	1.5840	0.980
Aug.	3.0020	1.5425	0.981
Sep.	4.2611	1.6256	0.989
Oct.	4.7361	1.7890	0.988
Nov.	8.3980	1.3860	0.967
Dec.	9.4988	1.0848	0.977

(***Source:*** Ododo (2006b))

Note: For n = 10, minimum value of r for significance at 0.05% level is 0.875.

Table 3: Latitude and Longitude of Stations Studied

S/No	*Station*	*Ø (^{o}N)*	*Θ (^{o}E)*	*S/No*	*Station*	*Ø (^{o}N)*	*Θ (^{o}E)*
1	Yola	9.22	12.50	35	Demsa	9.47	12.13
2	Ngurore	9.28	12.23	36	Loh	9.50	12.08
3	Gumti	7.63	11.75	37	Waduku	9.52	11.65
4	Gindin Dutse	7.72	11.82	38	Borrong	9.53	12.20
5	Tipsan	7.87	12.03	39	Gyawana	9.57	11.87
6	Kubaji	7.93	11.80	40	Farang	9.58	12.95
7	Supen	8.00	11.57	41	Lamurde	9.60	11.78
8	Sambaki	8.05	12.02	42	Bare	9.60	12.03
9	Toungo	8.10	12.03	43	Lafia	9.65	11.80
10	Tuduri	8.13	11.43	44	Bagale	9.67	13.08
11	Kojoli	8.12	12.2O	45	Tallum	9.75	12.00
12	Nadu	8.15	12.15	46	Dumne	9.78	12.40
13	Gurum	8.30	12.02	47	Bolki	9.78	12.53
14	Sugu	8.37	12.05	48	Song	9.82	12.60
15	Sankemi	8.60	12.28	49	Dogolo	9.82	12.83
16	Lengdo	8.70	12.48	50	Shelleng	9.88	12.00
17	Jada	8.73	12.15	51	Mbilla	9.90	12.60
18	Tola	8.75	11.95	52	Maiha	9.98	13.22
19	Tuli	8.78	12.65	53	Pella	10.15	12.93

20	Dasu	8.80	12.37	54	Parputa	10.17	12.28
21	Mayofarang	8.93	12.50	55	Gombi	10.17	12.73
22	Jarang	8.98	11.88	56	Tafe	10.18	12.17
23	Gurin	9.10	12.87	57	Muda	10.18	13.23
24	Karlahi	9.10	12.70	58	Jiwi	10.23	12.82
25	Nassarawo	9.18	12.20	59	Hong	10.23	12.93
26	Parda	9.18	12.72	60	Jangala	10.27	12.40
27	Bille	9.23	11.90	61	Mubi	10.27	13.27
28	Jimeta	9.27	12.45	62	Shuwa	10.28	12.58
29	Kpasham	9.27	11.75	63	Gardemna	10.33	12.40
30	Bali	9.28	11.78	64	Garkida	10.40	12.58
31	Dong	9.40	11.90	65	Kophri	10.50	12.78
32	Billachi	9.40	12.45	66	Bazza	10.57	13.32
33	Numan	9.45	12.03	67	Duhu	10.78	13.45
34	Kwa	9.47	11.63	68	Madagali	10.88	13.35

(***Source***: Microsoft Encarta Premium Suit (2004))

Iso-radiation Maps

The estimated radiations were used to construct both annual and monthly iso-radiation maps for Adamawa State, using computer software called SurRge Mapping and Gridding software which was obtained from Dressler (2006) through the internet. The annual iso-radiation map is shown in figure 1 while the monthly iso-radiation maps are shown in figures 2(a) – (l)

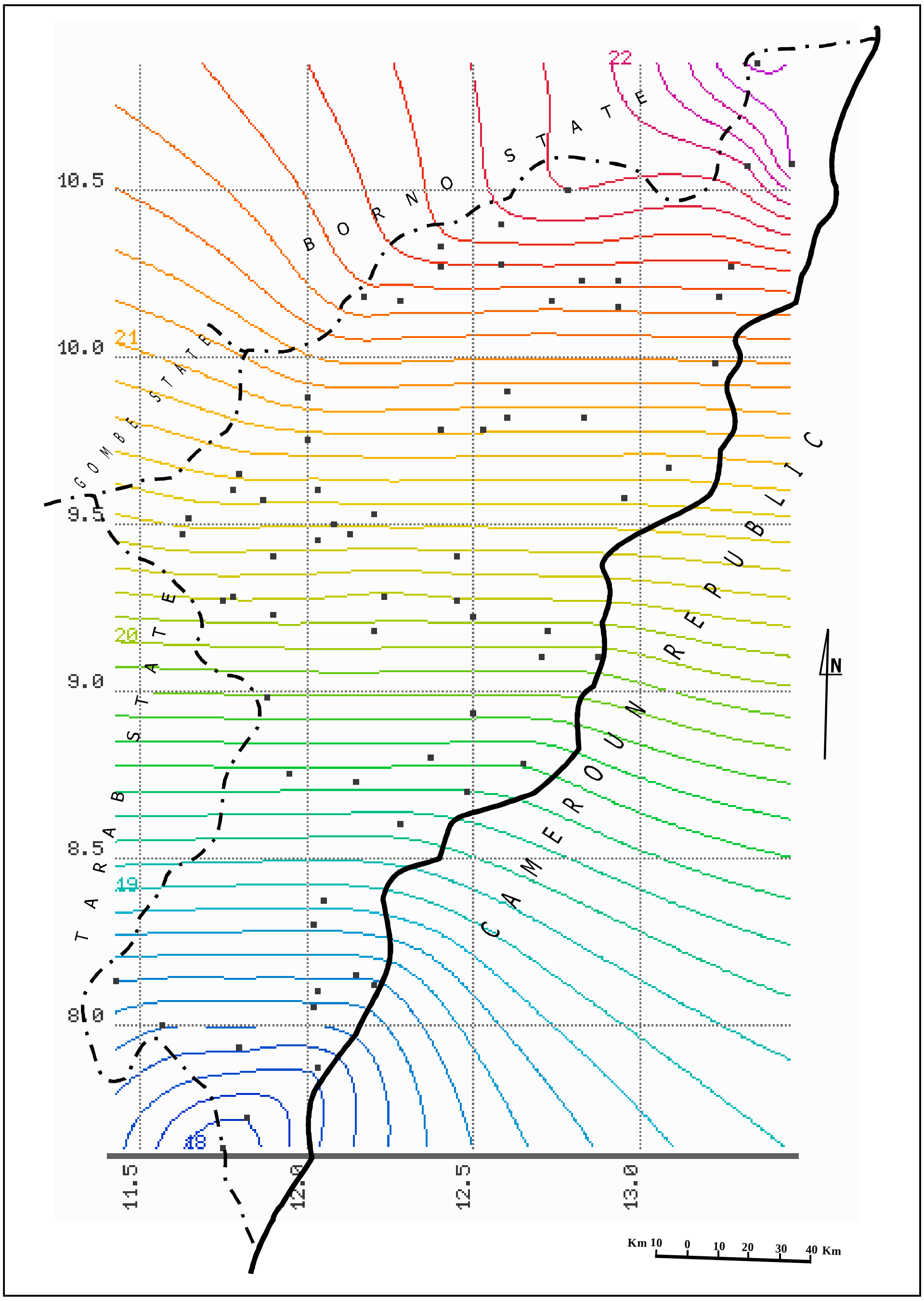

Figure 1: Annual Iso-Radiation Map of Adamawa State

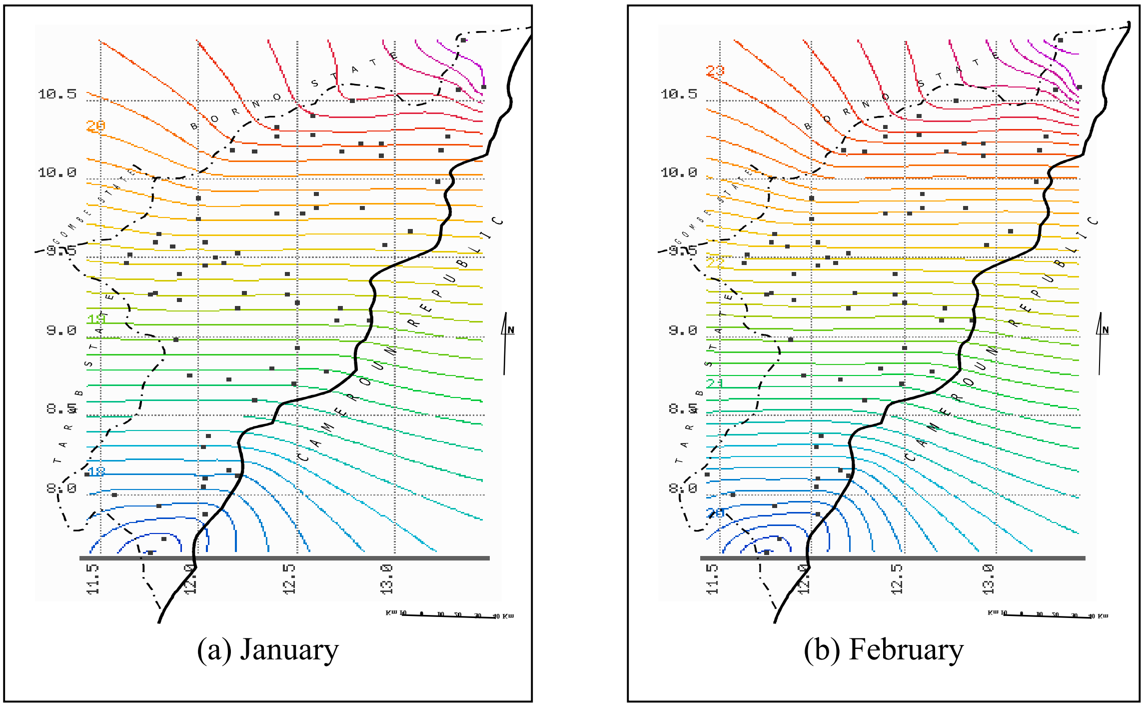

Figure 2(Cont): Monthly Iso-Radiation Map of Adamawa State

Conclusion

The estimated average values of annual radiation for the state range between 17MJ/m^{2}day and 23MJ/m^{2}day while the estimated average monthly radiation values range between 14MJ/m^{2}day and 24MJ/m^{2}day. Expectedly, the estimated radiations increase with latitude.

With a diffuse background radiation of about 7 MJm^{-2}day^{-1} (Ododo, 2006a) it implies that about half of global radiation will be diffuse for the months of July and August, leaving only about 7 – 8 MJm^{-2}day^{-1} as direct radiation. The large diffuse radiation may be good for agriculture but certainly not economically viable for the use of solar concentrators. Solar concentrators can be more efficient during the months of October – May.

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References

Adebayo A. A. (1999). Adamawa State in Maps: Introduction in Adebayo A. A. and Tukur A. L. (eds) ***Adamawa State in Maps***, Paraclete Publishers, Yola-Nigeria.

Dressler, M. (2006). SuRge Mapping and Gridding Software (http//www.geocities.com/miroslavdressler/surgemain.htm)

Microsoft Corporation (2004). Microsoft Encarta Premium Suit.

Ododo, J. C. (2006a). Uniform Background Diffuse Radiation in Nigeria, ***Nigerian Journal of Solar Energy***, Vol. 16, 134–137.

Ododo, J. C. (2006b). Private Communication.

Ododo, J. C. and Kundwal, M. E. (2007). The Solar Energy Potential of Adamawa State, Nigeria, ***Nigerian Journal of Solar Energy,*** Vol. 18, 88 – 104.

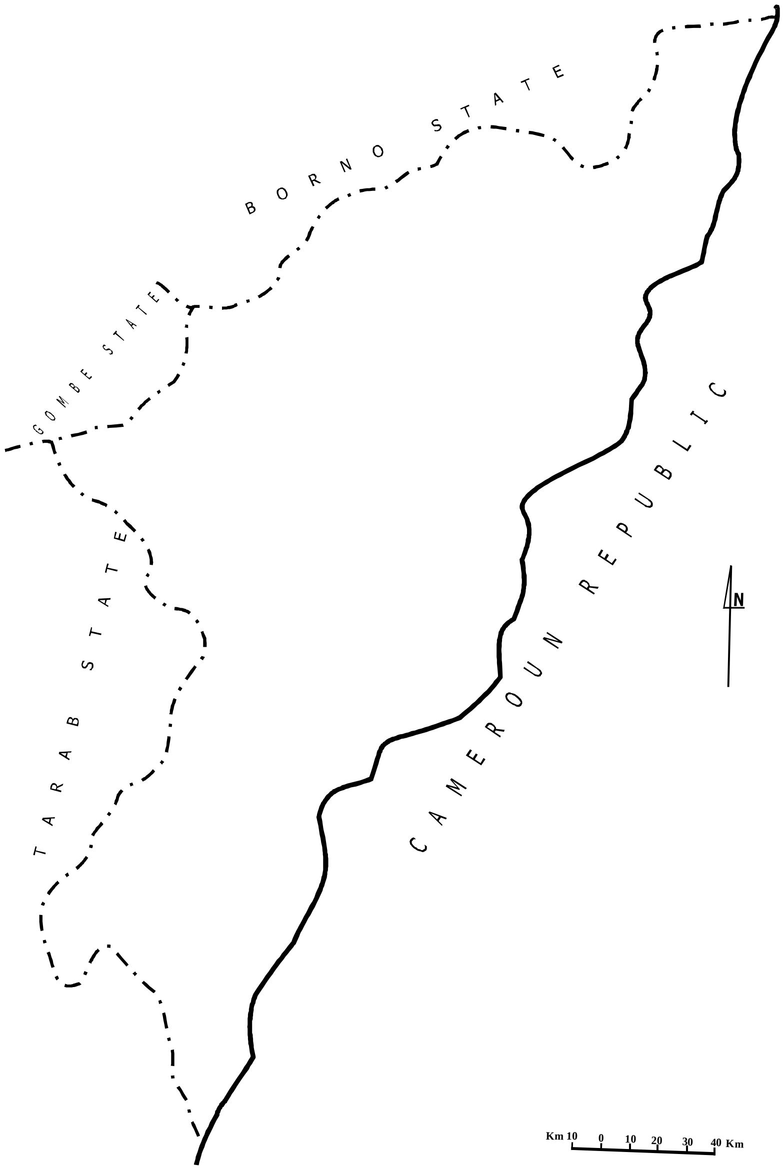
Ododo, J. C. and Sulaiman, A. T. (1993). Variation of Solar Radiation with Latitude, ***Nigerian Journal of Solar Energy,*** Vol. 12, 109 – 118.

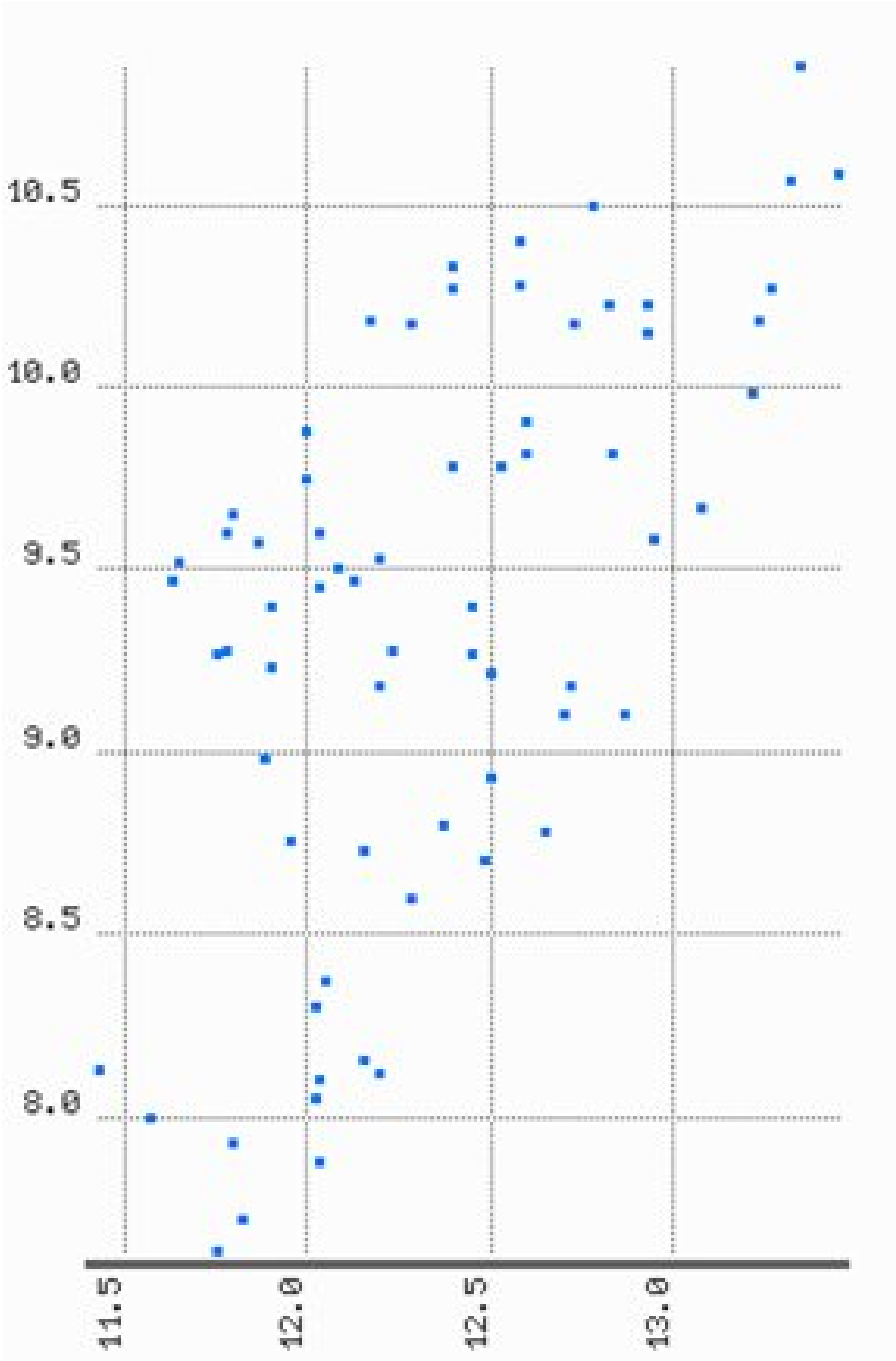
Ododo, J. C., Sambo, I., Aidan, J. and Dike, J. I. (1995). Regional Parameters for the Estimation of Solar Radiation in North-East and South-East Nigeria, ***Proceedings of Conference on Renewable and Alternative Energy Technologies,*** Nsukka-Nigeria, p 6.8 – 6.12.

Page, J. K. (1964). The Estimation of Monthly Mean Values of Daily, Total Short Wave Radiation on Vertical and Inclined Surfaces from Sunshine Records for Latitude 40^{o} South. ***Proceedings: UN Conference on New Sources of Energy,*** Vol. 4 Pg 378.

Swartman, R. K. and Ogunlade, O. (1967). Solar Radiation Estimates from Common Parameters, ***Solar Energy,*** Vol. 11, 170-172.

Appendix I: Map of Adamawa State showing the Locations of Stations Studied

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10.0
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