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Prediction of Bright Sunshine Duration and Solar Radiation over Sudan Using Simple Empirical Equations

Habiballa A. Mohamed*

National Institute of Desert Studies, University of Gezira, Wad Madani, Sudan

***Corresponding Author:** Habiballa A. Mohamed, National Institute of Desert Studies, University of Gezira, Wad Madani, Sudan, E-mail: habiballa1954@gmail.com*

ABSTRACT

This study was set to investigate the possibility of prediction of bright sun shine duration over Sudan using simple equations. Bright sunshine duration data was collected for three periods ; a pre 1963 period data set for 14 stations, a data set for 18 stations for the period 1961-1990 and also a data set for 18 stations for the period 1971-2000. In addition, a data set of solar radiation for 16 stations was obtained for the period 1951-1980.The ultimate source of the data was the Sudan Meteorological Authority. The data was analyzed for correlations between BSD and SR on one hand and the stations coordinates on the other hand using linear regression. The results showed that annual bright sunshine duration and to some extent annual solar radiation can be predicted for various geographical locations using simple empirical equations in the absence of better alternatives.

Keywords: *Prediction, sun shine duration, solar radiation, coordinates, Sudan*

INTRODUCTION

Bright sunshine duration was defined by the WMO[1]as the aggregate of the daily sub period in hours when the solar radiation load on a horizontal surface of a location is not less than 120W per square meter. Sunshine duration data are used in many ways including the calculations of global solar radiation and vegetation growth and performance, [2; 3] and crop water requirements using Penman-Monteith equation, [4]. Solar radiation reaching the surface of the earth is considered to be one of the most important sources of renewable energy. It is a primary factor in many applications such as solar energy systems, architecture, agriculture and irrigation, [5]. The accurate information of the solar radiation intensity at a given location is essential to the development of solar energy-based projects and in the long-term evaluation of the solar energy conversion systems performances. This information is used in the design of a project, in cost analysis, and in the efficiency calculations of a project. Furthermore, monthly mean daily data are needed for the estimation of long-term solar systems performances,[6]. Accurate knowledge of available solar energy with its direct and diffuse components in a particular place is of great importance in designing and sizing of solar energy conversion systems, [7]. In this sense, professionals such as agriculturists, architects, engineers, and others that require the application of solar energy need to be acquainted about the daily, monthly and climatic pattern of global irradiance over any location, [8]. Estimation of solar radiation is also essential for many applications including development of electrical energy from solar energy using photovoltaic cells. Many types of equations are used for estimation of global solar radiation from sunshine duration data including the Angstrom original equation, its derivatives and many others including linear, quadratic, cubic, and logarithmic equations, [6].Sudan, like many other African countries, is endeavored by a tremendous amount of annual solar radiation and sun shine duration, not only because of its geographical location between approximate latitudes of 3 and 22 north, and longitudes of 22 and 38 east, but also because of its huge area that covers five climatic zones extending from hyper-arid in the north to the humid in the extreme south. Such area requires an enormous amount of energy to keep it moving. Provision of any form of energy constitutes a major obstacle for development in the developing countries; let part thinking about clean or cheap renewable energy. It is therefore important to think about solar energy as cheap, abundant and renewable alternative energy source. This study aims to develop simple empirical equations to estimate annual bright sun shine duration in hours and also solar radiation over an expanded country like Sudan.

METHODOLOGY

Study Area and Data Collection

The study area covers the Sudan before separation which here by refers to South Sudan area as well. Sunshine duration data was collected as long term average or normal (30 years average) from Sudan Meteorological Authority (SMA) as an ultimate source for three periods; a pre 1963 period data set for 14 stations [9], a data set for 18 stations for the period 1961-1990 and also a data set for the same 18 stations for the period 1971-2000. In addition, a data set of solar radiation for 16 stations was obtained for the period 1951-1980. The stations in each of these sets are scattered a long and across Sudan. The stations and their coordinates and altitudes are shown in table 1.

Data Analysis

Regression analysis was used targeting correlations between sunshine duration in hours on one hand and latitudes, longitudes and altitudes on the other hand and also between solar radiation load and the same attributes. Table 1a, b and c show the various stations used for bright sunshine duration for the pre 1963 period, both 1961-1990 and 1971-2000 periods and for solar radiation load of various stations for the period 1951-1980, respectively.

Table1a. *Latitudes, longitudes and altitudes of 14 stations used for pre 1963 bright sunshine duration data analysis*

Station		Lat.	Long.	Alt.
W.halfa		21.82	31.35	190
Atbara		17.70	33.97	345
Khart.		15.60	32.55	380
Kassala		15.47	36.40	500
Medani		14.38	33.48	405
Obied		13.17	30.23	574
Kosti		13.17	32.73	380
Fasher		13.63	25.33	730
Genaina		13.48	22.45	805
Nohud		12.70	28.43	565
Malakal		09.55	31.65	390
Wau		07.70	28.02	435
Juba		04.87	31.60	457
Portsudan		19.58	37.22	002

Table1b. *Latitudes, longitudes and altitudes of 18 stations used for the periods 1961-1990 and 1971-2000 bright sunshine duration data analysis*

Station	Lat.	Long.	Alt.
W.halfa	21.82	31.35	190
Abu ham.	19.53	33.33	315
Dongola	19.17	30.48	228
Karima	18.55	31.85	249
Atbara	17.70	33.97	345
Portsudan	19.58	37.22	002
Khart.	15.60	32.55	380
Kassala	15.47	36.40	500
Medani	14.38	33.48	405
Gedaref	14.03	35.40	599
Sennar	13.55	33.62	418
Kosti	13.17	32.73	380
Obied	13.17	30.23	574
Fasher	13.63	25.33	730
Damazine	11.78	34.38	470
Kadugli	11.00	29.72	499
Malakal	09.55	31.65	390
Juba	04.87	31.60	457

Table1c. *Latitudes, longitudes and altitudes of 16 stations used for the period 1951-1980 solar radiation data analysis*

Station	Lat.	Long.	Alit.
Abu ham.	19.53	33.33	315
Aroma	15.85	36.15	043
Babanoosa	11.78	34.38	543
Dongola	19.17	30.48	228
Fasher	13.63	25.33	730
Elshowak	14.40	35.85	510
Gazala	11.47	26.28	485
Hudeiba	17.57	33.93	350
Juba	04.87	31.60	457
Kadugli	11.00	29.72	499
Malakal	09.55	31.65	390
Portsudan	19.58	37.22	002
Shambat	15.67	32.53	380
Medani	14.38	33.48	405
Toker	18.43	37.73	020
Zalingei	12.89	23.47	900

Results And Discussion

Effects of Latitude on Bright Sunshine Duration and Load of Solar Radiation

Figures 1a, b, and c show the effect of latitude of the station on its bright sunshine duration in hours per day for the various periods. Figure 1d shows the effect of latitude on the intercepted load of solar radiation in KWh/m2/day for 16 stations, while figure 1e shows the solar radiation for 14 stations instead of the 16 where Portsudan and Toker stations data were removed because they deviated remarkably from the remaining data. These two stations are Red Sea coastal stations and as such they are of turbid climate. It is clear that the trends are linear in all cases and that the bright sun duration remained almost the same for the three periods although it showed a little decrement with time. For example, a point at lat.15^o, long.30^o and alt. 400 meter above sea level (MASL) will give a BSD of 9.49, 9.30 and 9.02 for the pre 1963, 1961/1990 and 1971/2000 periods respectively and with a mean of 9.27 hours and non significant differences. On annual basis, over Sudan and South Sudan, and within the studied range of latitudes, and ignoring the rather minor effects of longitudes and altitudes, bright sunshine duration increased with latitudes at an average rate of 0.18 hours per day per degree north, and above a base of about 6.7 hours per day. The regression lines were of high correlations, high significance and low standard errors. Table 2 shows a summary of statistical attributes of linear regression for the three periods of BSD and the period of solar radiation. Portsudan, Toker and other Red Sea coastal and nearby stations showed both lower BSD hours and lower load of solar radiation compared to inland stations on similar latitudes. On the average, using latitude as the only variable and as shown in table 2, equation (2) seems to be the best choice for the prediction of BSD. The equation is simple and in the form:

$$BSD = 6.75 + 0.17 \text{ Lat.}$$

In fact, an average equation for the three periods will be as follows:

$$BSD = 6.66 + 0.17 \text{ Lat.}$$

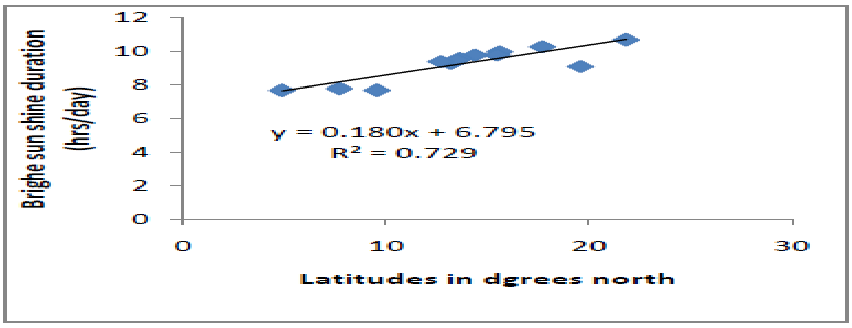

Figure1a. *Effects of latitudes on bright sunshine duration for 14 stations for pre 1963 data*

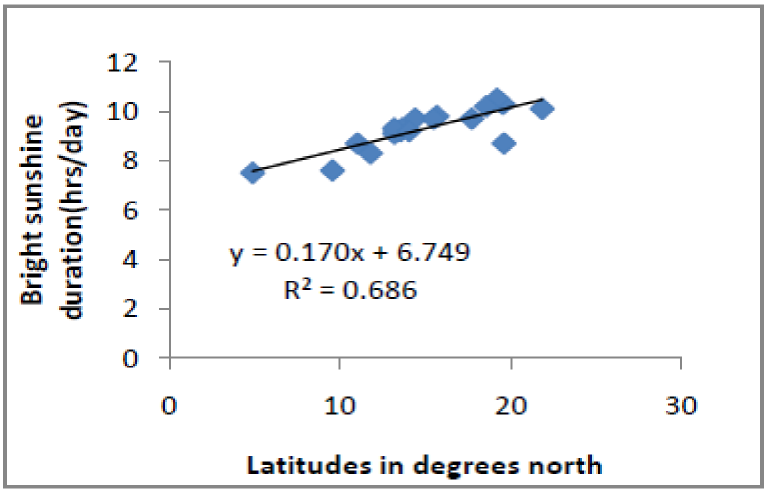

Figure1b. *Effects of latitudes on bright sunshine duration for 18 stations for 1961/1990 data*

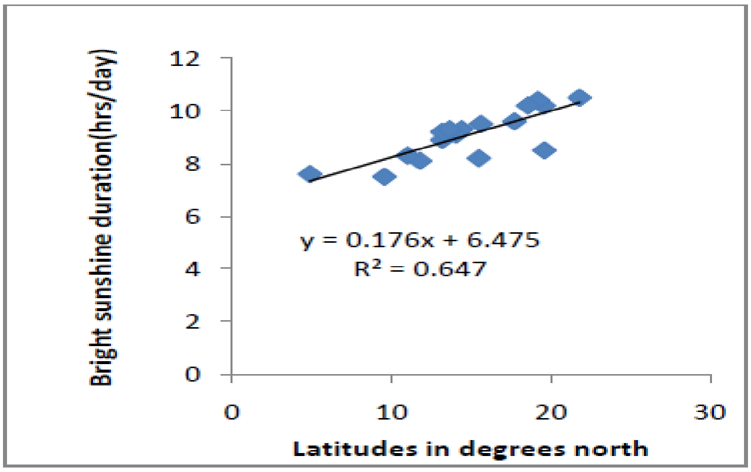

Figure1c. *Effects of latitudes on bright sunshine duration for 18 stations for 1971/2000 data*

This only differs slightly from the former equation. Table 2 also shows the parameters of linear regression of solar radiation vs. latitudes. When Portsudan and Toker were removed for their turbidity, the correlation becomes highly linear with an (R) of 0.85, a (P) of 0.0001 and an (SE) of 0.19. Therefore, equation 5 can be used to predict mean daily solar radiation given any location over Sudan and excluding the Red Sea coastal and nearby area. The equation is simple: SR=4.99+0.08Lat.

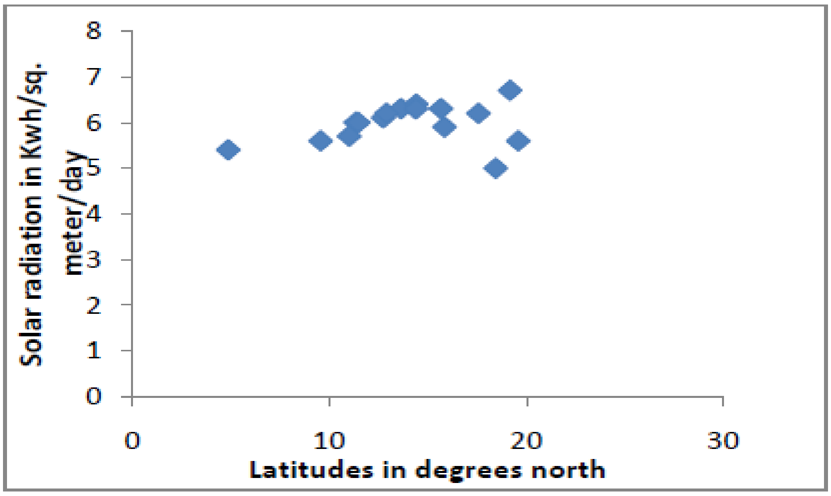

Figure1d. *Effects of latitudes on solar radiation for 16 stations for the 1951/1980 data*

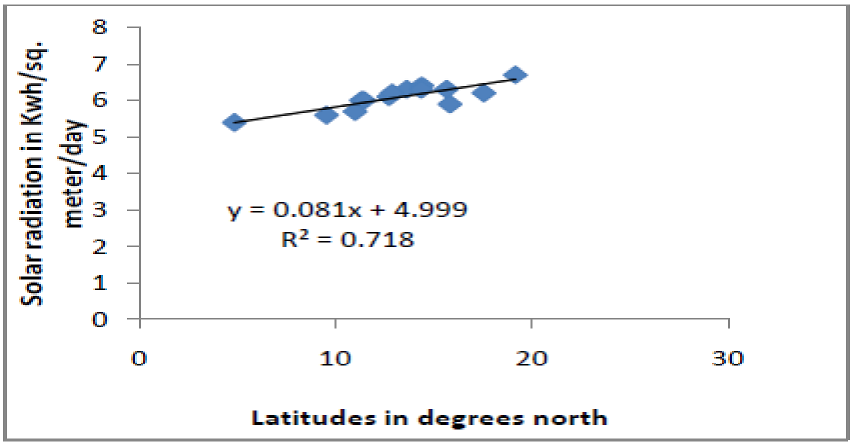

Figure1e. *Effects of latitudes on solar radiation for 14 stations for 1951/1980 data*

Effects of Longitude on Bright Sunshine Duration and Load of Solar Radiation

Longitudes showed no clear effects on BSD in all the three data sets although there was a declining trend as longitudes increased as shown in figures 2a, b, and c. The regression showed weak correlations, no significances and high standard errors as in table 3. Figure 2d shows the graph for the solar radiation. The figure exhibited two clear trends rather than one with highly linear correlations. This means that the SR is affected by longitudes more strongly than does the BSD, which is also evident in table 3 where RS exhibited higher correlation, higher significance and lower standard error.

Table2. *Effect of latitude on bright sunshine duration and solar radiation*

Period /Stations no.	R	P	SE	EQUATION
Pre 1963/14	0.85	0.0001	0.51	BSD = 6.79 + 0.18 Lat.……..(1)
1961-1990/18	0.83	2.17E-05	0.49	BSD = 6.75 + 0.17 Lat..……….(2)
1971-2000/18	0.80	5.71E-05	0.56	BSD = 6.48 + 0.18 Lat..…….....(3)
1951-1980/16	0.24	0.38	0.43	SR = 5.61 + 0.03 Lat.……….(4)
1951-1980/14	0.85	0.0001	0.19	SR = 4.99 + 0.08 Lat.….........(5)

E = Exponent to base 10.

Table3. *Effect of longitude on bright sunshine duration and solar radiation*

Period /Stations no.	R	P	SE
Pre 1963/14	0.12	0.67	0.97
1961-1990/18	0.02	0.92	0.88
1971-2000/18	0.19	0.46	0.93
1951-1980/16	0.33	0.21	0.42
1951-1980/14	0.04	0.89	0.35

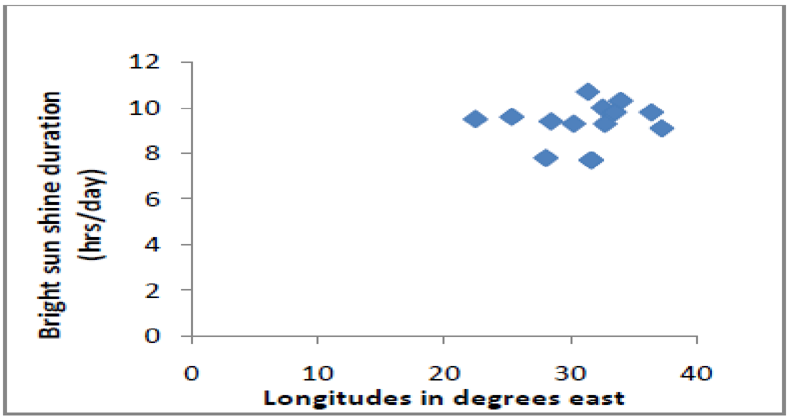

Figure2a. *Effects of longitudes on bright sunshine duration for pre 1963 data*

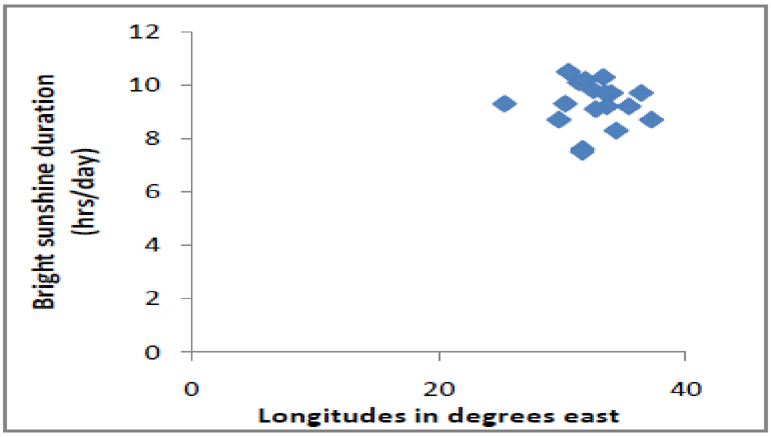

Figure2b. *Effects of longitudes on bright sunshine duration for 1961/1990 data*

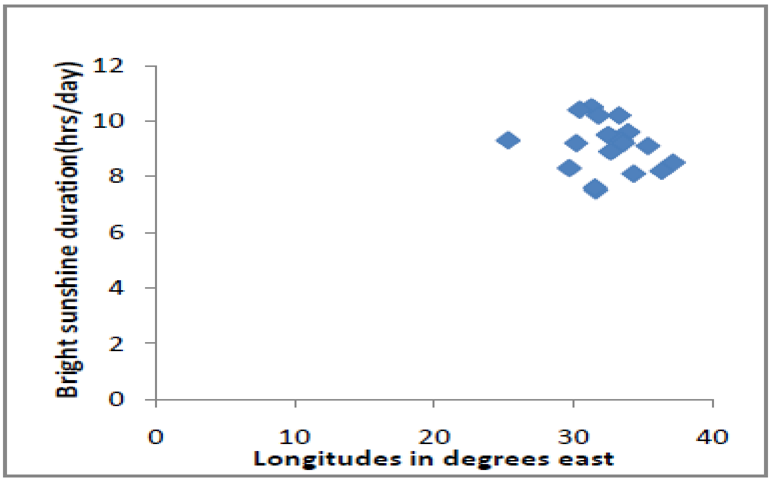

Figure2c. *Effects of longitudes on bright sunshine duration for 1971/2000 data*

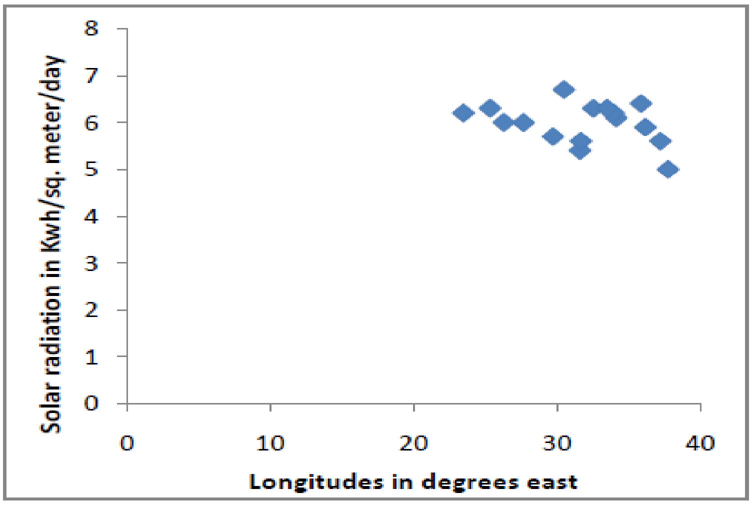

Figure2d. *Effects of longitudes on solar radiation for 1951/1980 data*

Effects of Altitudes on Bright Sunshine Duration and Load of Solar Radiation

Table 4 shows the effects of altitudes on BSD and SR. Altitudes showed almost no effects on BSD where the regression analysis showed low correlations, high standard errors and no significances for all periods. Unlike BSD, regression of solar radiation gave rather high correlation, low standard error and a moderate significance of 0.12, where solar radiation seems to increase with altitude, and this is acceptable because the distance of its attenuation decreases with height.

Table4. *Effect of altitudes on bright sunshine duration and solar radiation*

Period /Stations no.	R	P	SE
Pre 1963/14	0.06	0.83	0.98
1961-1990/18	0.24	0.34	0.86
1971-2000/18	0.31	0.22	0.89
1951-1980/16	0.40	0.12	0.41
1951-1980/14	0.02	0.89	0.35

Effects of the Combinations on Bright Sunshine Duration and Load of Solar Radiation

With the exception of the combination of longitudes and altitudes which showed no effects on the three period's bright sun shine duration, the effects of all other combinations were highly significant in all cases showing very strong correlations as can be seen from table 5. It is clear from table 5 that for the pre 1963 data the three factors showed the strongest (R) of 0.93, lowest SE of 0.38 and a very high significance. For the 1961/1990 period the three factors and the latitude plus altitude showed the best results and for the 1971/2000 the three factors showed the best results once again, but unexpectedly also latitudes plus longitudes. Therefore an equation linking the three factors will be the best choice to predict BSD. The most suitable equations are number (6) for the pre 1963 period, (7) for the 1961/1990 and (8) for the 1971/2000 and are as follows:

BSD = 3.6 + 0.21 Lat. + 0.04 Long. + 0.002 Alt.......(6)

BSD = 6.18 + 0.21 Lat. – 0.02Long. + 0.001 Alt.......(7)

BSD = 9.36 + 0.20 Lat – 0.11 Long. + 0.000 Alt.......(8)

The parameters of regression of these equations were shown in table 5.There seem to be an increasing trend of BSD with time course from the pre 1963 period to year 2000.For example at a point with Lat.15^{o} N, Long. E 30^{o} and Alt. 400 MASL the resulting BSD hours are 8.75, 9.13 and 9.30 respectively, with a mean of 9.06 hours, but with no significant differences. These increments may have resulted presumably from a decreasing cloud cover over Sudan due to declining rainfall trends during the progress of the last century (Mohamed, 1998; Mohamed, 2013) that lead to higher load of solar radiation reaching the earth and there by increased the BSD. With that in mind, it is probably advisable to use equation (8) for prediction of BSD over Sudan and SS in areas where no measurements are available. Ignoring the BSD variation with time course and analyzing the data for the three periods together showed high correlation (R = 0.88), high significance (P = 1.4E-14) and moderate SE, with an across spectrum equation of the form:

BSD = 6.81 + 0.21lat. – 0.04 long + 0.001alt…… (9)

And although this equation gives a good approximation to BSD using the three variables and the whole period data, it is not taking into account the current likely changes in climate. Regarding solar radiation, all combinations, with exception of longitudes and altitudes showed significant effects, with latitudes and altitudes showing the highest R and P, and the lowest SE. Since (R) was moderate to high, (0.68), it is not recommended that any of the equations be used for prediction of SR unless their use is justified by an unavailability of an alternative.

Table5. *Coefficient of correlation (R), standard error, (SE) and significance, (P) for the regression of combination of factors on bright sunshine duration (BSD) and solar radiation (SR) for the various periods.*

Period/Parameter	SR (1951-1980) R SE P	BSD(Pre1963) R SE P	BSD(1961-1990) R SE P	BSD(1970-2000) R SE P
Lat. &Long.	0.54 0.39 0.10	0.87 0.49 0.0004	0.85 0.48 6.0E-5	0.88 0.46 1.2E-5
Lat. & Alt.	0.68 0.34 0.02	0.92 0.39 2.3E-5	0.89 0.42 6.6E-6	0.83 0.54 0.0001
Long. & Alt.	0.40 0.42 0.32	0.13 1.01 0.90	0.28 0.88 0.55	0.47 0.86 0.15
Three factors	0.68 0.35 0.05	0.93 0.38 8.7E-5	0.89 0.42 3.4E-5	0.89 0.47 5.7E-5

In conclusion it can be seen that latitudes significantly affected BSD with a highly linear correlation and that BSD at any geographical location within the studied area can be approximated and predicted using simple empirical equations. Likewise, SR was also affected significantly by latitudes. On the other hand, longitudes showed on the average no effects on BSD and SR, although there was a declining trend east wards and where RS seems to be affected more than BSD. Altitude showed no clear effects on BSD, but it more or less affected the SR. The combination of the three parameters showed the highest effects on BSD and SR and gave the best equations for prediction of BSD and SR using simple equations in areas where no better alternatives exists.

References

[1] 1-WMO(World Meteorological Organization), (2003). Manual on the global observatory system. WMO-No. 544, Geneva.

[2] 2-Masaki Y, Kuwagata T, Ishigooka Y. (2009). Precise estimation of hourly global solar radiation for micrometeorological analysis by using data classification and hourly sunshine. Theoretical and Applied Climatology, 10.1007/s00704-009-0191-0

[3] 3-Revfeim, K.J.A. (1981). Estimating solar radiation income from 'bright' sunshine records. Quart. J. R. Met.SOC., 107: 427-435.

[4] 4-Allen, R.G., Pereira, L.S., Raes, D and Smith, M.(1998). Crop Evapotranspiration: Guide lines for computing crop water requirements.FAO Irrigation and Drainage Paper No.56., Rome.

[5] 5-Assi, A., Jama, M., Al-Shamisi, M.(2011). Prediction of global solar radiation in Abu Dhabi. ISRN Renewable energy. Volume 2012(2012).

[6] 6- Muzathik1, A.M., Nik1,W.B., Ibrahim2, M.Z. , Samo1, K.B., Sopian3, K. and Alghoul3, M.A. (2011).Daily global solar radiation estimate based on sun shine hours. International Journal of Mechanical and Materials Engineering (IJMME), Vol.6 (2011), No.1, 75-80

[7] 7-Mohammed, O. W. and Yanling,G **(2016).** Estimation of Diffuse Solar Radiation in the Region of Northern Sudan**.** International Energy Journal 16, 163-172

[8] 8- Osinowo,A.A and Emmanuel, C. O.(2014). Correlation of Global Solar Irradiance with some Meteorological Parameters and Validation of some Existing Solar Radiation Models with Measured Data over Selected Climatic Zones in Nigeria. International Journal for Innovation Education and Research www. ijier.net Vol.2-01, 2014

[9] 9-*Bhalotra*, Y.P.R. *(1963)*. *Meteorology* of the Sudan. Technical *Memoir No. 6*, Sudan Meteorological Service, Khartoum.

[10] 10-Mohamed, H.A.(1998): Rainfall in Sudan: Trend and Agricultural Implications. Sudan J. Agric. Res. 1:45- 48.

[11] 11-Mohamed, H.A.(2013): Sudan rainfall trends: Reversible drop or a part of a persistent climate change. Sudan J. Des. Res.5(1):62-74.

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