ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering
Tome XV [2017] – Fascicule 4 [November]

ISSN: 1584-2665 [print; online]
ISSN: 1584-2673 [CD-Rom; online]
a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

[1.]L.O. AFOLABI, [1.]O.T. ADEWUNMI, [1.]E.O. SELUWA,
[2.]G.A. SOLIU-SALAU, [2.] O.M. ODENIYI

PREDICTION OF SOLAR RADIATION PATTERNS FOR SUSTAINABLE IMPLEMENTATION OF SOLAR POWER GENERATION

[1.] Electrical/Electronics Engineering Department, The Federal Polytechnic Offa, Offa, Kwara State, NIGERIA
[2.] Mechanical Engineering Department, The Federal Polytechnic Offa, Offa, Kwara State, NIGERIA

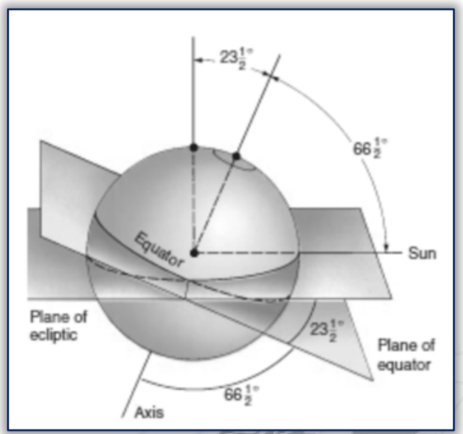
Abstract: The paper investigates the patterns of solar radiation in different function series and estimate the error for each function. The study aims at predicting the maximum solar energy generation per month, the pattern of solar radiation energy with sunshine hours and month with peak solar energy radiation. Exponent, linear, quadratic, cubic, logarithms, and exponential empirical models were used to predict the solar radiation and it was found that statistical, Cubic and quadratic empirical model has lowest RMSE and MBE and highest R^2 values. The months with highest estimated global solar radiation are the early dry season, August, October, November and December and it's possible by Installing PV panel to generate energy in order to reduce the cost of energy production because average monthly daily solar radiation is4.2 kWh/m2and 3.89 kWh/m2 in a year.
Keywords: Solar Radiation, Empirical models, RMSE, MBE, Sunshine Hour

1. THEORETICAL BACKGROUND

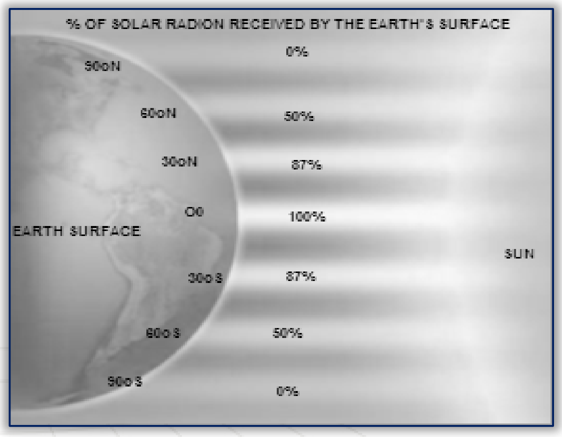
Towards the understanding sun-earth's relationships can leads to the study of variation of solar radiation received from place to place throughout the year and into an examination of the seasonal change on Earth. The seasonal variations in temperature, sunshine hour, pressure, cloud cover, wind speed, atmospheric turbidity, and relative humidity and so on, primarily caused fluctuation of the solar radiation received. Similarly, Heavy cloud cover also prevents solar radiation from reaching earth's surface than in a clear sky. However, cloud cover is irregular and unpredictable, and its effect is in a minor degree over long periods of time. However, two major phenomena that vary regularly for a given position on Earth as itrotates on its axis and revolve around the sun are(a) the duration of daylight and (b) the angle of the solar rays. The amount of daylight controls the duration of solar radiation, and the angle of the sun's rays directly affects the intensity of the solar radiation received. Together, the factors are the major factors that affect the amount of insolation available at any location on Earth's surface

In the Northern Hemisphere, Earth is actually closest to the sun in one season and farthest away in another season. The angle at which the sun's rays strike Earth's surface determines the amount of solar energy received per unit of surface area (see Figure 1.0). This amount in turn affects the seasons. Similarly,in the southern Hemisphere, the sun's rays are more oblique and spread over larger areas, thus receiving less energy per unit of area when the Northern hemisphere received maximum radiation and vice versa when its receive the minimum radiation which varies with the season of the year. There are two seasons in Nigeria, the rainy season and the dry season. In rainy season, the northern hemisphere is closer to the sun making Northern hemisphere has long sunshine hours and southern hemisphere having short sunshine hour. the winter hemisphere and the sun appears low in the sky, and its rays spread out over a much wider area, becoming less effective at heating the ground.

The latitude at which the noon sun is directly overhead is known as the sun's declination. Neglecting for the moment the influence of the atmosphere on variations in insolation during a 24-hour period, the amount of energy received by the surface begins after daybreak and increases as Earth rotates toward the time of solar noon. A place will receive its greatest insolation at solar noon when the sun has reached its zenith, or highest point in the sky, for that day. The amount of insolation then decreases as the sun angle lowers toward the next period of darkness. Obviously, at any location, no insolation is received during the darkness hours. However, the amount of daily insolation received at any one location on Earth varies with latitude. The seasonal limits of the most direct insolation are used to determine recognizable zones on Earth. Three distinct patterns occur in the distribution of the seasonal receipt of solar energy in each hemisphere. These patterns serve as the basis for recognizing six latitudinal zones, or bands, of insolation and temperature that circle Earth.



a)



b)

Figure 1. (a) The plane of the ecliptic is defined by the orbit of Earth around the sun. (b) The percentage of incoming solar radiation (insolation) striking various latitudes during an equinox date according to Lambert's Law.

Despite various patterns in the amount of insolation received in these zones, we can make some generalizations. For example, total annual insolation at the top of the atmosphere over particular latitude remains nearly constant from year to year (the solar constant). Furthermore, annual insolation tends to decrease from lower latitudes to higher latitudes (Lambert's Law together with Beer's Law). The closer to the poles a place is located, the greater will be its seasonal variations caused by fluctuations in insolation. Research having going on the prediction of the annual insolation received in a year and the next section previous works on determination of algorithm for predicting solar radiation in a place is presented.

2. EXISTING KNOWLEDGE AND AIM OF PRESENT WORK

Incoming solar radiation as become significant many areas such asits influence on the energy and water balance at the earth's surface, air and soil heating, evapotranspiration, meteorological parameters, photosynthesis, winds, and snow melt, agronomy, geography and others [Hunt et. al, 1998; McKenney et. al, 1999 and Swift, 1976]. Clouds, gases, pollution (including aerosol) and other factor decreases this available solar energy received by the earth and thus, earth gets about 800 times less solar energy from the Sun at each moment [Schiermeier et.al., 2008]. It indicates that the decrease in the total solar radiation received is influenced by many factors the percentage of sunshine and the atmospheric turbidity factor are the main factors affecting the surface solar radiation reduction. There is no correlation between cloud and ground solar insolation. However, the percentage of sunshine is affected mainly by cloud cover and air pollution. [Qi Yue et. al, 2015]

Solar energy has been proved to be an ultimate and reliable alternative source of energy to fulfil the most basic electricity needs through photovoltaic technology and because of its of its infinite and non-polluting nature [Schweizeret al., 1995 and Schweizer-Ries & Preiser, 1997]. Many researchers worldwide have seen the utilization of vast and abundant solar energy resources on the earth's surface for electricity production as one of the way to meet the world increasing energy demand as well as to mitigate global warming effect that results from excessive dependence on the fossil fuel [Ming et al., 2014; Akikur et al., 2013; Azoumah et al., 2011; and Bajpai et al., 2012].

Research show that amount of solar insolation received varied from month to month and from location to location [Oke, 1999 and Nayava, 2012]. Knowledge on seasonal (or monthly) and spatial distribution of solar energy is important for proper energy planning and to achieve optimum efficiency from the overall thermal/electrical system [Umeno, 2003]. Long-term knowledge of available solar insolation data in a particular location is essential in designing and predicting energy output of solar conversion system, these data are best obtained from measurements taken remotely at a particular location using various solar radiation measuring instruments. But due to high cost of calibration and maintenance of these instruments, solar radiation data are limited in many meteorological stations around the world and available only in few locations in the country, [Hunt et al. 1998].

For example, in [DHM, 1992-1999], the monthly mean solar radiation for each station was calculated based on 12-hour mean value (daily mean: 06:00-18:00) evaluated from semi-automatically recorded two-hour mean values. Similarly, seasonal mean solar radiation was derived from monthly mean values that fall under each respective season. The data availability in the study [Kanjiroba: 1993-1995 and 1999; Annapurna, Langtang and Khumbu: 1987-1994; and Makalu: 1993 and 1994] varies from station to station, because of the discontinuity and loss of data owing to remoteness causing delay in maintenance, repair and replacement of malfunctioning instruments.

The solar radiation data should be measured continuously and accurately measure over the long term. Unfortunately, solar radiation measurements are not easily available due to financial, technical or institutional limitations [Wu, et al. 2007]. Solar radiation modelling has been used in agricultural and forested areas, [Dubayah et. al, 1995; and Rich et. al, 1995]. The prediction formulas are powerful tools that can be used to model and investigate various highly complex and nonlinear phenomena. [Oliveira et. al , 2002] used measurements of global and diffuse solar radiations, at the Earth's surface, in the City of Sao Paulo, Brazil to develop correlation models to estimate hourly, daily and monthly diffuse solar radiation on horizontal surfaces. The polynomials derived by linear regression fitting were able to model satisfactorily the daily and monthly values of diffuse radiation.

Earlier attempts has been made to obtain the Global solar radiation from climatic variables such as sunshine duration [Prescott, 1940; Page, 1964; Boisvert et al., 1990; Soler, 1990; Rietveld, 1978; Angström, 1924; Reddy , 1971; Sayigh, 1979; FAO Technical Paper-56, 1998; Glover & McCullouch, 1958; Ahmad &Ulfat , 2004; Ulfat et. al., 2005 and 2008], air temperature range [De Jong & Stewart, 1993; Hargreaves et al., 1985; Bristow & Campbell, 1984], precipitation [De Jong & Stewart, 1993] and cloud-cover [Barker, 1992; Davies & McKay, 1988; Brinsfield et al., 1984]. [Reddy, 1971] suggested to incorporate geographical factors also.

For country like Nigeria located in tropical location, the economical and efficient application of solar energy seems inevitable because of abundant sunshine available almost throughout the year [Nwokoye, 2006]. Many models have been proposed over the years to predict the amount of solar radiation in some cities in Nigeria using various metrological data [Falayi et. al , 2011] presented that the correlations relating the diffuse fraction (Kd) with clearness index (KT), the relative sunshine duration (S/Smax), relative humidity and ratio of maximum to minimum daily temperature are more reliable for diffuse radiation predictions in the Nigerian environment than using each variable separately, [Burari et. al, 2001] developed a model for estimation of global solar radiation in Bauchi and found the regression coefficients a and bto be 0.24 and 0.46, respectively, [Sambo, 1986] developed a linear relation for Northern Nigeria, [Burari, et al., 2001] developed the linear relation for Bauchi, [Augustine & Nnabuchi, 2009] developed a quadratic relation for Calabar, Port Harcourt and Enugu, [Agbo et. al, 2010] developed empirical models for the correlation of monthly average global solar radiation with sunshine hours at Minna, Nigeria, [Okundamiya & Nzeako, 2011] proposed a temperature-based model for monthly mean daily diffuse solar radiation on horizontal surfaces for three cities: Abuja, Benin City and Katsina; in Nigeria, [Musa et. al, 2012] estimated the global solar radiation in Maiduguri, Nigeria using angstrom model, [Gana & Akpootu, 2013] developed four models for Kebbi, [Gana & Akpootu, 2013] used Angstrom type empirical correlation to estimate global solar radiation in north-eastern Nigeria,[Medugu & Yakubu, 2011] used Angstrom model to estimate mean monthly global solar radiation in Yola, Nigeria, [Udo, & Etuks, 2002] developed a model for Ilorin, [Akpabio, et al., 2005] developed models for Onne, [AkpabioL. & Etuk, 2003] established the relationship between global solar radiation and sunshine duration for Onne, with regression coefficients a and bhaving values of 0.23 and 0.38, respectively, [Okundamiya, & Nzeako, 2010] developed empirical model for estimating global solar radiation on horizontal surfaces for selected cities in the six geopolitical zones in Nigeria, others are [Sambo 1986; Fagbenle, 1990; Buhari & Sambo, 2001; Falayi & Rabiu, 2005; Falayi, et al., 2011; Augustine & Nnabuchi, 2009; Global Solar Radiation with Meteorological Data for Northern Nigeria, 1986; Burari &. Sambo, 2001, Okogbue & Adedokun, 2002; Akpabio & Etuk, 2003; Akpabioet al., 2004; and Falayi et al., 2008]. These researchers developed their models based on correlation of global solar radiation with sunshine hours for some of selected cities in Nigeria. It is observed that the regression coefficients are not universal but depend on climatic conditions and the nature of the pollutants of the environment [Tijjani, B.I. 2011].

The aim of this work is to develop different empirical correlations to estimate the global solar radiation in Offa based on the available climatic parameters of sunshine hours. The objective of this study is to evaluate six empirical models for estimating the diffuse fraction of solar radiation in studying of solar energy conversion system.Below are the correlation models proposed based on different empirical models

» Exponent empirical model [Kadir Bakirci, 2009]: $\bar{H}/H_0 = a\left(\bar{n}/\bar{N}\right)^b$

» Linear empirical model [Angstrom, 1924; Prescott, 1940; and Rietveld, 1978]: $\bar{H}/H_0 = a + b\,\bar{n}/\bar{N}$

» Quadratic empirical model [Akinoglu & Ecevit, 1990]: $\bar{H}/H_0 = a + b\,\bar{n}/\bar{N} + c\left(\bar{n}/\bar{N}\right)^2$

» Cubic empirical model [Samuel, 1991]: $\bar{H}/H_0 = a + b\,\bar{n}/\bar{N} + c\left(\bar{n}/\bar{N}\right)^2 + d\left(\bar{n}/\bar{N}\right)^3$

» Logarithmic empirical model [Ampratwum & Dorvio, 1999]: $\bar{H}/H_0 = a + b\log\left(\bar{n}/\bar{N}\right)$

» Exponential empirical model [Almorox et al., 2005]: $\bar{H}/H_0 = a + b\exp\left(\bar{n}/\bar{N}\right)$

3. RESULTS AND DISCUSSION

For the analyses, the data were grouped into early rainy season (April, May and June), late rainy season (July, August and September), early dry season (October, November and December) and late dry season (January, February and March). The early rainy season is characterised with little rainy and cloudy, late rainy season is characterised with heavy rain and cloudy, early dry season is characterised with shower, little winter, and late dry season is characterised with no rain, clear sky.

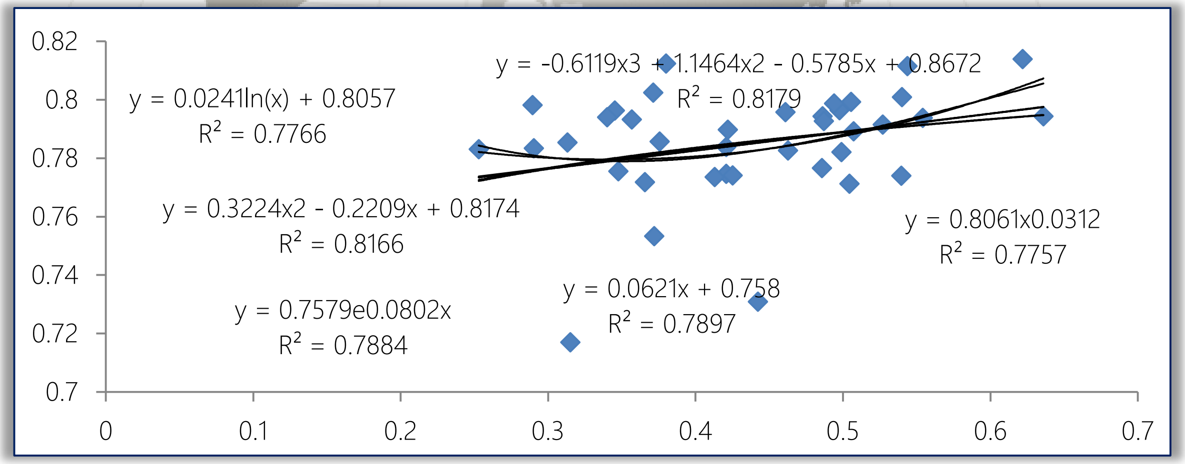


Figure 2. Correlation and regression graph of early dry (ED) season

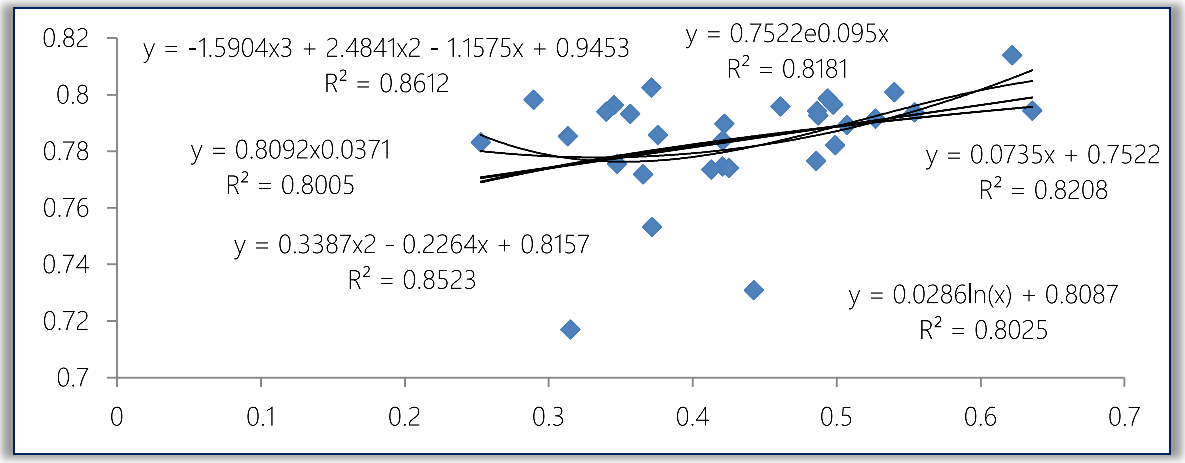


Figure 3. Correlation and regression graph of late dry (LD) season

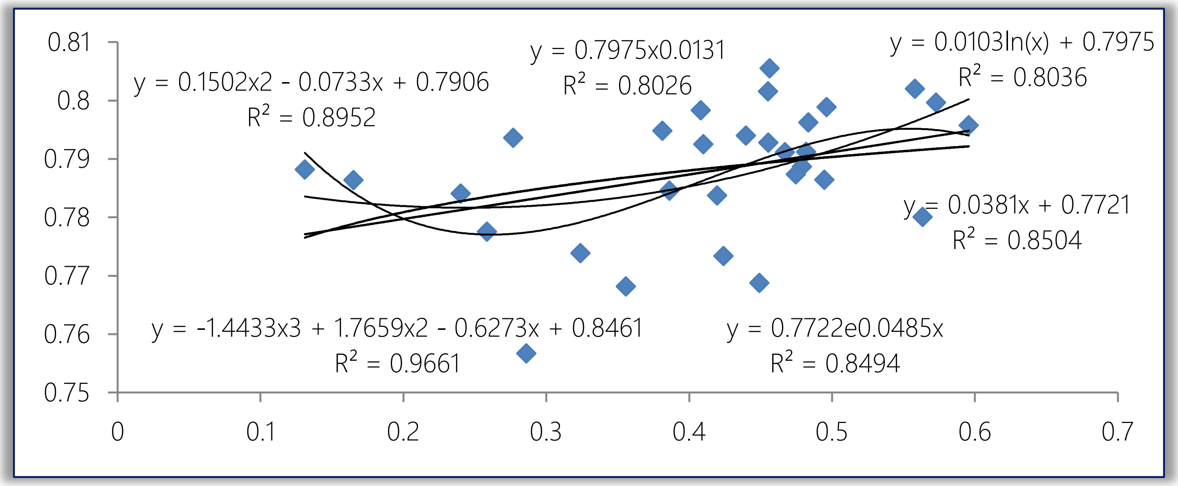


Figure 4. Correlation and regression graph of early rainy (ER) season

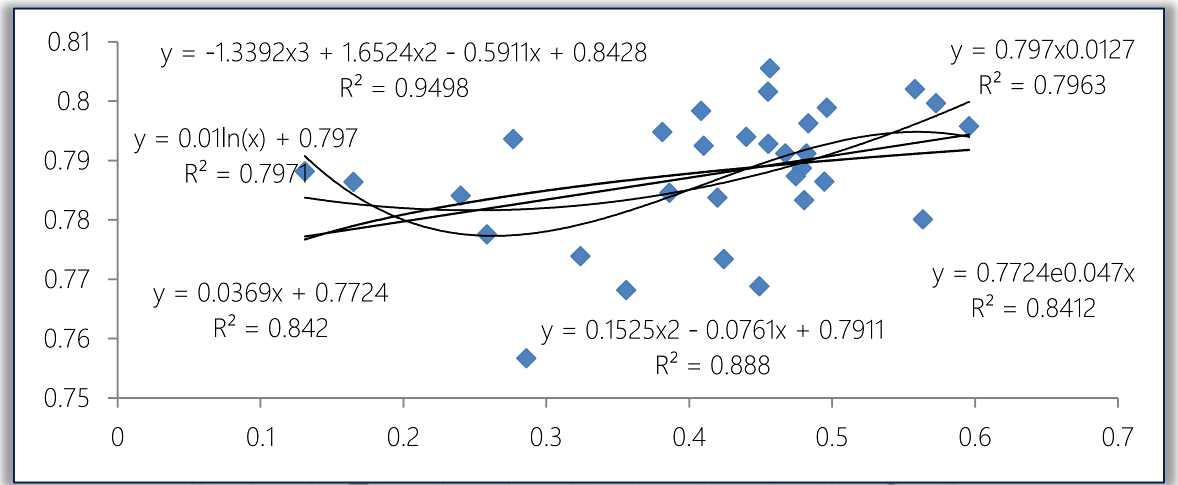


Figure 5. Correlation and regression graph of late rainy (LR) season

Table 1. Table of constants for the predicted empirical models

Models	Empirical Model Equation	Season	d	c	b	A
Exponent empirical model	$\bar{H}/H_0 = a(\bar{n}/N)^b$	ER	-	-	0.7975	0.0131
		LR	-	-	0.7970	0.0127
		ED	-	-	0.8092	0.0371
		LD	-	-	0.0806	0.0312
Linear empirical model	$\bar{H}/H_0 = a + b\,\bar{n}/N$	ER	-	-	0.0735	0.7522
		LR	-	-	0.0621	0.7580
		ED	-	-	0.0369	0.7724
		LD	-	-	0.0381	0.7724
Quadratic empirical model	$\bar{H}/H_0 = a + b\,\bar{n}/N + c(\bar{n}/N)^2$	ER	-	0.1525	-0.0761	0.7991
		LR	-	0.1502	-0.0733	0.7906
		ED	-	0.3224	-0.2209	0.8174
		LD	-	0.3387	-0.2264	0.8157
Cubic empirical model	$\bar{H}/H_0 = a + b\,\bar{n}/N + c(\bar{n}/N)^2 + d(\bar{n}/N)^3$	ER	-1.3392	1.6524	-0.5911	0.8428
		LR	-1.4433	1.7659	-0.6273	0.8461
		ED	-1.5904	2.4841	-1.1575	0.9453
		LD	-1.533	1.9986	-0.7516	0.8580
Logarithmic empirical model	$\bar{H}/H_0 = a + b\log(\bar{n}/N)$	ER	-	-	0.0110	0.7970
		LR	-	-	0.0103	0.7975
		ED	-	-	0.0241	0.8057
		LD	-	-	0.0286	0.7522
Exponential empirical model	$\bar{H}/H_0 = a + b\exp(\bar{n}/N)$	ER	-	-	0.7724	0.0470
		LR	-	-	0.7722	0.0485
		ED	-	-	0.7566	0.0822
		LD	-	-	0.7522	0.0930

Note: ER = early rainy, LR = late rainy, ED = early dry, LD = late dry seasons

Table 2. Statistical test results of the models

Models	Season	RMSE	MBE	R^2
Exponent empirical model	ER	4.200	3.996	80.26
	LR	3.890	2.814	79.63
	ED	3.150	3.211	80.05
	LD	3.410	3.142	77.57
Linear empirical model	ER	1.780	-0.502	85.04
	LR	1.380	-0.333	88.80
	ED	1.490	0.412	82.08
	LD	2.030	-0.541	78.79
Quadratic empirical model	ER	0.540	-0.051	89.52
	LR	0.620	-0.033	88.80
	ED	0.610	0.011	85.23
	LD	0.810	0.092	81.79
Cubic empirical model	ER	0.068	-0.006	96.61
	LR	0.091	0.004	94.98
	ED	0.102	0.136	86.12
	LD	0.080	0.041	81.79
Logarithmic empirical model	ER	4.031	3.101	80.36
	LR	4.110	2.889	79.71
	ED	4.302	-2.034	80.25
	LD	2.694	4.961	77.66
Exponential empirical model	ER	1.792	-0.105	84.94
	LR	0.883	-2.112	84.12
	ED	0.910	-0.094	81.81
	LD	0.840	0.132	78.84

Note: Mean Bias Error (MBE, in W/m2), Root Mean Square Error (RMSE, in W/m2) and coefficient of correlation (R^2, in %).

The study revealed that modelling solar radiation using the proposed method is possible with a high degree of reliability according to the statistical performance metrics obtained.The result showsthat all the modelsaresuitable for the prediction of the monthly global solar radiation with most suitable are cubic and quadratic empirical models for daily sunshine hours in locations which has similar weather patterns as Offa, Kwara state in Nigeria. Solar radiation receive is 4.2 kWh/m2 mostly and on average, Offa receives about 3.89 kWh/m2 of solar radiation in a year. It isobserved that cubic and quadratic empirical models yielded the lowest mean bias error(MBE), root mean square error (RMSE) and highest coefficient of correlation (R^2) values and hence is the best modelfor Offa and other similar environments. The low RMSE value is a measure of accuracy of a model. RMSE for exponent, linear, quadratic, cubic, logarithms, and exponential empirical models:

$3.150 \leq RMSE \leq 4.200$, $1.380 \leq RMSE \leq 2.030$, $0.540 \leq RMSE \leq 0.810$, $0.068 \leq RMSE \leq 0.102$, $2.694 \leq RMSE \leq 4.302$, and $0.840 \leq RMSE \leq 1.792$ (shown in Table 2.0).

It is also observed that Mean bias error for the models are:

$2.814 \leq MBE \leq 3.996$, $-0.541 \leq MBE \leq 0.412$,$-0.051 \leq MBE \leq 0.092$, $-0.006 \leq MBE \leq 0.136$, $-2.034 \leq MBE \leq 4.961$, and $-2.112 \leq MBE \leq 0.131$

respectively, with cubic and quadratic models yielded the lowest mean bias error (MBE) values and hence is the best model for Offaand other similar environments. The models with positive MBE values indicate over-estimation.

4. CONCLUSION

Prediction of solar radiation by using different empirical models to estimate the monthly global solar radiation is possible by the use of availability of abundant sunshine in the country. However, the values of the clearness index, K_T in Offa: $0.37 \leq K_T \leq 0.68$. This indicates that a reasonableportion of the global solar radiation is direct beam. Installation of PV panel is possible to generate energy which will reduce the cost of energy production. Solar tracking is also necessary for good performance of the systems despite cost constrain. This method is applicable especially forareas without solar radiation data, recognizing the potential of solar energy application. On average, Offa receives receive is 4.2 kWh/m2 mostly and on average, Offa receives about 3.89 kWh/m2 of solar radiation in a year. The highest solar radiation is estimated in early dry season between October, November and December.

References

[1.] 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, vol. 1(1), pp. 41-47.

[2.] Ahmad, F. and Ulfat I., 2004: Empirical Model for the correlation of Monthly Average Daily Global Solar Radiation with hours of sunshine on a horizontal surface at Karachi, Pakistan. Turkish J., Physics, vol. 28, pp. 301-307
[3.] AkpabioL. E. and Etuk S. E. 2003: ''Relationship between Global Solar Radiation and Sunshine Duration for Onne, Nigeria,'' Turk.J.Phys, vol. 27(1), pp. 161–167.
[4.] Angstrom A. J. and Roy Q. J. 1924:''Solar and Terrestrial Radiation. '' Q.J.R Met.Soc, vol. 50(1), pp. 121-126.
[5.] Barker, H.W., 1992: Solar radiative transfer through clouds possessing isotropic variable extinction coefficient. QJR Meteorol. Soc. Vol. 118, pp. 1145–1162.
[6.] Boisvert, J.B., Hayhoe, H.N., Dube´, P.A., 1990: Improving the estimation of global solar radiation across Canada. Agric. For. Meteorol. Vol. 52, pp. 275–286.
[7.] Brinsfield, R., Yaramanoglu, M., Wheaton, F., 1984: Ground level solar radiation prediction model including cloud cover effects. Solar Energy, vol. 33, pp. 493-499
[8.] Bristow, K.L., Campbell, G.S., 1984: On the relationship between incoming solar radiation and daily maximum and minimum temperature. Agric. For. Meteorol.Vol. 31, pp.159–166.
[9.] Davies, J.A., McKay, D.C., 1988: Estimating radiation from incomplete cloud data. Solar Energy, vol. 41, pp. 15-18
[10.] De Jong, R., Stewart, D.W., 1993: Estimating global solar radiation from common meteorological observations in western Canada. Can. J. Plant. Sci., vol. 73, pp. 509–518.
[11.] Department of Hydrology and Meteorology (DHM) 1992: Snow and Glacier Hydrology Data Year Book (1987 to 1992). SGHU, Dept. Hydrology and Meteorology, Govt. of Nepal.
[12.] DHM 1993: Snow and Glacier Hydrology Data Year Book (1993). SGHU, Dept. Hydrology and Meteorology, Govt. of Nepal.
[13.] DHM 1994: Snow and Glacier Hydrology Data Year Book (1994). SGHU, Dept. Hydrology and Meteorology, Govt. of Nepal.
[14.] DHM 1995: Snow and Glacier Hydrology Data Year Book (1995). SGHU, Dept. Hydrology and Meteorology, Govt. of Nepal.
[15.] DHM 1996: Snow and Glacier Hydrology Data Year Book (1996). SGHU, Dept. Hydrology and Meteorology, Govt. of Nepal.
[16.] DHM 1997: Snow and Glacier Hydrology Data Year Book (1997). SGHU, Dept. Hydrology and Meteorology, Govt. of Nepal.
[17.] DHM 1998: Snow and Glacier Hydrology Data Year Book (1998). SGHU, Dept. Hydrology and Meteorology, Govt. of Nepal.
[18.] DHM 1999: Snow and Glacier Hydrology Data Year Book (1999). SGHU, Dept. Hydrology and Meteorology, Govt. of Nepal.
[19.] Dubayah, R., and Rich, P. M., 1995: Topographic solar radiation models for GIS. International Journal of Geographic Information Systems 9, pp. 405 - 413.
[20.] Duffie, J.A., Beckman, W.A., 1991: Solar Engineering of Thermal Processes. John-Wiley & Sons, New York, pp. 109
[21.] Falayi E.O. Rabiu A.B., and Teliat R.O. 2011: Correlations to estimate monthly mean of daily diffuse solar radiation in some selected cities in Nigeria. Advances in Applied Science Research, 2011, vol. 2 (4), pp. 480-490.
[22.] FAO; 1988:Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56, FAO, Italy
[23.] Gana N. N. and Akpootu D.O. 2013: ''Angstrom Type Empirical Correlation for Estimating Global Solar Radiation in North-Eastern Nigeria,'' The International Journal of Engineering and Science (IJES), vol. 2(11), pp. 58-78.
[24.] Glover, J. and Mc-Culloch, F. 1958: The empirical relationship between solar radiation and hours of sunshine. Q.J.R. Met. Soc. Vol. 84(359), pp. 56-60.
[25.] Hargreaves, G.L., Hargreaves, G.H., Riley, P., 1985: Irrigation water requirement for the Senegal River Basin. J. Irrig. Drain. Eng. ASCE vol. 111, pp. 265–275.
[26.] Hunt, L. A., Kuchar, L., Swanton, C. J., 1998: Estimation of solar radiation for use in crop modeling. Agric. Forest Meteorol., vol. 91, pp. 293-300.
[27.] Intikhab, Ulfat, Firos, Faiza, Asif, 2011: Estimation of Solar Energy Potential of Islamabad. Pakistan, Proceeding of the Sharjah International Symposium on Nuclear and Renewable Energies for the 21 Century, Sharjah, UAE.
[28.] Liu B.Y.H and Jordan R.C. (1960).The interrelationship and characteristic distribution of direct, diffuse and total solar radiation.Solar Energy.Vol. 4, pp. 1–19.
[29.] McKenney, D. W., Mackey, B. G., Zavitz, B. L., 1999: Calibration and sensitivity analysis of a spatially distributed solar radiation model. International Journal of Geographical Information Science vol. 13 (1), pp. 49-65.
[30.] Medugu, D.W and Yakubu D. 2011: Estimation of mean monthly global solar radiation in Yola, Nigeria, Using Angstrom Model,' Advances in Applied Science Research, vol. 2(2), pp. 414 421.
[31.] Musa B, Zangina U. and Aminu M. 2012: Estimation of global solar radiation in Maiduguri, Nigeria using angstrom model, ARPN Journal of Engineering and Applied Sciences, vol. 7(12), pp. 1623-1627.
[32.] Nayava, J.L., 2012: Climates of Nepal and their implications, WWF Nepal. pp. 164.

[33.] Oke, T.R. 1999: Boundary Layer Climates (second edition). University Press, Cambridge. pp. 435.
[34.] Okundamiya M.S. and Nzeako M.S. 2011: Estimation of diffuse solar radiation for selected cities in Nigeria. ISRN Renewable Energy. vol.3 2011, Article ID 439410, pp. 6 doi:10.5402/2011/439410
[35.] Okundamiya, M. S and Nzeako, A. N. 2010:. ''Empirical model for estimating global solar radiation on horizontal surfaces for selected cities in the six geopolitical zones in Nigeria,'' Research Journal of Applied Science, Engineering and Technology, vol. 2(8): pp. 805–812.
[36.] Oliveira A.P., Escobedo J.F., Machado A.J., and Soares J. 2002: Correlation models of diffuse solar-radiation applied to the city of São Paulo, Brazil. Applied Energy. vol. 71 (1), pp. 59–73.
[37.] 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 40ºN-40ºS.Proceeding of the UN Conf. on New Sources of Energy, 1:4 Paper S/98 378.
[38.] Prescott, JA. 1940: Evaporation from a water surface in relation to solar radiation. Tran. R. Soc. S. Austr. vol. 64,pp. 114-118.
[39.] Qi Yue, Fang Shi-Bo, Zhou Wen-Zuo, 2015: Correlative analysis between the changes of surface solar radiation and its relationship with air pollution, as well as meteorological factor in East and West China in recent 50 years, Vol. 64(8) 089201
[40.] Reddy, S.J., 1971: An empirical method for the estimation of total solar radiation, Solar Energy vol. 13, pp. 289-290
[41.] Rich, P. M., Hetrick, W. A., and Saving, S. C., 1995: Modeling topographic influences on solar radiation: a manual for the SOLARFLUX model. Los Alamos National Laboratory Report LA-12989-M.
[42.] Rietveld, M.R., 1978: A new method for estimating the regression coefficients in the formula relating solar radiation to sunshine. Agric. Meteorol. Vol. 19, pp. 243–252
[43.] Sanusi Y.K. and Abisoye S.G. 2011: Estimation of solar radiation at Ibadan, Nigeria. Journal of Emerging
[44.] Sayigh, A.A.M., 1979: Estimation of total solar radiation intensity - A universal formula, Journal of Eng. Sci. - Vol.5 (1), 1979 - Collage of Eng., Univ. of Riyadh. The paper was also presented as a course material of the 7th Course on Solar Energy Conservation - ICTP - Trieste, Italy, 1986
[45.] Schiermeier Q, Tollefson J, Scully T, Witze A, Morton O., 2008: Energy alternatives: electricity without carbon. Nature 2008; vol. 454, pp. 816-23.
[46.] Schweizer P., J.N. Shrestha, and D. Sharma. 1995. What can Solar Electricity provide for the Himalayan People? The case of Nepal. 13th European Photovoltaic Solar Energy Conference and Exhibition, Nice: E.C., France. pp. 1791-1795.
[47.] Schweizer-Ries P., and K. Preiser. 1997. Socio-Technical analysis of solar home systems in the Nepalese Himalaya. 14th European Photovoltaic Solar Energy Conference, Barcelona, Spain.pp. 2552-2555.
[48.] Soler, A., 1990: Statistical comparison for 77 European stations of 7 sunshine-based models. Solar Energy vol. 45 (6), pp. 365–370.
[49.] Supit, I. 1994: Global radiation. Publication EUR 15745 EN of the Office for Official Publications of the EU, Luxembourg.
[50.] Supit, I., van Kappel, R.R., 1998: A simple method to estimate global radiation. Solar Energy vol. 63, pp. 147–160.
[51.] Swift, L. W., 1976. Algorithm for solar radiation on mountain slopes. Water Resources Research vol. 12, pp. 108-112.
[52.] Tiwari, GN and Suleja, Sangeeta. 1997: Solar Thermal Engineering System, Narosa Publishing House, New Delhi, India.
[53.] Ulfat I., Ahmed F., Javed F., Usman A., and Kanwal F., 2008: Recital of Some Existing Sunshine-Based Models of Global Solar Radiation, Karachi University Journal of Science, 2008, vol. 36
[54.] Ulfat, Intikhab, Ahmad, Firoz, Siddiqui, Imran. 2005: Determination of Angstrom coefficient for the prediction of monthly average daily Gobal Solar Radiation Horizontal surface at Karachi, Pakistan. Kar. Univ. Jour. Sci. vol. 33(1 & 2), pp. 7-11.
[55.] Umeno, M. 2003. Research and development of amorphous carbon thin film solar cell supported by NEDO (in Japanese). Antenna No. vol. 54, pp. 1-2.

ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering