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Estimation of Diffuse Solar Radiation in the Region of Northern Sudan

Osman Wageiallah Mohammed* and Guo Yanling*[1]

Abstract – *Information of diffuse solar radiation at a given location is essential for study and designing solar energy systems. However, many places around the world, like region of Northern Sudan, have no measurement for this solar radiation component. In this study, seven new empirical models have been developed for estimation of monthly average daily diffuse solar radiation on a horizontal surface in the region of Northern Sudan. Data of global solar radiation and sunshine hours recorded at two stations located within the region has been used. Performance of new developed models has been evaluated by using different statistical indicators. Results revealed that the models based on clearness index showed better performance than the models based on sunshine fraction. However, the hybrid model (model M 24) developed on the basis of both clearness index and sunshine fraction, expressed the highest performance. Consequently, this model is recommended to assess diffuse solar radiation in the region under consideration. Furthermore, it can also be applicable to adjacent sites that possess the similar climatic conditions and lack measurement for diffuse solar radiation.*

Keywords – correlation models, diffuse solar radiation, Northern Sudan, solar energy, sunshine duration.

1. INTRODUCTION

Global energy consumption has been significantly increased. Natural reserves of fossil fuels are diminishing and their burning have resulted in environmental degradation at a high pace [1]. This scenario has augmented the need to develop renewable energy resources. Solar energy is considered to be one of the most important sources of renewable energy. Accurate knowledge of available solar energy with its direct and diffuse components in a particular place are of great importance in designing and sizing of solar energy conversion systems [2], [3]. Unfortunately in many developing countries such as Sudan, solar radiation data, especially in term of diffuse component is not available [4]. It is attributed to the cost of measuring equipment, its maintenance and calibration requirements [5].

The region of Northern Sudan is situated between the longitudes $25^o\ 3'E$ and $35^o\ 30'E$, and the latitudes $16^o N$ and $22^o N$. It comprises an area of about 471×103 km^2. Climate of the region is arid hot desert with scorching summer and rare rains [6]. In the region, solar energy resources are plentiful. Monthly average daily global solar radiation can reach up to 27.55MJ/m^2.day (corresponding to 7.65 kWh/m^2.day) and monthly average daily sunshine hours can rise up to 11.13 h/day. So the solar energy resources available here can be considered as one of the highest in world [7]. However, in this vast area only two stations at Hudeiba and Dongola are equipped to measure global solar radiation. No provision to record diffuse solar radiation has been established yet, though the sunshine duration is measured at many sites.

As reported by Badescu [8] and some other authors, in the absence of data for diffuse solar radiation, common practice is to estimate it by using other available meteorological data. Such data includes sunshine hours, global solar radiation, air and soil temperatures, number of rainy days, humidity and precipitation [9], [10]. Based on these parameters many empirical models have already been developed [11], [12]. Among these parameters the most commonly used are sunshine hours and global solar radiation [9], [13]. Liu and Jordan developed the first model for estimation of diffuse solar radiation [14]. Their model correlated diffuse fraction (H_d/H) with clearness index (K_T). Diffuse fraction can be defined as the ratio of diffuse radiation to global radiation. On the other hand clearness index is the ratio of global radiation to extraterrestrial radiation. Subsequently, lot of studies have been conducted for estimation of horizontal diffuse solar radiation at different locations by using other parameters like relative sunshine hours (n/N). In this ratio n refers to measured monthly average daily sunshine hours and N refers to monthly average daily maximum possible sunshine hours. According to a recent review of this topic made by Khorasanizadah and Mohammadi [9], most of the presented models correlate diffuse fraction to clearness index, relative sunshine hours or to the combination of them. However, as reported by Dervishi and Mahdavi, performance of these models decreases once they are transferred to other locations than those developed for [15].

As per literature, some authors tried to develop models to predict diffuse component at specific sites that lack data by using a group of pre-developed models. Such models had already been created and calibrated for other locations [16]. They used a set of well-known global models in addition to some other models which might were developed for locations with different

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climate and geography. This method can lead to unnoticed errors and inaccurate estimation of diffuse radiation since there are no measured values to calibrate the developed models. A new rational approach has been adopted in this study to overcome this lacuna. This approach encompasses to develop empirical models for estimation of diffuse solar radiation in the region of Northern Sudan. To avoid the errors which can arise by inappropriate selection of used models, the map of Köppen-Geiger climate classification [6] is proposed to be the basis for selection of the pre-developed models. It will ensure similar climatic conditions for the study site and the locations for which the selected models had already been developed.

In spite of huge solar energy resources at hand, neither measurement nor any reliable model exist to predict the diffuse component in this region till this study. So the main objectives of this study are: (i) to develop and evaluate empirical models for estimation of horizontal diffuse solar radiation in the region of Northern Sudan (ii) to compare the predicted results derived from new models with those reported by NASA [17] in order to test the reliability of new developed models.

2. DATA AND METHODOLOGY

In the region of Northern Sudan, two stations at Hudeiba (17.57° N and 33.93° E) and Dongola (19.17° N and 30.48° E) have records for both global solar radiation and sunshine hours. Experimental data used in this study were recorded and checked by Sudan Meteorological Authority during the period of 1973 – 1993. At the said stations, sunshine duration and daily global solar irradiance were recorded by Campbell-Stokes heliograph and Robitsch pyranometers respectively. Accuracy of these instruments was estimated to be better than 5% when calibrated [7]. Available data pertaining to daily measurements of each month were averaged followed by the mean values of every month for this time span. It led to monthly average values which were required in present study. Data reported by NASA for the time period 1983 – 2006 has been used for comparison. These data were obtained from the NASA Langley Research Center web portal supported by the NASA LaRC POWER Project [17].

In the absence of measured data for diffuse solar radiation in the region, 17 models were selected from previous studies to estimate the diffuse component. 9 of the selected models are well-known and have been considered as good models to estimate diffuse solar radiation along the globe. Remaining 8 models were carefully chosen from the literature for certain locations which were put in the same climatic conditions under Köppen-Geiger climate classification. Figure 1 shows the study area and locations of selected models on the map of Köppen-Geiger. Figures 2 (a, b) elucidate three parameters. It includes monthly mean values of temperature, annual means of relative humidity and precipitation for the study area and selected sites. Values from these Figures depict that the whole area is arid hot desert, characterized by clear skies with intensive solar radiation, dry air with high temperature and erratic rains. In these Figures, data presented for Shambat, Hudeiba, Dongola, Aswan and Farafra sites were reported by World Meteorological Organization (WMO). For Al-Jawf, Sebha and Baghdad data were obtained from http://jrcc.sa and climatemps.com.

The used models can be grouped in three categories. In the first group the diffuse fraction (H_d/H) is a function of the clearness index (K_T). In the second group the (H_d/H) is a function of relative sunshine hours (n/N). Third group represents the diffuse fraction as a function of both K_T and n/N. Used models are presented in Table 1.

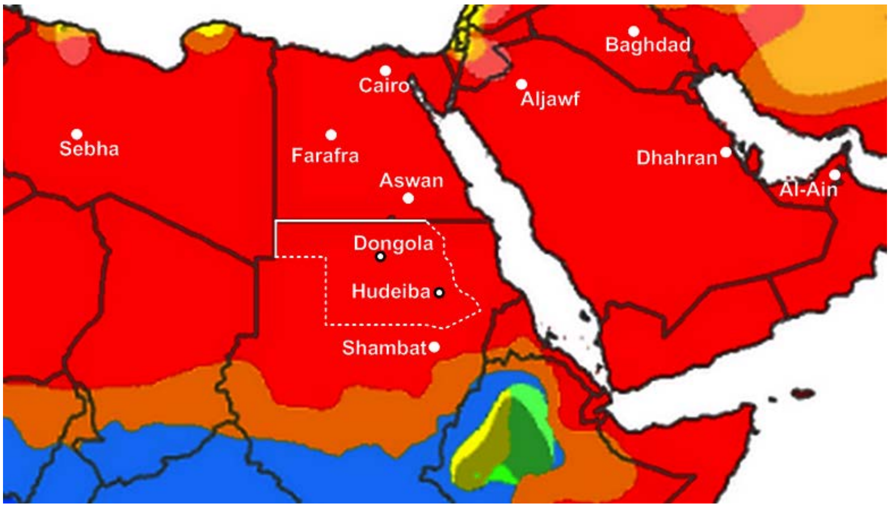

Fig 1. The study area and locations of selected models on Köppen-Geiger's map [6].

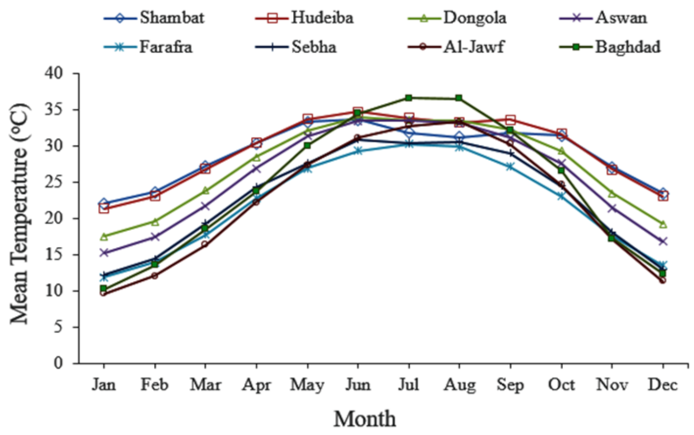

Fig 2a. Monthly mean temperature for the study area and selected locations.

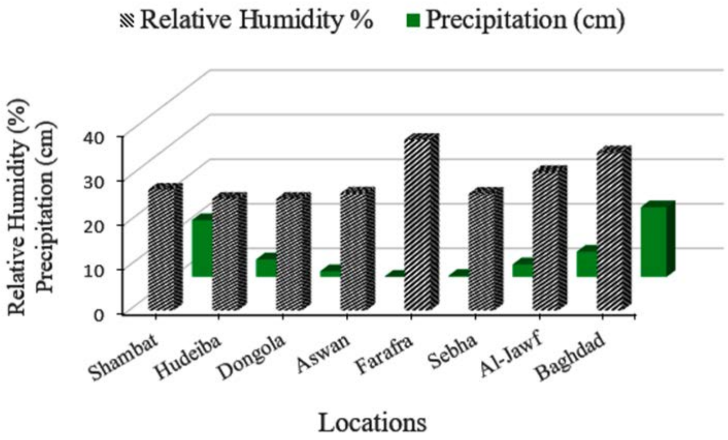

Fig 2b. Annual mean relative humidity and precipitation for the study area and selected locations.

Table 1. Models used in this study and their locations.

Model No.	Regression equation	Authors and Locations
M 1	$\frac{H_d}{H} = 1.0 - 1.13\ K_T$	Page [14]
M 2	$\frac{H_d}{H} = 1.03 - 1.17K_T$	Omer for Shambat in central Sudan [18]
M 3	$\frac{H_d}{H} = 0.999 - 1.1283K_T$	Alnaser [19] for Bahrain
M 4	$\frac{H_d}{H} = 1.102 - 1.299K_T$	AL-Hamadani *et al.*[20] for Baghdad
M 5	$\frac{H_d}{H} = 0.91138 - 0.96225K_T$	Gopinathan and Solar [21]
M 6	$\frac{H_d}{H} = 1.390 - 4.027K_T + 5.531K_T^2 - 3.108K_T^3$ For $0.3 < K_T < 0.7$	Klein [14] and recommended by Yousef [22] for Doha (Qatar)
M 7	$\frac{H_d}{H} = 1.311 - 3.022K_T + 3.427K_T^2 - 1.821K_T^3$ For $\omega_s > 81.4$ and $0.3 \le K_T \le 0.8$	Erbs *et al.* [9] and recommended by Ahwide et al. for Sebha in Libya [23]
M 8	$\frac{H_d}{H} = 1.317 - 3.023K_T + 3.372K_T^2 - 1.769K_T^3$ For $0.3 \le K_T \le 0.8$	Erbs *et al.* [9],
M 9	$\frac{H_d}{H} = 1.6932 - 8.2262K_T + 25.5532K_T^2 - 37.87K_T^3 + 19.8178K_T^4$	Bahel [24]
M 10	$\frac{H_d}{H} = 0.636 - 0.279K_T - 0.194K_T^2 - 0.383K_T^3$	Ibrahim for Cairo, Egypt [9]
M 11	$\frac{H_d}{H} = 0.791 - 0.635\frac{n}{N}$	Iqbal [9]
M 12	$\frac{H_d}{H} = 0.677 - 0.497\frac{n}{N}$	Khalil and Alnajjar for UAE[25]
M 13	$\frac{H_d}{H} = 0.650 - 0.494\frac{n}{N}$	AL-Hamadani *et al.* for Baghdad [20]
M 14	$\frac{H_d}{H} = 0.79819 - 0.69930\frac{n}{N}$	Gopinathan and Solar [21]
M 15	$\frac{H_d}{H} = 1.00 - 1.06K_T - 0.05\frac{n}{N}$	Omer for Shambat in central Sudan [18]
M 16	$\frac{H_d}{H} = 0.87813 - 0.3328K_T - 0.53039\frac{n}{N}$	Gopinathan and Solar [21]
M 17	$\frac{H_d}{H} = 0.7980 - 0.7475K_T - 0.0702\frac{n}{N}$	Elminir *et al.* for Egypt [26], and recommended by Despotovic *et al.* for the arid areas throughout the world[10]

In these equations, H_d is monthly average daily diffuse solar radiation (MJ/m^2), H is monthly average daily global solar radiation (MJ/m^2), H_o is monthly average daily extraterrestrial radiation (MJ/m^2), n is monthly average daily sunshine hours (h) and N is monthly average daily maximum possible sunshine hours.

The monthly average daily extraterrestrial radiation (H_o) is calculated by using the following equations for the average day of the month which is taken as recommended by Klein [14]:

$$H_o = \frac{24\times 3600 G_{sc}}{\pi}\left(1 + 0.033\cos\frac{360n}{365}\right) \times \left(\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta\right) \quad (1)$$

Where G_{sc} is a solar constant taken as $1367 Wm^{-2}$, n is number of days of a year starting from first of January, ϕ represents latitude of the site, δ is solar declination and ω_s is mean sunrise hour angle.

Solar declination is calculated by:

$$\delta = 23.45\sin\left(\frac{360(284+n)}{365}\right) \quad (2)$$

Mean sunrise hour angle (ω_s) is calculated by:

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \quad (3)$$

While the monthly average maximum daily sunshine hours (N) is given for average day of the month by Cooper's formula[14]:

$$N = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta) \quad (4)$$

Data for diffuse solar radiation at all stations within the region are not available. Thus, the models (M1 – M17) have been used to estimate the diffuse component of solar radiation both at Hudeiba and Dongola. The average of the predicted values by these 17 models for each value of K_T and n/N are used to calibrate 7 new regional models (M18 – M24) developed in this study. The purpose of this approach is to eliminate the difference between estimation of the 17 models, since there is no way to select the best model without measured data [27], [28]. General forms of the proposed models are presented in Table 2. Out of the 7 proposed models, 3 are based on clearness index and 3 rely on relative sunshine hours. The last one is based on both clearness index and relative sunshine hours. Measured global radiation and sunshine hours for both stations are portrayed in Figures 3 and 4, respectively. High values of global radiation and sunshine hours indicate that huge solar energy potential rests with the region.

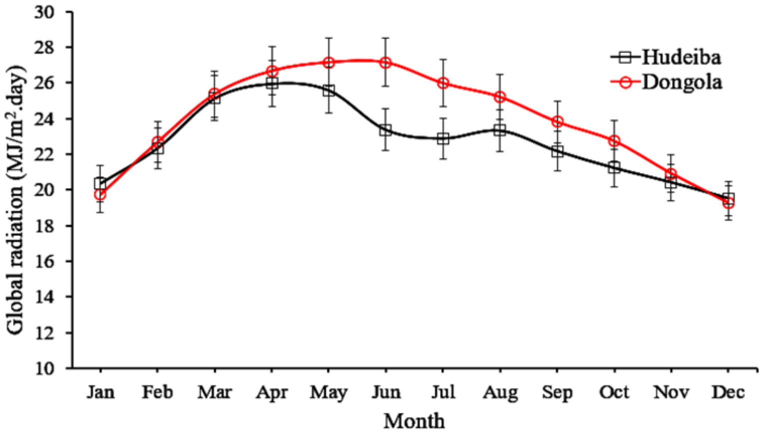

Fig. 3. Measured global solar radiation in Northern Sudan (error bars indicate 5% accuracy).

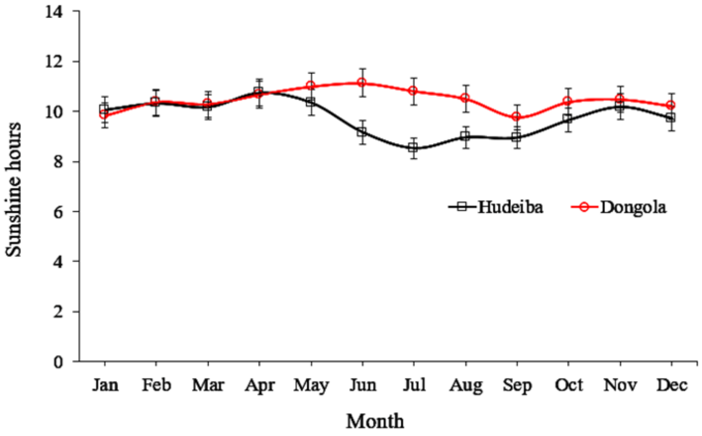

Fig. 4. Measured sunshine hours in Northern Sudan (error bars indicate 5% accuracy).

Table 2. General forms of the models developed in this study.

Model type	Regression equation
Linear, based on clearness index	$\frac{H_d}{H} = a + bK_T$
Logarithmic, based on clearness index	$\frac{H_d}{H} = a + b\ln(K_T)$
Quadratic, based on clearness index	$\frac{H_d}{H} = a + bK_T + cK_T{}^2$
Linear, based on sunshine fraction	$\frac{H_d}{H} = a + b\left(\frac{n}{N}\right)$
Logarithmic, based on sunshine fraction	$\frac{H_d}{H} = a + b\ln\left(\frac{n}{N}\right)$
Quadratic, based on sunshine fraction	$\frac{H_d}{H} = a + b\left(\frac{n}{N}\right) + c\left(\frac{n}{N}\right)^2$
Linear hybrid, based on both clearness index and sunshine fraction	$\frac{H_d}{H} = a + bK_T + c\left(\frac{n}{N}\right)$

3. COMPARISON TECHNIQUES

Performance of the new developed models has been evaluated by using different statistical parameters which include: mean absolute percentage error (MAPE), mean bias error (MBE), mean absolute bias error (MABE), root mean square error (RMSE), sum of the square of relative error (SSRE), relative standard error (RSE), standard deviation of the residual (SD) and uncertainty at 95% (U_{95}) in addition to the coefficient of determination (R^2). These statistical parameters are defined by the following equations:

$$MAPE = \frac{1}{n}\left[\sum_{i=1}^{i=n}\frac{|p_i - o_i|}{o_i} \times 100\right] \quad (5)$$

$$MBE = \frac{1}{n}\left[\sum_{i=1}^{i=n}(p_i - o_i)\right] \quad (6)$$

$$MABE = \frac{1}{n}\left[\sum_{i=1}^{i=n}|p_i - o_i|\right] \quad (7)$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{i=n}(p_i - o_i)^2\right]^{0.5} \quad (8)$$

$$SSRE = \sum_{i=1}^{i=n}\left(\frac{p_i - o_i}{o_i}\right)^2 \quad (9)$$

$$RSE = \sqrt{\frac{SSRE}{n}} \quad (10)$$

$$SD = \frac{1}{n}\left[\sum_{i=1}^{i=n} n(p_i - o_i)^2 - \left(\sum_{i=1}^{i=n}(p_i - o_i)\right)^2\right]^{0.5} \quad (11)$$

$$U_{95} = 1.96(SD^2 + RMSE^2)^{0.5} \quad (12)$$

$$R^2 = \frac{\sum_{i=1}^{i=n}(p_i - p_m).(o_i - o_m)}{\sqrt{\left[\sum_{i=1}^{i=n}(p_i - p_m)^2\right]\left[\sum_{i=1}^{i=n}(o_i - o_m)^2\right]}} \quad (13)$$

In these equations, the *i*th observed data point is noted as o_i and the *i*th predicted data is noted as p_i. Mean values of the observed and predicted data point are noted as o_m and p_m respectively, n is the number of data point and m is the number of regression coefficients in the model. For better data modeling, R^2 should approach to 1 while remaining parameters should be close to zero.

For more confidence, the predictions of the recommended model have also been compared with the data obtained by NASA at Hudeiba and Dongola. Since there is no measurement for diffuse solar radiation at ground stations in the region.

4. RESULTS AND DISCUSSION

By using the available measured data for global radiation and sunshine hours at Hudeiba and Dongola stations, a set of new seven models have been developed. New models are expressed in Table 3. These models have been evaluated at two stations on the basis of average values obtained from the 17 selected models. The results of statistical tests are presented in Table 4. For each statistical parameter, the best obtained value is shown in bold. Based on these values, it is observed that 3 clearness index based models (M 18 – M 20) show better performance, at two stations, as compared with relative sunshine hours based models (M 21 – M 23). The model developed on the basis of both clearness index and relative sunshine hours (model M 24) resulted in the highest accuracy as compared to other 6 models. As shown by Figure 5, model M 24 perfectly fits to the averaged values of the 17 models at both Hudeiba and Dongola. The figure also shows the quantities of diffuse radiation recorded by NASA at the two locations. It is evident that the predicted amounts of diffuse radiation by model M 24 for both sites are in a good agreement with NASA data.

Predicted values and that recorded by NASA are presented in Table 5. At Dongola, monthly average daily horizontal diffuse solar radiation varies between 3.49 MJ/m^2 and 6.57 MJ/m^2. These values fluctuate between 3.93 MJ/m^2 and 7.73 MJ/m^2 for Hudeiba. As shown, diffuse solar radiation at the two sites is maximum during July and is minimum during December. Additionally it is noticed that throughout the year, diffuse radiation at Hudeiba is slightly higher than at Dongola. Monthly average diffuse fractions or cloudiness index (which is defined as the ratio of diffuse to global radiation) for the two stations are placed at Figure 6. At Hudeiba, the maximum diffuse fraction is

0.34 which occurs during July while the minimum is 0.20 to be expected in January. Yearly average thus comes to 0.26. At Dongola, maximum diffuse fraction is 0.26 taking place during September and the minimum is only 0.17 to be reached in November. Yearly average hence arrives at 0.22. These values indicate that the region of Northern Sudan receives most of its solar energy as direct radiation and enjoy a sunny condition throughout the year. The results endorse the geographical location of this region in Sahara Desert.

Table 3. The new models developed in this study.

Model No.	Regression equation
M 18	$\frac{H_d}{H} = 0.9329 - 1.0208K_T$
M 19	$\frac{H_d}{H} = -0.0247 - 0.679\ln(K_T)$
M 20	$\frac{H_d}{H} = 1.3563 - 2.297K_T + 0.9568{K_T}^2$
M 21	$\frac{H_d}{H} = 0.7392 - 0.5961\left(\frac{n}{N}\right)$
M 22	$\frac{H_d}{H} = 0.1534 - 0.476\ln\left(\frac{n}{N}\right)$
M 23	$\frac{H_d}{H} = 0.6169 - 0.2901\left(\frac{n}{N}\right) - 0.1893\left(\frac{n}{N}\right)^2$
M 24	$\frac{H_d}{H} = 0.888 - 0.737K_T - 0.176\left(\frac{n}{N}\right)$

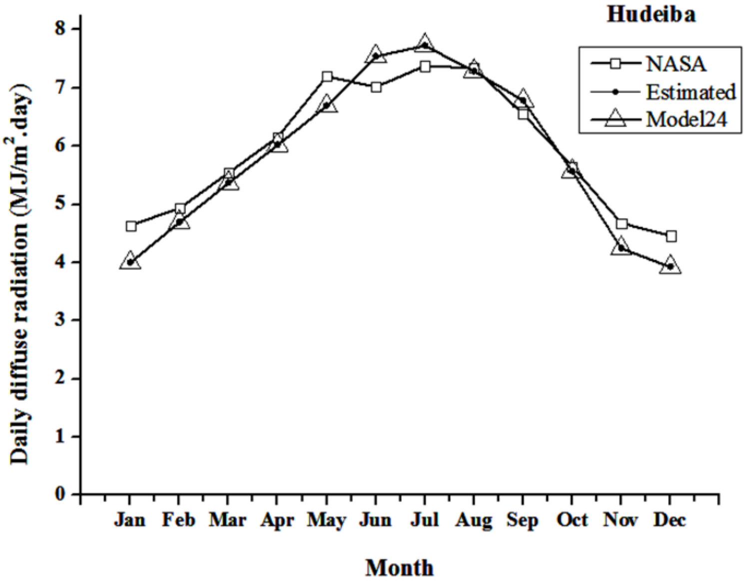

Fig. 5a. The estimated and predicted diffuse radiation at Hudeiba.

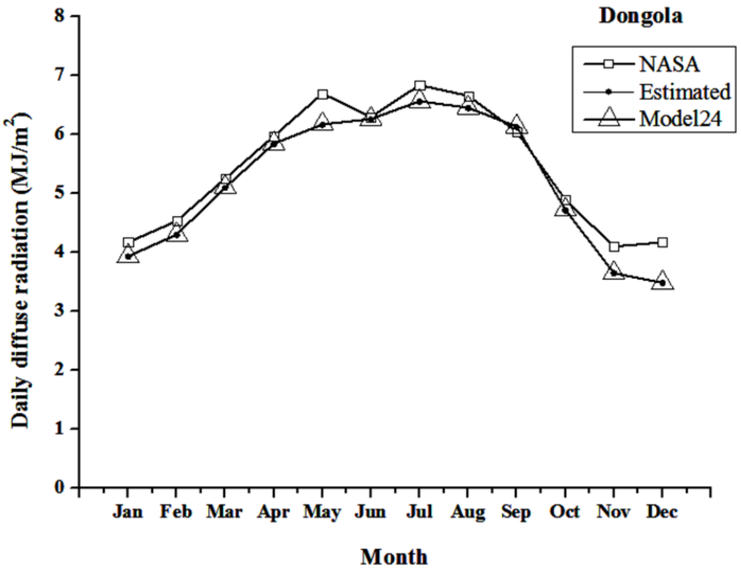

Fig. 5b. The estimated and predicted diffuse radiation at Dongola.

Table 4. Statistic results for validation of developed models.

Location	statistic	Model No.						
		M 18	M 19	M 20	M 21	M 22	M 23	M 24
Hudeiba								
	R^2	0.9929	0.9944	0.9944	0.9559	0.9504	0.9565	0.9999
	MAPE	1.5119	1.2640	1.2365	3.5527	3.7983	3.4300	0.1249
	MBE	0.0108	0.0114	0.0114	-0.0527	-0.0497	-0.0535	0.0066
	MABE	0.0834	0.0677	0.0662	0.1928	0.2110	0.1836	0.0066
	RMSE	0.0973	0.0794	0.0767	0.2287	0.2466	0.2231	0.0070
	SSRE	0.0038	0.0028	0.0026	0.0223	0.0236	0.0221	0.0000
	RSE	0.0179	0.0152	0.0148	0.0431	0.0444	0.0429	0.0014
	SD	0.0931	0.0760	0.0734	0.2190	0.2361	0.2136	0.0067
	U_{95}	0.2639	0.2153	0.2082	0.6206	0.6691	0.6054	0.0191
Dongola								
	R^2	0.9929	0.9944	0.9944	0.9559	0.9504	0.9565	0.9999
	MAPE	1.1746	1.3089	1.3556	3.0855	3.3104	3.2375	0.1523
	MBE	-0.0122	-0.0192	-0.0202	0.0594	0.0500	0.0672	0.0081
	MABE	0.0616	0.0664	0.0681	0.1639	0.1718	0.1710	0.0081
	RMSE	0.0802	0.791	0.0816	0.2189	0.2247	0.2225	0.0085
	SSRE	0.0028	0.0030	0.0033	0.0204	0.0216	0.0213	0.0000
	RSE	0.0152	0.0157	0.0165	0.0412	0.0425	0.0421	0.0016
	SD	0.0768	0.0757	0.0781	0.2096	0.2151	0.2130	0.0082
	U_{95}	0.2176	0.2147	0.2214	0.5940	0.6098	0.6037	0.0231

5. CONCLUSION

Accurate information and reliable solar radiation data for a specific location is very important to study and design the systems that use solar energy. Unfortunately this type of data is unavailable for many places. In particular, data of diffuse solar radiation is not recorded in most of the developing countries. The region of Northern Sudan has huge solar energy resources which can be regarded among the highest in the world. It is an irony that no facility to record diffuse solar radiation has been provided in this promising region yet. In this study, 7 new models have been developed to estimate the monthly average diffuse component of solar radiation in the region. Average values obtained from 17 models, carefully selected from the literature, have been used to calibrate the new models. Nine statistical parameters have been used to evaluate the models' performance. As a result, the new models which are based on the clearness index (models M 18 –M 20) performed better than the models based on sunshine fraction (models M 21 – M 23). It is pertinent to note that the hybrid model which is developed on the basis of both clearness index and sunshine fraction (model M24) delivered the highest performance according to all statistical parameters. This model is given as:

$$\frac{H_d}{H} = 0.888 - 0.737K_T - 0.176\left(\frac{n}{N}\right) \qquad \text{(model M 24)}$$

Moreover, values predicted by this model correspond to the values reported by NASA for both Hudeiba and Dongola Stations. Resultantly, this model is recommended for estimation of diffuse solar radiation in the region of Northern Sudan. Additionally, suggested model can also be effectively used to calculate this parameter for adjacent sites bearing the same climate and lack of measured data.

Finally, the study established that for locations which have no measured data for diffuse solar radiation, use of the Köppen-Geiger map of climate classification in selecting most appropriate models from literature will lead to good results.

Table 5. Monthly average diffuse solar radiation at the two stations.

Month	Diffuse radiation at Hudeiba (MJ/m^2.day)			Diffuse radiation at Dongola (MJ/m^2.day)		
	Estimated	Model M 24	NASA	Estimated	Model M 24	NASA
Jan.	4.00	4.00	4.64	3.93	3.94	4.18
Feb.	4.69	4.70	4.93	4.30	4.30	4.54
Mar.	5.37	5.38	5.54	5.10	5.11	5.26
Apr.	6.02	6.03	6.16	5.83	5.85	5.98
May	6.69	6.70	7.20	6.16	6.18	6.70
Jun.	7.54	7.55	7.02	6.25	6.27	6.30
Jul.	7.73	7.73	7.38	6.56	6.57	6.84
Aug.	7.29	7.29	7.34	6.45	6.46	6.66
Sep.	6.78	6.79	6.55	6.12	6.13	6.05
Oct.	5.57	5.57	5.65	4.72	4.73	4.90
Nov.	4.24	4.25	4.68	3.65	3.65	4.10
Dec.	3.92	3.93	4.46	3.49	3.49	4.18
yearly	5.82	5.83	5.96	5.21	5.22	5.47

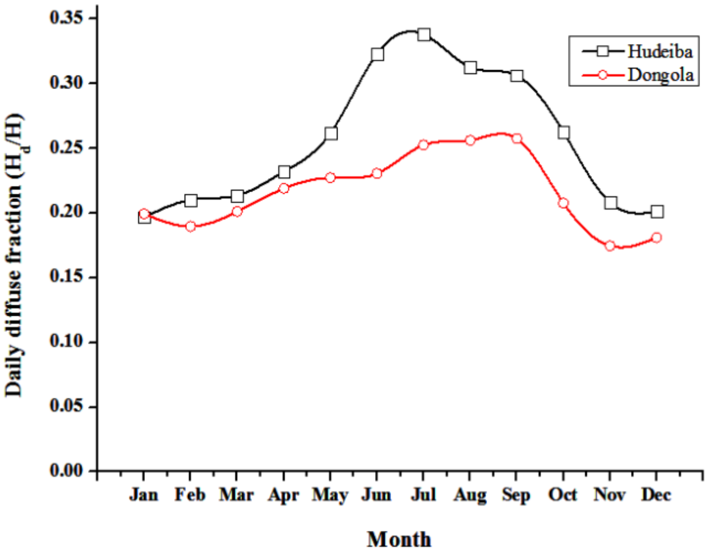

Fig. 6. The monthly average diffuse fractions.

ACKNOWLEDGEMENT

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NOMENCLATURE

H	monthly average daily global solar radiation (MJ/m^2)
H_d	monthly average daily diffuse solar radiation (MJ/m^2)
H_o	extraterrestrial solar radiation (MJ/m^2)
K_T	clearness index
a, b, c	correlation coefficients
n	monthly average of sunshine duration (h)
N	monthly average maximum daily hours of sunshine (h)
G_{sc}	solar constant ($= 1367 W m^{-2}$)
n	number of days of year starting from the first of January
R^2	coefficient of determination
MBE	mean bias error
$MABE$	mean absolute bias error
$MAPE$	mean absolute percentage error
$RMSE$	root mean square error
SD	standard deviation of the residual
U_{95}	uncertainty at 95%
$SSRE$	sum of square relative error
RSE	relative standard error

Greek letters

ϕ	latitude of the site (°)
δ	solar declination (°)
ω_s	sunset hour angle (°)

REFERENCES

[1] Sabzpooshani M. and K. Mohammadi. 2014. Establishing new empirical models for predicting monthly mean horizontal diffuse solar radiation in city of Isfahan, Iran. *Energy* 69: 571-577.

[2] Torres J., De Blas M., García A. and De Francisco, A., 2010. Comparative study of various models in estimating hourly diffuse solar irradiance. *Renewable Energy* 35: 1325-1332.

[3] Hussain M., Rahman L., and Rahman M.M., 1999. Technical note: techniques to obtain improved predictions of global radiation from sunshine duration. *Renewable Energy* 18: 263-275.

[4] Bakirci K., 2009. Models of solar radiation with hours of bright sunshine: a review. *Renewable and Sustainable Energy Reviews* 13: 2580-2588.

[5] De Oliveira A.P., Machado A., Escobedo J.F. and Soares, J., 2002. Diurnal evolution of solar radiation at the surface in the city of São Paulo: seasonal variation and modeling. *Theoretical and Applied Climatology* 71: 231-249.

[6] Peel M.C., Finlayson B.L. and McMahon T.A., 2007. Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences Discussions* 4: 439-473.

[7] Omer A.M., 1997. Compilation and evaluation of solar and wind energy resources in Sudan. *Renewable Energy* 12: 39-69.

[8] Akinoglu G. 2008. Recent advances in the relations between bright sunshine hours and solar irradiation. In *Modeling Solar Radiation at the Earth's Surface*. Badescu V, ed. Berlin: Springer, 2008, pages 112-141.

[9] Khorasanizadeh H. and Mohammadi K., 2016. Diffuse solar radiation on a horizontal surface: Reviewing and categorizing the empirical models. *Renewable and Sustainable Energy Reviews* 53: 338-362.

[10] Despotovic M., Nedic V., Despotovic D. and Cvetanovic S., 2016. Evaluation of empirical models for predicting monthly mean horizontal diffuse solar radiation. *Renewable and Sustainable Energy Reviews* 56: 246-260.

[11] El-Sebaii A. and F. Al-Agel. 2013. Estimation of horizontal diffuse solar radiation from common meteorological parameters: a case study for Jeddah, Saudi Arabia. *International Journal of Ambient Energy* 34: 92-99.

[12] Naser A., 2010. An estimation of the monthly average daily diffuse solar radiation on horizontal surfaces over Libya. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 33: 317-326.

[13] Journée M. and C. Bertrand. 2011. Quality control of solar radiation data within the RMIB solar measurements network. *Solar Energy* 85: 72-86.

[14] Duffie J.A. and W.A. Beckman. 2013. *Solar Engineering of Thermal Processes*, 4th edition. John Wiley & Sons, Hoboken, New Jersey. Pages 12-133.

[15] Dervishi S. and A. Mahdavi. 2012. Computing diffuse fraction of global horizontal solar radiation: A model comparison. *Solar Energy* 86: 1796-1802.

[16] Bakirci K., 2012. The calculation of diffuse radiation on a horizontal surface for solar energy applications. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 34: 887-898.

[17] NASA. *Surface meteorology and solar energy. A Renewable Energy Resource, release 6.0*, Retrieved May 1, 2016 from the World Wide Web: https://eosweb.larc.nasa.gov/sse/

[18] Omer A.M., 1994. Diffuse solar radiation over Shambat, Khartoum North. *Renewable Energy* 4: 227-233.

[19] Alnaser W., 1989. Empirical correlation for total and diffuse radiation in Bahrain. *Energy* 14: 409-414.

[20] Al-Hamdani N., Al-Riahi M. and Tahir K., 1989. Estimation of the diffuse fraction of daily and monthly average global radiation for Fudhaliyah, Baghdad (Iraq). *Solar Energy* 42: 81-85.

[21] Gopinathan K. and A. Soler. 1995. Diffuse radiation models and monthly-average, daily,

diffuse data for a wide latitude range. *Energy* 20: 657-667.

[22] Abdalla Y.A., 1987. Solar radiation over Doha (Qatar). *International Journal of Solar Energy* 5: 1-9.

[23] Ahwide F., Spena A. and El-Kafrawy A., 2013. Correlation for the average daily diffuse fraction with clearness index and estimation of beam solar radiation and possible sunshine hours fraction in Sabha, Ghdames and Tripoli-Libya. *APCBEE Procedia* 5: 208-220.

[24] Bahel V., 1987. Statistical comparison of correlations for estimation of the diffuse fraction of global radiation. *Energy* 12: 1257-1263.

[25] Khalil A. and A. Alnajjar. 1995. Experimental and theoretical investigation of global and diffuse solar radiation in the United Arab Emirates. *Renewable Energy* 6: 537-543.

[26] Elminir H.K., Azzam Y.A. and Younes F.I., 2007. Prediction of hourly and daily diffuse fraction using neural network, as compared to linear regression models. *Energy* 32: 1513-1523.

[27] Aras H., Balli O. and Hepbasli A., 2006. Estimating the horizontal diffuse solar radiation over the Central Anatolia Region of Turkey. *Energy Conversion and Management* 47: 2240-2249.

[28] Ulgen K. and A. Hepbasli. 2009. Diffuse solar radiation estimation models for Turkey’s big cities. *Energy Conversion and Management* 50: 149-156.