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Prediction of the Diffuse Solar Energy on Horizontal at Different Selected Locations

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Abstract

The main objective of this paper is to predict the diffuse solar energy on a horizontal surface by using data of global solar energy (H) and diffuse solar energy (H_d) at different selected geographical locations in Saudi Arabia during the period time from 1980 to 2019. The low values of the root mean square error RMSE for all correlations indicated a good agreement between the measured and calculated values of H_d. The negative values of mean percentage error MPE % for all models show that for all locations, the proposed correlations slightly overestimate H_d, and the absolute values of MPE never reach 1.35%. The first, second and third order correlations between the diffuse solar fraction H_d/H and the clearness index K_t and between the diffuse transmittance H_d/H_0 and the sunshine hours have been proposed for the selected locations using the method of regression analysis. The differences between the measured and calculated values of H_d show that a first order correlation between H_d/H and K_t can be used for estimating H_d at the present locations with good accuracy. However, second order correlations between H_d/H or H_d/H_0 and S/S_o are recommended for estimating H_d at these locations. The average annual differences between measured and calculated values of diffuse solar energy H_d on horizontal at selected sites in the present research are discussed.

Keywords

Diffuse Solar Radiation (DSR), Statistical Indicators, Solar Energy, Meteorological Data and Empirical Model

1. Introduction

Solar energy is considered 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 is of great importance in designing and sizing of solar energy conversion systems. A crucial input required in the simulation of buildings' energy performance is the availability of detailed information on the magnitudes of diffuse and direct irradiance data. Moreover, configuration and sizing of solar energy systems (e.g. photovoltaic cells, solar-thermal collectors) necessitates reliable solar radiation measurements. However, concurrent measured data of global and diffuse irradiance on horizontal surface or direct normal solar irradiance are available only for a limited number of locations [1] [2] [3]. The measurement of global horizontal irradiance is rather simple and cost-effective. It can be, conceivably, an integral part of the sensory equipment of every building. Given global solar irradiation measurements on a horizontal surface (as the most widely available data), direct and diffuse solar radiation components can be obtained through various correlations [4]. The models are usually expressed in terms of first to fourth degree polynomial functions relating the diffuse fraction k_d (ratio of the diffuse-to-global solar radiation) with the clearness index k_t (ratio of the global-to-extraterrestrial solar radiation on horizontal surface), as well as to other variables such as solar altitude, air temperature, relative humidity. Although these models are typically derived following sound approaches, their performance appears to lessen once they are applied to regions other than those, which provided the initial data for model development [5].

Solar radiation data is the basic input for solar applications, such as photovoltaic, solar thermal systems and passive solar design. The data should be reliable and can be used at any time to design, optimize and evaluate the performance of solar technology at any site. However, it is not economically feasible to install solar radiation measuring instruments wherever possible. Therefore, the use of mathematical models to forecast the solar radiation in a given area has proved to be a viable option based on the measurement results of limited locations [6] [7] [8]. Unfortunately, in many developing countries, solar radiation measurement is not yet available because they cannot afford the equipment and measurement technology. Hence, it is vital to create methods for evaluating solar radiation based on more promptly accessible meteorological data. Within the design and execution examination of solar energy projects, particularly within the design and measure assurance of solar PV as a future alternative energy source, exact forecast of diffuse solar radiation (DSR) is essential. Careful thought of DSR can much better assess the productivity of the solar system [9] [10] [11] [12]. In addition, in several regions of the world, there is no or very little measurement of diffuse solar radiation. Because of their wide application in other places, they can measure total horizontal irradiance and other standard meteorological variables, such as sunshine duration, temperature and relative humidity. In the field of meteorology and agriculture, given global solar radiation data and some meteorological parameters, the diffusion component can be obtained through various correlations. Recently, extensive research has been conducted in many parts of the world to estimate DSR using the most widely available data. Many authors have proposed empirical formulas to use the clearness index (K_t: the ratio of global solar radiation to extraterrestrial solar radiation), or use the fraction of hours of sunshine to forecast the monthly average on a horizontal surface of DSR, or in combination. A model for predicting daily DSR using sunshine fraction (the ratio of sunshine duration to the maximum possible sunshine time), clarity index and haze factor is also proposed. Facts have proved that the model that uses both the clarity index and the sunshine score is the best choice for estimating DSR [13] [14] [15] [16] [17].

The utilization of solar energy will facilitate scale back the demand for standard energy. Therefore, owing to this, solar power is taken into account to be the proper resolution to the energy crisis facing the globe nowadays. During this method, radiation information should be established for places of interest that is sometimes a requirement for the institution and commission of star facilities. In any case, it is not possible to form careful observations of native environmental condition. This can be the case for several developing countries (such as Saudi Arabia). Though these countries could have high radiation potential, they lack comfortable radiation info results in fewer energy plans to be explored and enforced [18] [19] [20] [21] [22].

The quality of radiation is typically outlined in step with its composition, specifically incident and diffuse solar radiation. Among these elements, the number of diffuse radiation is usually unsure, because of additionally to location parameters; it is chiefly littered with several native geographic factors and climatically characteristics. Most accessible information bases are equipped with data on world radiation and need info on diffuse radiation. This can be because of the sometimes-higher value of putting in a meteorological workplace to examine elements. Therefore, empirical models are sometimes wont to measure diffuse radiation. The written kind proposes a range of various models to estimate the common monthly average radiation, that uses input factors (such as world radiation and daytime) and different climatically factors (such as humidness, pressure, precipitation, and temperature) to estimate. Among these, world radiation and sunshine amount are imperative factors used at intervals the advancement of experimental models for diffuse radiation [14] [23] [24] [25] [26].

The main objective of the present research is to correlate the monthly average daily diffuse fraction $H_d = H$ with the monthly average daily clearness index K_t or the fraction of possible number of sunshine hours S/S_o for selected locations in Saudi Arabia. In addition, the ratio of H_d to H_0 or the diffuse transmittance is correlated the ratio S/S_o for the considered locations. Therefore, the data available for the considered locations are then combined and used to develop correlations for all Saudi Arabia that can be used for estimation of H_d for any location of Saudi Arabia. The data were obtain; part from the Meteorological and Environmental Protection Agency (MEPA) and other part from the station of Al-Baha University in Saudi Arabia.

2. Data and Methodology

In the present research, the monthly average of daily global solar radiation H, diffuse solar radiation and the number of bright sunshine hours S available for three selected sites in Saudi Arabia (Al-Aqiq, Hail and Dammam) for the years from 1980 and 2019 are used. The geographical information of the selected locations are summarize in Table 1.

In the present research, the regression analysis is used for the proposed models, where the estimate and is the diffuse fraction (K_d) or diffuse coefficient (K_D) and the predictors are sunshine ratio (S/S_o) and clearness index (K_t). Thus, the models can be defined for diffuse fraction and diffusion coefficient as follows [27] [28] [29] [30] [31]:

$$K_d = \frac{H_d}{H},\ K_D = \frac{H_d}{H_o} \cong f\left(\frac{S}{S_o}\right) \tag{1}$$

$$K_d = \frac{H_d}{H},\ K_D = \frac{H_d}{H_o} \cong f\left(K_t\right) \tag{2}$$

where H_0, H, and H_d are the monthly mean daily extraterrestrial solar radiation, global solar radiation and diffuse solar radiation on a horizontal surface, respectively. Mathematically, sunshine ratio (S/S_o) and clearness index ($K_t = H/H_o$), S and S_o are the sunshine duration and maximum possible sunshine duration, respectively.

The monthly average daily extraterrestrial solar radiation on a horizontal surface is calculated from the following equation [32]-[38]:

$$H_o = \frac{24}{\pi} H_{SC}\left\{1 + 0.033\cos\left(\frac{360}{365}n\right)\right\}\left[\cos\varphi\cos\delta\sin\omega + \frac{\omega}{180}\sin\varphi\sin\delta\right] \tag{3}$$

where H_{sc} is the solar constant, n is the Julian day of the year, φ is the location latitude, and δ is declination angle, ω_s is the sunset hour angle. δ and ω_s are mathematicallydefined as:

$$\delta = 23.45\sin\left\{360\frac{n+284}{365}\right\} \tag{4}$$

$$\omega_s = \cos^{-1}\left(-\tan\varphi\tan\delta\right) \tag{5}$$

We can obtained the maximum possible sunshine duration (S_o) from ($S_o \frac{2}{15}\omega_s$).

Table 1. The geographical information of the selected sites in the present research.

Site	Latitude (N)	Longitude (E)	Elevation (m)	The period of data
Al-Aqiq	20˚16'	41˚38'	1573 m	1980 - 2019
Hail	27˚52'	41˚69'	992 m	1980 - 2019
Dammam	26˚23'	49˚53'	10 m	1980 - 2019

The correlations to which the measured data are fitted are as follow [39]-[44]:

$$\frac{H_d}{H} = 0.548 - 0.847\frac{S}{S_o} \tag{6}$$

$$\frac{H_d}{H} = 0.287 + 0.0.052\frac{S}{S_o} - 0.3289\left(\frac{S}{S_o}\right)^2 \tag{7}$$

$$\frac{H_d}{H} = 3.245 - 5.489\frac{S}{S_o} + 2.654\left(\frac{S}{S_o}\right)^2 - 0.245\left(\frac{S}{S_o}\right)^3 \tag{8}$$

$$\frac{H_d}{H} = 2.658 - 2.158K_t \tag{9}$$

$$\frac{H_d}{H} = 1.654 - 8.324K_t + 4.325\left(K_t\right)^2 \tag{10}$$

$$\frac{H_d}{H} = 3.256 - 2.589K_t + 4.358\left(K_t\right)^2 - 1.658\left(K_t\right)^3 \tag{11}$$

$$\frac{H_d}{H_o} = 0.589 - 0.432\frac{S}{S_o} \tag{12}$$

$$\frac{H_d}{H_o} = -1.356 + 5.324\frac{S}{S_o} - 2.547\left(\frac{S}{S_o}\right)^2 \tag{13}$$

$$\frac{H_d}{H_o} = -0.5928 + 4.604\frac{S}{S_o} - 6.857\left(\frac{S}{S_o}\right)^2 + 3.068\left(\frac{S}{S_o}\right)^3 \tag{14}$$

In the present research, the results mentioned in the above section are used with the following correlations to express the dependence of diffuse radiation on various parameters in models of Equations (6)-(14) as follow [41] [42]:

$$\frac{H_d}{H} = a + b\frac{S}{S_o} \tag{15}$$

$$\frac{H_d}{H} = a + b\frac{S}{S_o} + c\left(\frac{S}{S_o}\right)^2 \tag{16}$$

$$\frac{H_d}{H} = a + b\frac{S}{S_o} + c\left(\frac{S}{S_o}\right)^2 + d\left(\frac{S}{S_o}\right)^3 \tag{17}$$

$$\frac{H_d}{H} = a + bK_t \tag{18}$$

$$\frac{H_d}{H} = a + bK_t + c\left(K_t\right)^2 \tag{19}$$

$$\frac{H_d}{H} = a + bK_t + c\left(K_t\right)^2 + d\left(K_t\right)^3 \tag{20}$$

$$\frac{H_d}{H_o} = a + b\frac{S}{S_o} \tag{21}$$

$$\frac{H_d}{H_o} = a + b\frac{S}{S_o} + c\left(\frac{S}{S_o}\right)^2 \tag{22}$$

$$\frac{H_d}{H_o} = a + b\frac{S}{S_o} + c\left(\frac{S}{S_o}\right)^2 + d\left(\frac{S}{S_o}\right)^3 \tag{23}$$

where *a*, *b*, *c* and *d* are regression coefficients that depend on the site. The measured values of global solar radiation and diffuse solar radiation obtained with Epply Pyranometer, together with the corresponding sunshine duration values for the different selected locations in Saudi Arabia in the present research.

The accuracy of estimation of H_d is tested by calculating the mean bias error (MBE), root mean square error (RMSE) and the mean percentage error (MPE). Generally, low values of RMSE and MPE are desirable. Positive MBE shows overestimation while negative MBE indicates under estimation. The MBE, RMSE and MPE are defined as in the following equations [45] [46] [47] [48] [49]:

$$\text{MBE} = \frac{1}{n}\sum\left(H_{di,c.} - H_{di,m.}\right) \tag{24}$$

$$\text{RMSE} = \left\{\frac{1}{n}\left[\sum\left(H_{di,c.} - H_{di,m.}\right)^2\right]\right\}^{1/2} \tag{25}$$

$$\text{MPE\%} = \frac{1}{n}\sum\left[\left(H_{di,m.} - H_{di,c.}\right)/H_{di,m}\right]\times 100 \tag{26}$$

where $H_{di,c}$ and $H_{di,m}$ are the *i*th calculated and measured values of H_d and *n* is the number of observations.

3. Results and Discussion

The performance and evaluation of the statistical indicators mean bias error MBE, root mean square error RMSE, mean percentage error MPE%, correlation coefficients R, stander error S.E. and regression coefficients for the different selected location in Saudi Arabia during the period time from 1980 to 2019 are listed in **Tables 2-4**. From the analysis of the combined data for selected locations in the present research, relationships are obtained to express the diffuse radiation from various parameters. The obtained values of the regression coefficients, statistical indicators, correlation coefficient (R) and standard error estimate (S.E) of the models (15)-(23) are summarize in **Tables 2-4**. From these tables, we may noticed that, the values of regression constants *a*, *b*, *c* and *d* for all models are different values according to geographical information of site to another one during the period time in the present research, with the stander error estimate (S.E.). From the results of **Tables 2-4**, it is seen that the values of correlation coefficients are higher than 0.86 for all models with except in a few models. The Models (17), (20) and (23) are given the higher values of correlation coefficients 0.935, 0.962 and 0.974 in Al-Aqiq site respectively, while Models (16), (20) and (21) are given 0.957, 0.936 and 0.942 in Hail site respectively, also Models (17), (20) and (21) are given 0.957, 948 and 965 in Dammam site respectively. For statistical indicators, the values of MBE for all models are given some negative and other positive, this due to the correlations are overestimate and

Table 2. The values of statistical indicators MBE, RMSE, MPE%, R^2, S.E. and regression coefficients for Al-Aqiq site in the present study.

Models	Regression coefficients				MBE	RMSE	MPE%	R	S.E
	a	*b*	*c*	*d*					
(H_d/H) and (K_t)									
Model (15)	2.316	−1.657	-	-	0.005	0.009	−0.634	0.869	0.027
Model (16)	−3.245	9.324	11.214	-	0.008	0.006	−1.263	0.894	0.032
Model (17)	122.5	−235.4	426.8	115.2	0.009	0.007	−1.342	0.935	0.045
(H_d/H) and (S/S_o)									
Model (18)	−3.256	0.345	-	-	0.003	0.008	−0.658	0.826	0.019
Model (19)	0.658	−3.298	−65.324	-	−0.002	0.004	−0.389	0.884	0.027
Model (20)	−0.984	−1.265	5.326	365.8	0.005	0.005	−0.854	0.962	0.036
(H_d/H_o) and (S/S_o)									
Model (21)	0.687	−0.857	-	-	0.007	0.006	−0.523	0.891	0.042
Model (22)	−1.235	2.354	−3.654	-	0.005	0.003	−0.158	0.963	0.037
Model (23)	0.635	−3.958	4.326	425.7	−0.004	0.007	−0.298	0.974	0.025

Table 3. The values of statistical indicators MBE, RMSE, MPE%, R^2, S.E. and regression coefficients for Hail site in the present study.

Models	Regression coefficients				MBE	RMSE	MPE%	R	S.E
	a	*b*	*c*	*d*					
(H_d/H) and (K_t)									
Model (15)	1.356	−1.326	-	-	0.003	0.005	−1.221	0.895	0.016
Model (16)	−2.547	6.325	9.325	-	0.006	0.002	−2.214	0.957	0.028
Model (17)	245.8	125.7	325.7	234.5	0.007	0.004	−0.658	0.912	0.031
(H_d/H) and (S/S_o)									
Model (18)	2.356	−0.168	-	-	0.005	0.006	−0.954	0.913	0.025
Model (19)	−0.452	2.658	−35.625	-	−0.006	0.003	−0.563	0.841	0.037
Model (20)	−0.532	1.478	−4.326	435.6	0.009	0.005	−0.723	0.936	0.024
(H_d/H_o) and (S/S_o)									
Model (21)	0.265	0.689	-	-	0.006	0.008	−0.785	0.942	0.032
Model (22)	2.356	−1.369	2.689	-	0.004	0.002	−0.362	0.885	0.026
Model (23)	−0.852	2.378	−6.359	356.7	−0.003	0.005	−0.485	0.875	0.019

underestimate values of diffuse fraction H_d. The low values of the RMSE for all correlations indicate good agreement between the measured and calculated values of H_d. The negative values of MPE for all models show that for all locations, the proposed correlations slightly overestimate H_d. The results in this research are similar results in the previous study [24] [35]. Generally, the absolute values of MPE never reach 1.35%. This means that, very good agreement between the measured and calculated data and a good fitting exists between the monthly average daily values of the diffuse fraction (H_d/H) and (K_t) or (S/S_o) and between the diffuse transmittance (H_d/H_0) and (S/S_o) for all selected locations in the present research.

Table 4. The values of statistical indicators MBE, RMSE, MPE%, R^2, S.E. and regression coefficients for Dammam site in the present study.

M	Regression coefficients				MBE	RMSE	MPE%	R^2	S.E
	a	*b*	*c*	*d*					
(H_d/H) and (K_t)									
Model (15)	−2.356	1.652	-	-	0.009	0.006	−0.862	0.951	0.022
Model (16)	1.234	−9.325	−5.327	-	0.007	0.007	−0.752	0.887	0.031
Model (17)	135.2	145.8	268.4	311.4	0.004	0.002	−1.325	0.957	0.027
(H_d/H) and (S/S_o)									
Model (18)	3.245	0.237	-	-	0.008	0.008	−0.523	0.892	0.034
Model (19)	0.632	−1.895	25.314	-	−0.005	0.004	−1.358	0.865	0.026
Model (20)	−0.249	2.347	5.326	265.8	0.003	0.005	−0.498	0.948	0.019
(H_d/H_o) and (S/S_o)									
Model (21)	0.468	0.689	-	-	0.005	0.007	−1.114	0.965	0.027
Model (22)	−2.378	−1.369	−3.648	-	0.009	0.005	−1.356	0.907	0.023
Model (23)	−0.189	2.378	4.359	198.6	−0.006	0.003	−0.687	0.897	0.018

The relationship between measured and calculated values of H_d by using different models for selected locations during the period time in the present research are show in Figures 1-3. From these figures, we indicate that the behavior of the measured values of the diffuse solar energy and the calculated values, which obtained from models 15 to 23 for all selected sites in the present study are nature shape with the path of the diffuse solar energy in the day. On the other meaning from these figures, the maximum values occur around in summer months, while the minimum occur in winter months for all location in the present research. The differences between measured values of diffuse solar energy and estimated by different models varies from 1.5% to 3.4% for all sites in this study. Generally, the results of these figures and the latter results which confirmed graphically for each month for all locations under present research. Therefore, the obtained results are show in Figures 1-3 for sites in this study. From the results of Figures 1-3, it is concluding that the second and third order correlations between H_d/H and K_t do not significantly improve the accuracy of estimation of diffuse radiation see in Figure 1. On the other hand, a second order correlation between H_d/H or H_d/H_0 and S/S_o gives the desired accuracy of estimation of diffuse radiation for all considered locations see in Figure 2 and Figure 3 and the values of regression coefficients in Tables 2-4. The percentage error for a single month rarely exceeds ±7% for any of the locations in the present research. Furthermore, Models (15), (19) and (22) with the aid of the values of the regression constants given in Tables 2-4 are recommended for estimating the horizontal monthly average diffuse radiation at selected locations in the present study. The results in this research are similar results in the previous study [24] [35].

The empirical models correlations in the form of Equations (15), (19) and (22) for all Saudi Arabia are developed. They may then be used for estimating H_d for

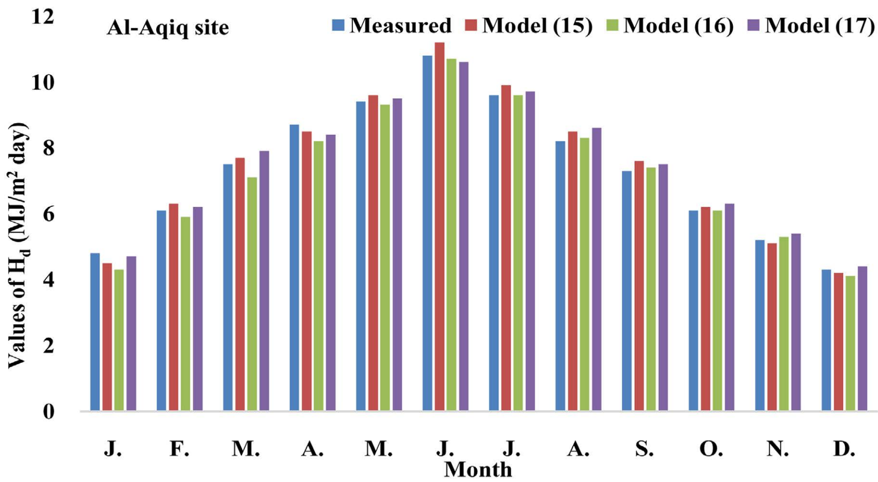

Figure 1. The relationship between measured and calculated values of H_d by using different models at Al-Aqiq site in the present research.

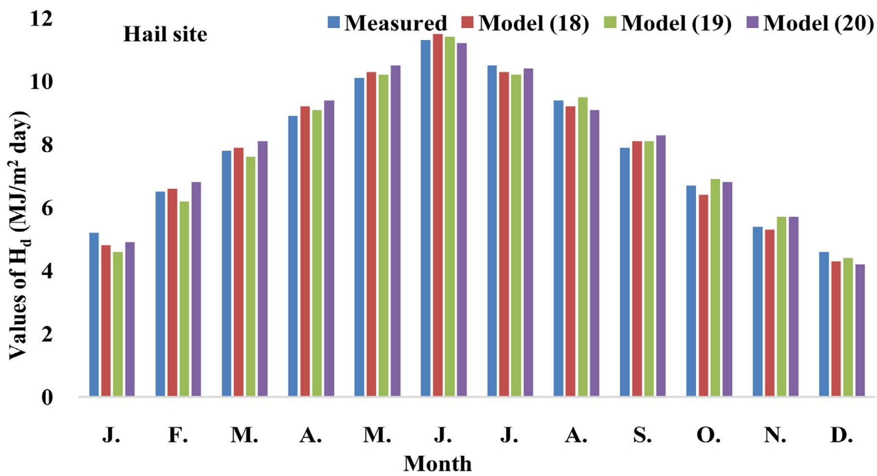

Figure 2. The relationship between measured and calculated values of H_d by using different models at Hail site in the present research.

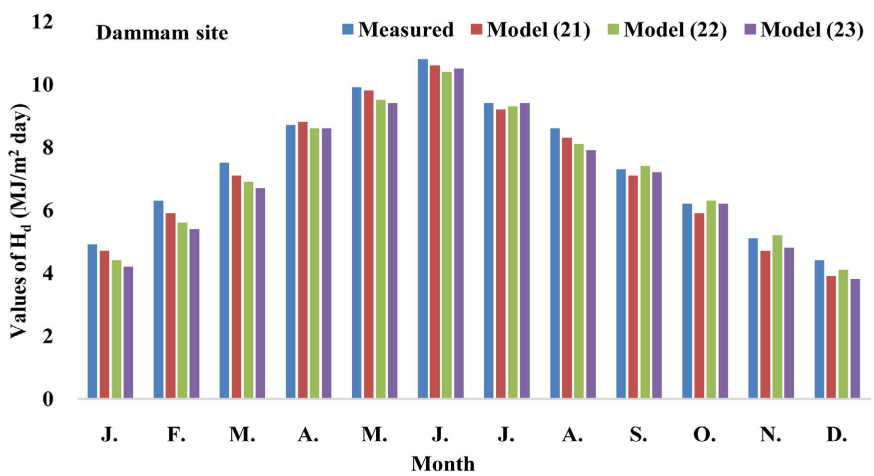

Figure 3. The relationship between measured and calculated values of H_d by using different models at Dammam site in the present research.

any location of Saudi Arabia. For this purpose, the measured data available from the selected sited in the present research are combined and analyzed (3 × 12 = 36 sets of values). Figure 4 and Figure 5 provide the variations of H_d/H with K_t and S/S_o, respectively. Figure 6 shows the variations of H_d/H_0 and S/S_o using the data collected for the three selected locations in the present research. A linear correlation between H_d/H and K_t found to fit the measured data see in Figure 4. Furthermore, second order correlations between H_d/H and S/S_o see in Figure 5, and H_d/H_0 and S/S_o are remarkable in Figure 6.

The following correlations have been obtained for all Saudi Arabia:

Model A:

$$H_d/H = 2.245 - 1.859K_t, \quad R^2 = 0.82 \tag{27}$$

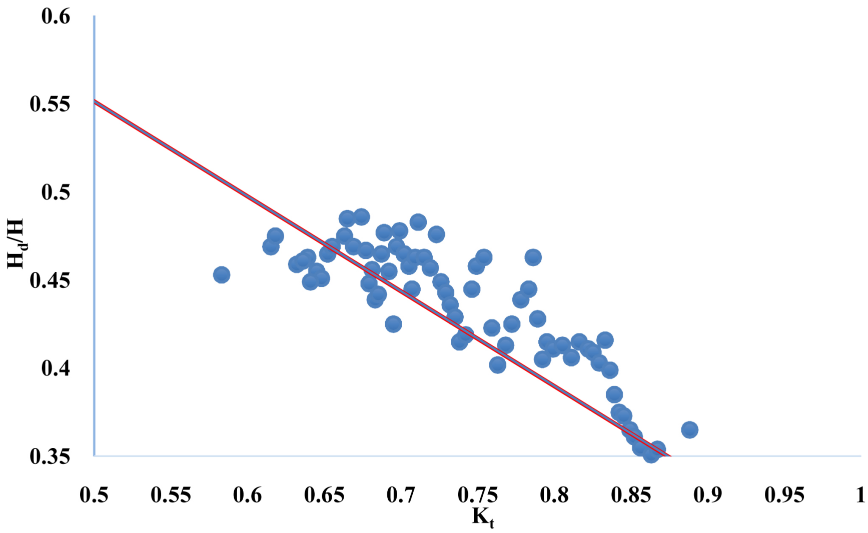

Figure 4. The correlation of the diffuse fraction with the clearness index in the present research.

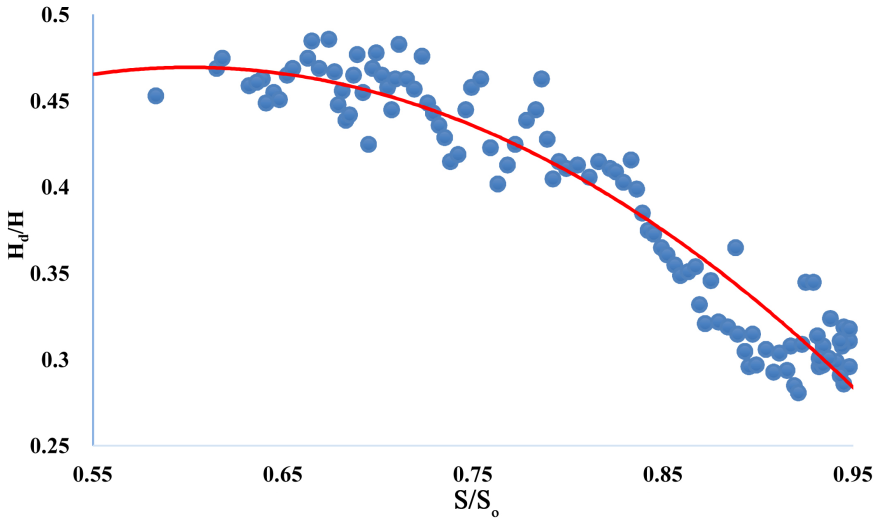

Figure 5. The correlation of the diffuse fraction with the sunshine hours in the present study.

Model B:

$$H_d/H = -0.468 + 3.657(S/S_o) - 2.324(S/S_o)^2, \quad R^2 = 0.89 \tag{28}$$

Model C:

$$H_d/H_o = -0.168 + 2.341(S/S_o) - 0.759(S/S_o)^2, \quad R^2 = 0.86 \tag{29}$$

The models from (27) to (29) are then employed for calculating the diffuse solar energy H_d for the selected locations in the present research. Figures from (7) to (9) present comparisons between the measured and calculated diffuse solar energy H_d for Al-Aqiq, Hail and Dammam locations respectively. From the results of Figures 7-10, it is obvious that there is a good agreement between the

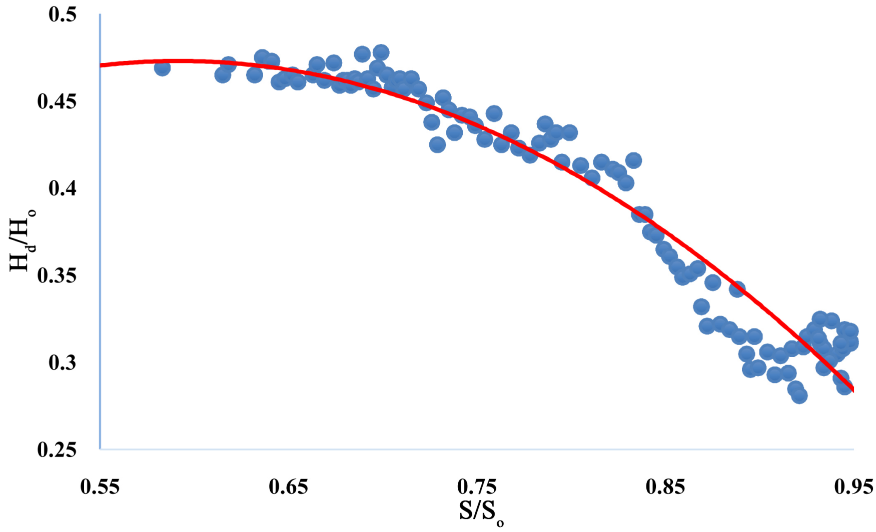

Figure 6. The correlation of the diffuse transmittance with the sunshine hours in the present research.

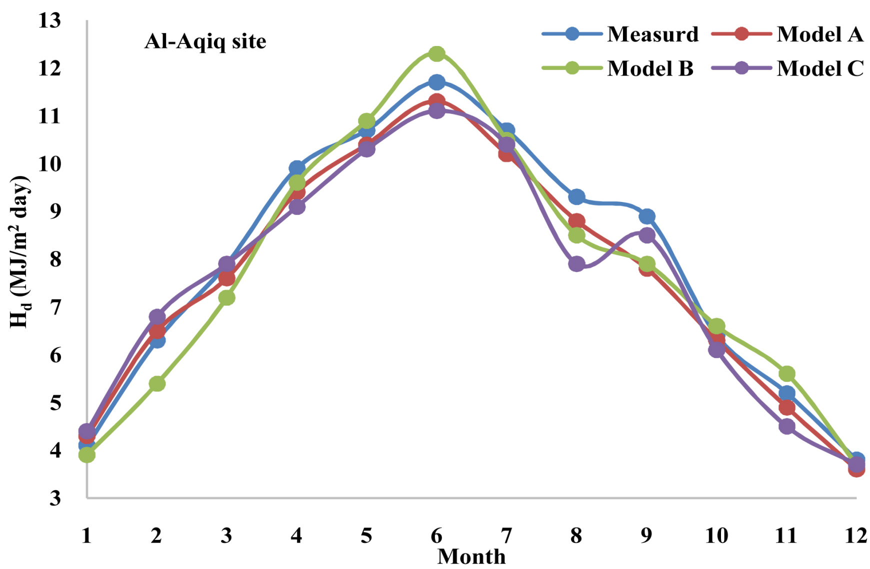

Figure 7. The difference between measured and calculated values of H_d at Al-Aqiq site in

the present study.

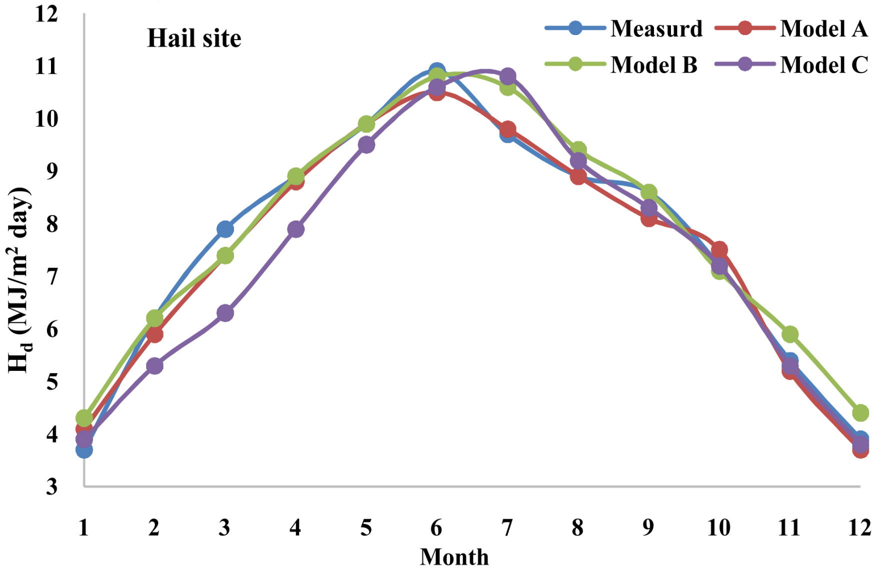

Figure 8. The difference between measured and calculated values of H_d at Hail site in the present study.

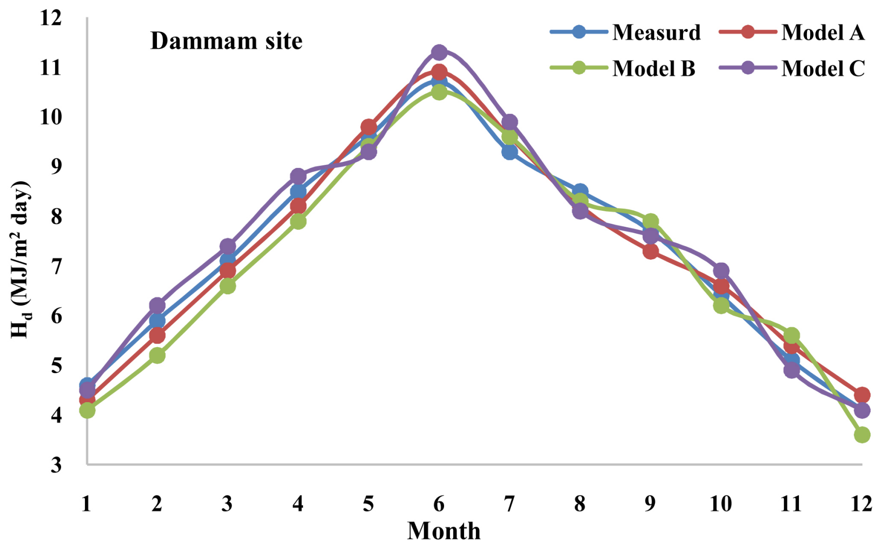

Figure 9. The difference between measured and calculated values of H_d at Dammam site in the present study.

measured and calculated data of H_d. The best estimate is obtained for Hail site see in **Figure 8** and Hail site see in **Figure 9**, where the maximum percentage error is found to be ±9%. The maximum percentage errors are ±12% for Al-Aqiq site see in **Figure 7**. Therefore, comparisons between the measured and calculated annual averages of H_d indicated that the all Saudi Arabia correlations (Models A, B and C) could be used for estimating the annual averages of H_d with excellent accuracy. The results in this research are similar results in the previous study [24] [35]. The average annual differences between measured and calculated values of diffuse solar energy H_d on horizontal at selected sites in the present research are summarizes in Figure 10, the results obtained are a good

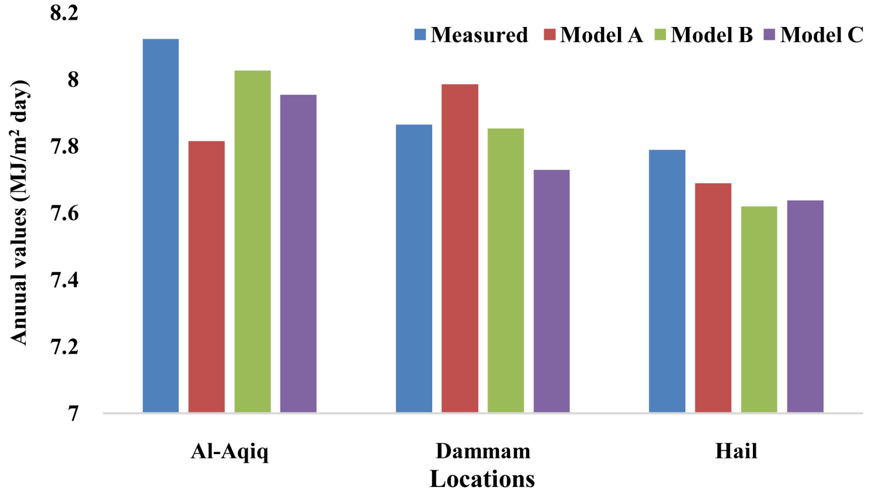

Figure 10. The average annual differences between measured and calculated values of diffuse solar energy on horizontal at selected sites in the present research.

agreement is clear.

4. Conclusion

The available measured data of global solar energy and diffuse solar energy for the three selected locations in Saudi Arabia during the period time from 1980 to 2019 are used to develop the model empirical correlations as a function of sunshine duration (S/S_o) and clearness index (K_t) for predicted horizontal diffuse radiation energy at these sites. The values of regression constants a, b, c and d for all models are different values according to geographical information of site to another one during the period time in the present research, with the stander error estimate (S.E.). The correlation coefficients are higher than 0.86 for all models except for a few models. Models (17), (20) and (23) are given the higher values of correlation coefficients 0.935, 0.962 and 0.974 in Al-Aqiq site respectively, while Models (16), (20) and (21) are given 0.957, 0.936 and 0.942 in Hail site respectively, also Models (17), (20) and (21) are given 0.957, 948 and 965 in Dammam site respectively. For statistical indicators, the values of MBE for all models are given some negative and other positive, this is due to the correlations are overestimated and underestimated values of diffuse fraction H_d. The low values of the RMSE for all correlations indicate good agreement between the measured and calculated values of H_d. The negative values of MPE for all models show that for all locations, the proposed correlations slightly overestimate H_d. The absolute values of MPE never reach 1.35%. This means that very good agreement between the measured and calculated data and a good fitting exists between the monthly average daily values of the diffuse fraction (H_d/H) and (K_t) or (S/S_o) and between the diffuse transmittance (H_d/H_0) and (S/S_o) for all selected locations in the present research. The first order of correlation modeling between the diffuse solar fraction and the clearness index has been proposed. In addition, the second order of correlations modeling between the diffuse solar fraction or the diffuse transmittance and the maximum possible number of sunshine hours are found to fit the measured data. The comparisons between the measured and calculated annual averages of H_d indicated that all Saudi Arabia correlations (Models A, B and C) could be used for estimating the annual averages of H_d with excellent accuracy. The average annual differences between measured and calculated values of diffuse solar energy H_d on horizontal at selected sites in the present research are summarized. All Saudi Arabia modeling correlations (Models A, B and C) can be used for predicting of diffuse solar energy H_d during the period time in the present research at the present locations as well as at any Saudi Arabia site with a reasonable accuracy. Therefore, the proposed modeling correlations can be used to accurately for estimating the annual averages of horizontal diffuse solar energy, which helps in predicted of the long-term performance of the various solar energy devices.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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