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A Comprehensive Study of Solar Energy Components by Using Various Models on Horizontal and Inclined Surfaces for Different Climate Zones

Samy A. Khalil

Solar and Space Department, National Research Institute of Astronomy and Geophysics (NRIAG), Cairo, Egypt
Email: samynki@yahoo.com

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Abstract

The main objective of this research is to analyze the monthly average daily of global (*H*), beams (*B*) and diffuses (*D*) solar irradiance on a horizontal surface at four selected sites (El-Kharga, Hurghada in Egypt and Dammam, Hail in Saudi Arabia) during the period time from 1980 to 2020. The empirical models between (H/H_o) and meteorological parameters along with the values of (MBE), (RMSE), MPE, R^2 and the t-Test statics are discussed. The results in this study indicate good agreement between observed and calculated values of total solar energy and diffuse solar fraction. The results for south facing surfaces of the (RMSE) for different slope at different models in the present research are discussions. Nine different models between isotropic and anisotropic used to estimate the diffuse solar radiation on a tilted surface at selected sites in this study. The absolute relative values of RMSE for the south-facing surface ranges from 7 to 41.3 at El-Kharga and Hurghada sites, Egypt in the present study for Koronakis and Stevenand Unsworth (SU) models respectively. The values of (RMSE), for the south-facing surface ranges from 9.3 to 39.7 at Dammam and Hail sites, Saudi Arabia in the present research for Koronakis and Klucher models respectively. For west-facing surface the values of RMSE range from 11.2 to 47.3 for Badescu and Koronakis models at El-Kharga and Hurghada sites, Egypt respectively, while values of RMSE range from 6.5 to 38.5 for Klucher and Reindl *et al.* models at Dammam and Hail sites, Saudi Arabia. The models Koronakis, Klucher and Stevenand Unsworth (SU) models are given the most accurate estimate for the south-facing surface, and Badescu, Koronakis, Klucher and Reindl *et al.* models are good performs better estimated for the west-facing surface.

Keywords

Linear Regression, Root Mean Square, Solar Radiation, Mean Bias Error, Modeling, Isotropic Models, Anisotropic Models, Inclined Surface

1. Introduction

The sun controlled irradiance episode on an even surface could have direct support point and diffuse sun-situated energy. The made daylight based energy models used assessments of sun situated energy values, which portrays the mathematical relations between the sun controlled energy and the meteorological variables like temperature, sogginess and light extent. These models used to measure the bar and diffuse sun-controlled energy by using the metrological data open at any area. Sun controlled energy of light utilization at any site is dependent upon the idea of the sun-arranged movement. Obviously, the daylight put together change impinging with respect to any inconsistent surface through the monthly and diurnal assortments [1].

Sun based light is measure at various regions all around the planet. Unfortunately, these regions are generally moved in made countries, and are meager inside the causing situation, daylight based light data are pivotal commitments for sun controlled energy applications, for instance, photovoltaic, sun arranged warm structures, and isolates daylight based plan. Trial endorsements of sun-situated models are consequently a key and pressing activity to give conviction to producers and modelers that their specific estimations emulate truth [2] [3] [4] [5] [6]. The sun-situated radiation that shows up at the outside air is subject to ingestion, reflection and transmission processes through the air-preceding showing up at the world's surface. Sun based radiation data are a fundamental commitment for sun fueled energy application like photovoltaic, sun situated warm system and disengaged sun-controlled plan. The data should be reliable and instantly helpful for plan, smoothing out and execution distinction of sun situated applied sciences for a specific site and sun fueled radiation is exceptionally fundamental for the most strong sketch of sun based energy change units [7] [8] [9].

In the beyond thirty years, numerous exact models have used to assess sun powered radiation using accessible meteorological [10] [11] [12] [13], geological and climatological boundaries. Among these boundaries, daylight span [14] [15], air temperature [16], scope and longitude [17], precipitation [18], relative mugginess [16] [19] and [20], wind speed and shadiness [21]-[26] utilized. The most in many cases involved boundary for assessing sun-powered radiation is daylight hours. In this regard, the changed model of Angstrom condition, among in excess of a couple of connections, has widely used to gauge the all sun based light on flat surface [27]-[35].

In a huge part of the sun situated strength applications, willing surfaces at express angels widely used. The sun irradiance on a level floor has assessed in lots of meteorological stations round the area. There are different styles to expect to survey daylight on willing surface from contrasting level real factors. This anticipates, in sweeping, the store of express information on the degree of diffuse and facilitate even irradiance. Different diffuse piece models kept in [36]-[43]. These models ordinarily imparted to the extent that polynomial capacities bearing on the diffuse piece to the clearness record. A willing surface daylight based enlightenment structure made by means of Olmo *et al.* [44] requires best the even floor sun fueled light, with inescapability and sun based zenith focuses as enter limits.

Various daylight based energy models have presented in the composing using mathematical straight [45]-[53] and nonlinear abilities [54]-[60], fake mind network [61]-[71] and comfortable reasoning [72] [73] [74]. A huge viewpoint in showing daylight based energy is the accuracy of the made model, which evaluated using verifiable botches like the mean by mean absolute percentage error (MAPE), mean biase error (MBE) and root mean square error (RMSE). A first rate MBE cost exhibits how much confusion inside the expected general daylight based strength as well as the opposite way around. By and by, RMSE gives information on the quick stretch of time largely execution of the variation and is a level of the type of the normal characteristics across the purposeful data. RMSE similarly proposes the show of the made version in anticipating future individual characteristics. A huge fine RMSE proposes a colossal deviation in the ordinary expense from the conscious worth [71].

The isotropic plans rely upon that the significance of diffuse sky radiation is uniform over the sky curve. Subsequently, the diffuse radiation episode on a moved surface relies on an immaterial part of the sky vault seen through it. The anisotropic models then again, expect that the anisotropy of the diffuse sky radiation inside the circumsolar area (sky near the sun circle) notwithstanding the isotropically allotted diffuse perspective from the rest of the sky curve (horizon illuminating division) [75] [76] [77] [78] [79]. In preferred, the straightforward piece of radiation on willing surfaces made from isotropic, circum sun and horizon illuminating variables.

The aim of this work is comprehensive of solar energy components on horizontal and different slope surfaces for different climate zones (El-Kharga and Hurghada in Egypt and Dammam and Hail in Saudi Arabia). Moreover, evaluation of statistical indicators consequences to assessment fashions of solar energy on horizontal and inclined floor inside the decided on web sites by way of the usage of empirical models to estimate the solar radiation on horizontal and inclined surfaces.

2. Instrumentations and Climate sites

The global, direct and diffuse solar radiation incident on a horizontal surface at four selected locations in the present work, two sites in Egypt (El-Kharga and Hurghada sites) and another two in KSA (Dammam and Hail sites) are clear that in **Table 1**.

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

Sites	Latitude	Longitude	Elevation	The period of data	Country
El-Kharga	25˚45'	30˚55'	32 m	1980-2020	Egypt
Hurghada	27˚15'	33˚48'	14 m	1980-2020	
Dammam	26˚23'	49˚53'	10 m	1980-2020	Saudi Arabia
Hail	27˚52'	41˚69'	992 m	1980-2020	

The radiation information for Egyptian and Saudi Arabia areas of the relating periods acquired from the Egyptian Meteorological Authority (EMA) and Environmental Protection Device (EPD) separately. The records units utilized incorporate infer hourly and everyday upsides of world and diffuse sunlight on a flat airplane. Generally speaking sun radiation became estimated the utilization of Eppley unnecessary accuracy pyranometer aware of 300 - 3000 nm, while some other accuracy pyranometers outfitted with a unique concealing gadget, SBS form, became used to degree diffuse light. The shadow bandstand built of anodized aluminum, weighs roughly 24 lb and utilizations a 300 band of roughly 2500 measurement to hue the pyranometer. Since the shadow band shows the sensor from a part of the episode diffuse radiation rolling in from the sky, a remedy made to the estimations following Batlles *et al.* [3] [80] [81] [82] [83] [84]. Absolute sunlight based radiation information recorded by the Eppley Precision Spectral Pyranometer (PSP) at all stations. The precision of these pyranometers compares to the top of the line as indicated by the World Meteorological Organization order [85]. These instruments adjusted consistently towards a reference gadget recognizable to the world Radiometric Reference (WRR) kept up with at Davos, Switzerland [86] [87]. With regards to the alignment authentications of the producers, responsiveness is roughly 9 $\mu V/W \cdot m^{-2}$, temperature reliance is ±1% over surrounding temperature range −20˚C to +49˚C, linearity is ±0.5% from 2800 $W \cdot m^{-2}$, and cosine is ±1% from standardization 0 - 700 pinnacle point of view and ±3% for 70 - 800 peak demeanor. The outright exactness of alignment is ±3% - 4%.

There are relatively few mannerisms there of psyche of Egypt that could affect credits of the moan association, which we will approach here. Cloud characteristics and air temperature trade from one season to some other as follows: In frigid weather patterns is the hour of cloud sorts, conventionally dim to the quick shaft and immaterial temperature, further to low turbidity of the air. In spring is suggest through the segment of close to nothing and shallow warm depressions, impelling Khamasin climate. Vertical deceivability is disintegrate methodically with extending soil content in the lower layers. After the passage of these distresses, fogs shape and level deceivability are, lessen an immense sum inside the environment. In summer, extreme temperature, high straightforwardness and murky fogs make progress, in spite of their life; the sky is 'smudged' constraint of the time, in light of significant layer of best in class dust particles associated with central area tropical air. The buildup content falls particularly while Mediterranean flying demonstrations up, associated with amazing climate cumulus. In pre-winter, the climate is direct on typical. Morning hazes and low fogs wreck after daybreak [3] [50].

Saudi Arabia is depict with a wild environment, notwithstanding the south-western piece of the country, which shows a semi-dried environment. Summers inside the gigantic district are remarkably rankling and dry, starting from 27˚C to 43˚C in the inland regions and 27˚C to 38˚C in shoreline locale. In winter, the temperature ranges among 8˚C to 20˚C inside within parts while better temperatures (19˚C - 29˚C) had been report inside the ocean front areas of red Ocean [88].

3. Basic of Solar Energy

3.1. Solar Radiation on Horizontal Surface (H_o)

The extraterrestrial solar radiation (H_o) on the horizontal surface is calculating by the following equation [3] [89]:

$$H_{oh} = (24/\pi) * I_{sc} * E_o * \left[\cos\varphi \cos\delta \sin\omega + (\pi\omega/180)\sin\varphi \sin\delta\right] \quad (1)$$

where E_o is the correction factor of the Earth's orbit and ω is the sunrise/sunset hour angle given by:

$$E_o = 1 + 0.033\cos(360N/365), \quad (2)$$

$$\omega = \cos^{-1}(-\tan\varphi \tan\delta) \quad (3)$$

where I_{sc} is the solar constant equal 1367 W/m^2, N is the day of the year, (φ) is latitude angle and the solar declination angle of the sun (δ). Figure 1 represents the declination and the hour angle of the sun. Which given in degrees according to Spencer [90] as:

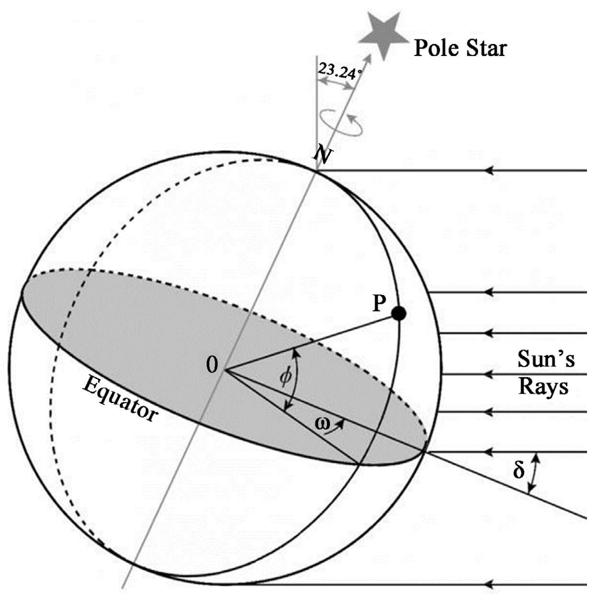

Figure 1. Fundamental sun angles; declination (δ) and hour angle (ω).

$$\delta = 23.34\sin\left[360/365\right]\left(284 + N\right) \quad (4)$$

3.2. Components of Solar Energy

The components of solar energy: beam and diffuse radiation shown in **Figure 2**. The solar radiation received from the Sun without having been scattered by the atmosphere is called beam solar energy, and received from the Sun after its direction have been changed by scattering by the atmosphere is called diffuse solar energy [91] [92] [93].

The total solar radiation is the sum of the beam (B) and diffuse solar (D) radiation on a surface (Equation (5)). The most common measurements of solar radiation are total radiation on a horizontal surface, often referred to as global radiation on the surface.

$$G = B + D \quad (5)$$

Additionally, reflected radiation (albedo) is also describe. It accounts for the sunlight that has been reflect off non-atmospheric objects such as the ground.

4. Models of Solar Radiation on Horizontal Surface

The solar energy models developed in the past based on linear and nonlinear models [94]. These models give a correlation between solar energy on a horizontal surface and some meteorological variables parameters. A commonly used linear model for this purpose that defines the total solar energy in terms of the extraterrestrial solar energy given [95] [96] [97] as follows:

$$H = \left[A + B\left(S/S_o\right)\right]H_o \quad (6)$$

$$H = \left[A + B\left(S/S_o\right) + C\left(S/S_o\right)^2\right]H_o \quad (7)$$

$$H = \left[A + B\left(S/S_o\right) + CT\right]H_o \quad (8)$$

$$H = \left[A + B\left(S/S_o\right) + CR_h\right]H_o \quad (9)$$

$$H = \left[A + BT + CR_h\right]H_o \quad (10)$$

$$H = \left[A + B\left(T_{\max} - T_{\min}\right) + cc_w\right]H_o \quad (11)$$

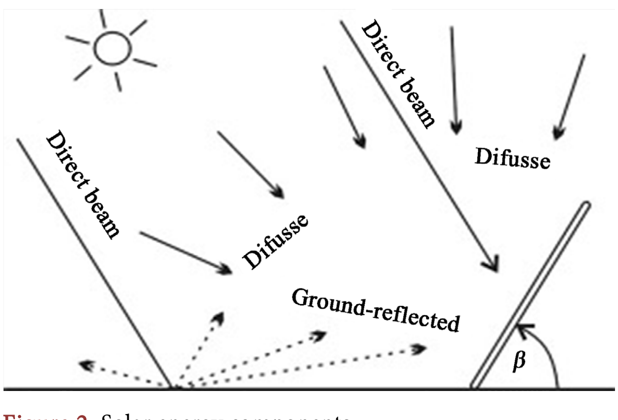

Figure 2. Solar energy components.

$$H = \left[A + B\left(T_{\max} - T_{\min}\right)^{0.5} + cc_w \right] H_o \quad (12)$$

$$H = \left[A + B\left(S/S_o\right) + cc_w \right] H_o \quad (13)$$

$$H = \left[A + B\left(S/S_o\right)^c \right] H_o \quad (14)$$

where A, B and C are empirical constant coefficients and S_o is the maximum possible monthly average daily sunshine duration or the day length.

5. Calculating the Beam and Diffuse Solar Radiation on Horizontal Surface

The average hourly daily diffuse radiation incident on a horizontal surface, the diffuse fraction (H_d/H) and diffuse transmittance (H_d/H_o) were correlated to first, second and third order correlations of the clearness index (K_t) and the relative number of sunshine hours (S/S_o) [3] [57]. It is found that the second and third order correlations do not improve the accuracy of estimation of (H_d). Therefore, the following correlations have obtained for Cairo:

$$H_d/H = 5.817 - 6.517K_t, \quad R^2 = 0.972 \quad (15)$$

$$H_d/H = 8.342 - 6.455\left(S/S_0\right), \quad R^2 = 0.958 \quad (16)$$

$$H_d/H_o = 3.815 - 5.319\left(S/S_0\right), \quad R^2 = 0.932 \quad (17)$$

$$H_d/H_o = 4.912 - 6.894K_t, \quad R^2 = 0.985 \quad (18)$$

$$H_d/H = 6.314 - 5.131K_t + 0.136\left(S/S_0\right), \quad R^2 = 0.982 \quad (19)$$

$$H_d/H_0 = 5.292 - 4.226K_t - 0.321\left(S/S_0\right), \quad R^2 = 0.991 \quad (20)$$

Equations from (15) to (20) were used to calculate (H_d) and the obtained results were compared with the measured values of (H_d). The accuracy of estimating (H_d) was checked by calculating the MBE, RMSE, MPE, R^2 and the t-Test.

6. Models of Solar Energy on Inclined Surface

The total solar irradiation on a horizontal surface has measured in many meteorological stations around the world. There are some of fashions to be had to estimate solar irradiation on an inclined surface from the radiation on a horizontal surface. A slope surface solar energy model developed by using Olmo *et al.* [3] [10] and [44] requires best the horizontal surface sun irradiation with prevalence and sun zenith angles as enter parameters.

The Olmo *et al.* [3] [44] version turned into advanced to estimate the sun radiation on inclined surfaces the usage of the data accrued on horizontal surfaces. In the case of no ground reflections, the Olmo *et al.* model estimates the global irradiance (H_β) on an inclined surface from the corresponding solar radiation (H) on a horizontal surface by the following equation:

$$H_\beta/H = \Psi_o \quad (21)$$

where (β), is the surface inclination angle and (Ψ_o) is a function that converts the horizontal solar radiation to that incident on a tilted surface and given as:

$$\Psi_o = \exp\left[-K_t\left(\theta^2 - \theta_z^2\right)\right] \quad (22)$$

where (θ) and (θ_z) in radians, are the incidence and solar zenith angles, respectively, and K_t is the hourly clearness index. Further, Olmo *et al.* [44] proposed a multiplying factor (F_c) to take into account anisotropic reflections and it given as:

$$F_c - 1 = \rho \sin^2\left(\theta/2\right) \quad (23)$$

where (ρ) is the albedo of the underlying surface, this is the most commonly used expression for the radiation reflected from the ground. In this work, a constant value for the albedo used equal to 0.2. The Olmo *et al.* model for determining the global solar radiation on an inclined surface from that on a horizontal surface is then:

$$H_\beta / H = \Psi_o F_c \quad (24)$$

The hourly total solar irradiance incident on a tilted surface (H_{Th}) can divided into three components; the beam component from direct irradiation of the tilted surface (B_{Td}) and the ground reflected (R_{Th}) and sky-diffuse (H_{Th}) components:

$$H_{Th} - B_{Td} = +H_{Th} + R_{Th} \quad (25)$$

The isotropic model can used to compute the reflected component on the tilted surface. So, Equation (25) can written again as follows:

$$H_{Th} = B_h \cos(\theta)/\cos(Z) + R_d D_h + H_h \rho\left[1-\cos(S)\right]/2 \quad (26)$$

where B_h, D_h and H_h are hourly direct, diffuse and total solar radiation on a horizontal surface, either measured directly or estimated from each other. R_d is the ratio of the hourly diffuse irradiation incident on a tilted surface to that on a horizontal surface.

The monthly average daily total radiation on a tilted surface (H_T) normally estimated by individually considering the direct beam (H_B), diffuse (H_D) and reflected components (H_R) of the radiation on a tilted surface. Thus for a surface tilted at a slope angle from the horizontal, the relation gives the incident total radiation:

$$H_T = H_B + H_D + H_R \quad (27)$$

Several models have been proposed by various authors [3] [6] [30]-[35] [98] to calculate solar radiation on tilted surfaces from the available data on a horizontal surface. The daily beam radiation received on an inclined surface can expressed as:

$$H_B / R_b = H_g - H_d \quad (28)$$

where H_g and H_d are the monthly mean daily global and diffuse radiation on a horizontal surface, and R_b is the ratio of the average daily beam radiation on a tilted surface to that on a horizontal surface. The daily ground reflected radiation could written as:

$$H_R/H_g = \rho\frac{1-\cos\beta}{2} \tag{29}$$

where (β) is the tilt angle of the solar panel, Liu and Jordan [6] [99] have suggested that (R_b) can be estimated by assuming that it has the value which would be obtained if there were no atmosphere. For surfaces in the northern hemisphere, sloped towards the equator, the equation for (R_b) given as:

$$R_b = \frac{\cos(\varphi-\beta)\cos\delta\sin\omega_{ss} + \omega_{ss}\sin(\varphi-\beta)\sin\delta}{\cos\varphi\cos\delta\sin\omega_{ss} + \omega_{ss}\sin\varphi\sin\delta} \tag{30}$$

where (ω_{ss}) is the sunset hour angle for tilted surface for the mean day of the month. For surfaces in the southern hemisphere, sloped towards the equator, the equation for R_b given as follow:

$$R_b = \frac{\cos(\varphi+\beta)\cos\delta\sin\omega_{ss} + \omega_{ss}\sin(\varphi+\beta)\sin\delta}{\cos\varphi\cos\delta\sin\omega_{ss} + \omega_{ss}\sin\varphi\sin\delta} \tag{31}$$

Then, the total solar radiation on a tilted surface can expressed as follow:

$$H_T = (H_g - H_d)R_b + H_g\rho\frac{1-\cos\beta}{2} + H_d R_d \tag{32}$$

where, ρ is the constant which depend on the type of ground surrounding tilted surface and is called the ground reflectance, values are assumed 0.2, according to Equation (32) for hot and humid tropical location, ρ is equal 0.5 for dry tropical sites and equal 0.9 for snow covered ground.

7. Diffuse Solar Energy Models on Inclined Surface

The models used to estimate the ratio of diffuse solar radiation on a tilted surface to that of a horizontal labeled as isotropic and anisotropic models. The method for the hourly sky diffuse sun radiation incident on an willing plane is given by product of the hourly diffuse sun radiation incident on a horizontal floor and the configuration factor from the surface to the sky, (1 + cosβ)/2. For surface tilted by an angle (β) from the horizontal plane, the total solar irradiance can written as following:

$$H_{d,T}/H_{d,H} = \frac{1-\cos\beta}{2} \tag{33}$$

The isotropic model given by Badescu model (Ba) [100] as follow:

$$R_d = \frac{3+\cos(3\beta)}{4} \tag{34}$$

The relation gives Tian *et al.* model (Ti) [101]:

$$R_d = 1-\beta/180 \tag{35}$$

Koronakis model (Kr) [102] given as follow:

$$R_d = 1/3\left[2+\cos(\beta)\right] \tag{36}$$

Liu and Jordan (LJ) [99] given as follow:

$$R_d = \frac{1+\cos\beta}{2} \tag{37}$$

In addition to isotropic diffuse and circumsolar radiation, the Reindl Model also accounts for horizon brightening and employs the same definition of the anisotropic model. The relation gives Reindl *et al.* model (Re) [103]:

$$R_d = \left(H_b/H_o\right)R_b + \left[1-\left(H_b/H_o\right)\frac{1+\cos\beta}{2}\right]\left[1+\left(H_b/H_g\right)^{1/2}\sin^3\left(\beta/2\right)\right] \tag{38}$$

Skartveit and Olseth model (SO) [104] given as follow:

$$R_d = \left(H_b/H_o\right)R_b + \Omega\cos\beta + \left[1-\left(H_b/H_o\right)-\Omega\right]\frac{1+\cos\beta}{2} \tag{39}$$

where

$$\Omega = \max\left[0,\left(0.3-2H_b/H_o\right)\right]. \tag{40}$$

Steven and Unswoth model (SU) [105] given by as follow:

$$R_d = 0.51R_b + \frac{1+\cos\beta}{2} - \left(1.74/1.26\pi\right)\left[\sin\beta - \beta\left(\pi/180\right)\cos\beta - \pi\sin^2\left(\beta/2\right)\right] \tag{41}$$

The relation gives Hay model (Ha) [106]:

$$R_d = \left(H_b/H_o\right)R_b + \left[1-\left(H_b/H_o\right)\right]\frac{1+\cos\beta}{2} \tag{42}$$

Klucher model, 1979 (Kl) [107], this model is based on a study of clear sky conditions by Temps and Coulson, 1977 [108]. Klucher's formulation of the hourly sky diffuse solar radiation incident on an inclined surface is:

$$H_{d,T} = H_{d,g}\left\{\frac{1+\cos\beta}{2}\left[1+F_1\sin^3\left(\beta/2\right)\right]\left[1+F_1\cos^2\theta_z\sin^3\theta_z\right]\right\} \tag{43}$$

where F_1 is the modulating function given by: $F_1 = (H_{d,g}/H_g)^2$, when the skies are completely overcast, $F = 0$, Klucher's model reverts to the isotropic model.

Perez model (Perez *et al.*, 1986; P8, and Perez *et al.*, 1990; P9) [109] [110] is more computationally intensive and represent a more detailed analysis of the isotropic diffuse, circumsolar and horizon brightening radiation by using empirically derived coefficients. The total irradiance on tilted surface given by the following equation:

$$H_T = H_{h,b}R_b + H_{h,d}\left[\left(1-F_1\right)\frac{1+\cos\beta}{2} + F_1\frac{a}{b} + F_2\sin\beta\right] + H_h\rho\frac{1-\cos\beta}{2} \tag{44}$$

Here, F_1 and F_2 are circumsolar and horizon brightness coefficients, respectively, and (a) and (b) are terms that take the incidence angle of the sun on the considered slope into account. The terms (F_1), (F_2), (a) and (b) computed using the following equations:

$$F_1 = \max\left[0,\left(f_{11} + f_{12}\Delta + \frac{\pi\theta_z}{180}f_{13}\right)\right] \;\&\; F_2 = f_{21} + f_{22}\Delta + \frac{\pi\theta_z}{180}f_{23} \tag{45}$$

$$a = \max\left(0^\circ,\cos\theta\right) \;\&\; b = \max\left(\cos 85,\cos\theta_z\right) \tag{46}$$

The coefficients f_{11}, f_{12}, f_{13}, f_{21}, f_{22}, and f_{23} derived based on a statistical analysis of empirical data for specific locations. Two different sets of coefficients derived for this model [109] [110].

8. Evaluation of Models by Using Statistical Methods

In the present study, estimated global solar radiation data and tilted global solar radiation at different selected sites in the present research climatic conditions compared with the data measured by Egypt and Saudi Arabia meteorological department. The performance and comparison of the individual models was determined by utilizing statistical methods. The accuracy and performance of the derived correlations in predicting of global solar radiation evaluated because of the following statistical error tests; mean bias error (MBE), root mean square error (RMSE), mean percentage error (MPE), maximum absolute relative error (MARE), mean absolute error (MAE), root mean square relative error (RMSRE), coefficient of determination (R^2) and t-Test statistic. These statistical error indices defined as [3] [10]:

$$\text{MBE} = \frac{1}{n}\sum_{i=1}^{n}\left(H_{i,m} - H_{i,c}\right) \tag{47}$$

$$\text{RMSR} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(H_{i,m} - H_{i,c}\right)^2} \tag{48}$$

$$\text{MPE} = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{H_{i,m} - H_{i,c}}{H_{i,m}}\right)\times 100 \tag{49}$$

$$\text{MARE} = \max\left(\left|\frac{H_{i,m} - H_{i,c}}{H_{i,m}}\right|\right) \tag{50}$$

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}\left|H_{i,m} - H_{i,c}\right| \tag{51}$$

$$\text{RMSRE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\left(H_{i,m} - H_{i,c}\right)/H_{i,m}\right]^2} \tag{52}$$

$$\text{R}^2 = 1 - \left[\sum_{i=1}^{n}\left(H_{i,m} - H_{i,c}\right)^2 \Big/ \sum_{i=1}^{n}\left(H_{i,m} - H_{m.\,avg}\right)\right]\times 100 \tag{53}$$

$$\text{t-Test} = \frac{\sqrt{(n-1)\text{MBE}^2}}{\sqrt{\text{RMSE}^2} - \sqrt{\text{MBE}^2}} \tag{54}$$

9. Results and Discussion

The monthly average daily of total solar radiation (H), beams (B) and diffuses (D) solar radiation on a horizontal surface at four selected sites in the present work during the period time from 1980 to 2020 shows in **Figure 3**. From this figure, we notice that, the highest values of solar radiation components are lies in summer months, while the lowest values indicate in winter months, but the values of solar radiation components in spring and autumn months are lies between highest and lowest values at all selected sites in the present work. Generally, the beam component is more dominant than diffuse component and winter

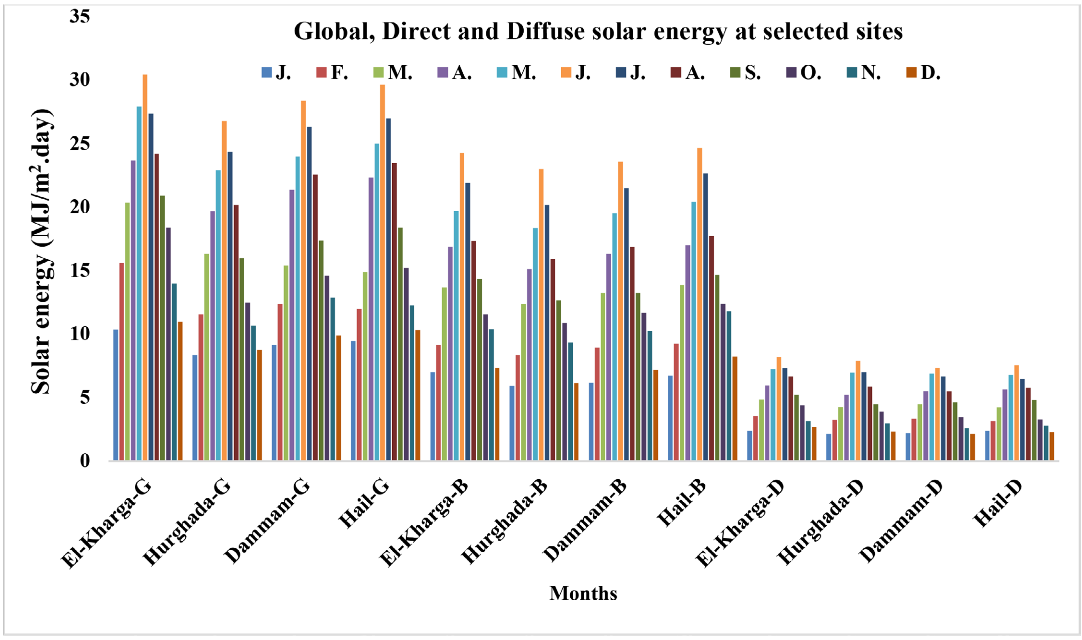

Figure 3. Monthly average daily of global (G), direct (B) and diffuse (D) solar radiation on horizontal surface in selected sites in the present work.

months, the beam radiation represents nearly vary from 62% to 71% of total radiation, while diffuse radiation represents nearly vary from 23% to 34% of total radiation at all selected locations in the present research. In addition, it is clear that the solar irradiance measurements strongly affected by cloud. Surface measurements of the diffuse component of the solar irradiance are particularly sensitive to cloud amount. The clouds divided into (1) a cloudless day, and (2) an overcast morning and an afternoon with broken clouds. In many cloud days, the conditions varied throughout the day from overcast in the morning, with cloud gradually breaking up throughout the afternoon to the early evening when the clouds cleared completely. These results are in good an agreement with other work given by [6].

The estimation of total solar radiation on horizontal surface by using empirical correlations from Equations (6) to (14) are proposed for all selected sites in the present work using the meteorological data during the period time (1980-2020). From the analysis of the measured and calculated values of (H), the regression equations between (H/H_o) and meteorological variables along with the values of the results of statistical indicators at the different climate zone in the present work (MBE), (RMSE), MPE, R^2 and the t-Test statics are clear in **Tables 2-5**. From these tables, we indicate that, the values of correlation coefficients (R^2) are higher than 0.96 and the values of the RMSE varies the range from 1.98 - 5.89, at all selected locations in the present research. This indicating good agreement between measured and estimated values of total solar radiation (H). In addition, from **Table 2** it clear that, the negative values of the MPE show that, Equations ((7)-(10), (13) and (15)) slightly overestimate the values of the total solar radiation (H), but Equations ((11), (12) and (14)) slightly underestimate of the global solar radiation (H) at El-Kharga site, Egypt. While the negative values of the MPE show that, Equations ((7)-(10), (13)-(15)) slightly overestimate the values of the total solar radiation (H), but Equations (11) and (14) slightly underestimate of the global solar radiation (H) at Hurghada site, Egypt is show in Table 3. The sites in Saudi Arabia shown in Table 4 & Table 5. From these tables we indicate that, the negative values of the MPE show that, Equations ((7), (8), (11)-(13) and (15)) slightly overestimate the values of the total solar radiation (H), but Equations ((9), (10) and (14)) slightly underestimate of the global solar radiation (H) at Dammam site, Saudi Arabia. The negative values of the MPE show that, Equations ((7), (8), (11)-(13)) slightly overestimate the values of the total solar radiation (H), but Equations ((9), (10), (14) and (15)) slightly underestimate of

Table 2. The values of regression constants and statistical indicators at El-Kharga site in the present work by using different models.

No. of Model	Regression coefficients			MBE	RMSE	MPE%	R^2	t-Test
	A	*B*	*C*					
Equation (7)	0.445	0.389	–	−2.65	5.17	4.86	0.968	4.11
Equation (8)	0.511	0.357	0.532	−3.89	4.25	3.54	0.974	3.24
Equation (9)	0.377	0.521	0.611	−3.74	4.98	−2.57	0.986	3.45
Equation (10)	0.412	0.456	0.547	−1.65	3.67	1.68	0.993	2.34
Equation (11)	0.256	0.624	0.465	1.35	3.16	3.45	0.994	3.74
Equation (12)	0.348	0.542	0.389	4.32	5.54	−2.89	0.967	5.32
Equation (13)	0.542	0.375	0.438	−3.58	5.89	−3.45	0.957	6.32
Equation (14)	0.287	0.587	0.547	2.65	3.11	5.27	0.974	4.75
Equation (15)	0.435	0.472	0.657	−3.27	4.35	6.37	0.958	3.89

Table 3. The values of regression constants and statistical indicators at Hurghada site in the present work by using different models.

No. of Model	Regression coefficients			MBE	RMSE	MPE%	R^2	t-Test
	A	*B*	*C*					
Equation (7)	0.385	0.489	–	−3.65	4.35	3.47	0.974	3.58
Equation (8)	0.425	−0.391	0.475	−4.32	3.56	2.58	0.968	4.21
Equation (9)	0.478	0.438	0.578	−2.98	4.32	−2.13	0.974	4.32
Equation (10)	0.536	0.358	0.478	−2.54	2.65	2.68	0.985	3.25
Equation (11)	0.368	0.489	0.623	2.35	4.77	4.32	0.983	3.78
Equation (12)	0.456	0.389	0.457	−3.78	3.87	−3.78	0.957	4.32
Equation (13)	0.478	0.412	0.527	−2.87	4.25	−4.28	0.967	5.32
Equation (14)	0.389	−0.475	0.389	1.35	2.98	4.35	0.981	3.24
Equation (15)	0.547	0.368	0.537	−2.89	3.45	5.29	0.964	5.27

Table 4. The values of regression constants and statistical indicators at Dammam site in the present work by using different models.

No. of Model	Regression coefficients			MBE	RMSE	MPE%	R^2	t-Test
	A	*B*	*C*					
Equation (7)	0.258	0.655	–	−3.36	2.98	3.21	0.962	3.25
Equation (8)	0.369	0.295	0.356	−5.24	4.11	2.89	0.958	3.65
Equation (9)	0.325	0.524	0.425	3.56	3.65	1.89	0.981	2.47
Equation (10)	0.478	0.411	0.395	4.23	3.92	3.78	0.952	4.32
Equation (11)	0.452	0.389	0.524	−3.85	2.57	2.58	0.991	2.21
Equation (12)	0.524	0.256	0.358	−2.85	3.21	4.25	0.974	3.65
Equation (13)	0.385	0.489	0.411	−3.47	2.56	−3.78	0.959	4.25
Equation (14)	0.289	−0.532	0.368	2.54	1.98	5.34	0.978	3.27
Equation (15)	0.411	−0.467	0.489	−4.21	3.71	4.75	0.968	4.77

Table 5. The values of regression constants and statistical indicators at Hail site in the present work by using different models.

No. of Model	Regression coefficients			MBE	RMSE	MPE%	R^2	t-Test
	A	*B*	*C*					
Equation (7)	0.338	0.524	–	−3.58	3.54	4.25	0.974	2.68
Equation (8)	0.456	0.384	0.258	−4.32	2.68	2.25	0.965	3.14
Equation (9)	0.427	0.457	0.341	2.35	4.32	3.25	0.984	3.24
Equation (10)	0.524	0.365	0.415	3.45	3.24	3.45	0.975	4.75
Equation (11)	0.568	0.321	0.478	−3.28	3.41	4.31	0.968	2.85
Equation (12)	0.478	0.357	0.328	−2.57	4.21	5.32	0.985	1.89
Equation (13)	0.432	0.425	0.468	−3.14	3.65	−2.89	0.964	3.25
Equation (14)	0.353	0.511	0.387	4.25	2.45	4.37	0.982	2.45
Equation (15)	0.387	0.487	0.521	3.87	3.42	3.78	0.974	3.28

the global solar radiation (H) at Hail site, Saudi Arabia. In all cases, the absolute values of the MPE never reach 1.65%, indicating very good agreement between the monthly average of daily total solar radiation and the other meteorological parameters. Also from Tables 2-5, it is see that, the values of (t-Test) changes from model to another model according to models from Equations (6)-(14). Thus, the model, which gives the smallest values of the t-Test, then it considered as the best model for estimating the total solar radiation at all selected sites with an acceptable error. This means that the models of Equations ((10)-(12) and (14)) are good estimate for the total solar radiation in selected locations El-Kharga, Hurghada, Dammam and Hail respectively during the period time in the present work.

Table 6, show that, the differences between the measured ($H_{d,m}$) and estimated ($H_{d,c}$) values of the diffuse solar radiation at al selected sites in the present research along with the values of mean base error (MBE), root mean square error (RMSE), mean percentage error (MPE), and t-Test statics. From this table, it is clear that, the low values of the (RMSE) for all models indicate a good agreement between measured and estimated values of diffuse solar radiation (H_d) at selected locations. The (MPE) values imply that the proposed correlations slightly overestimate (H_d) at all websites inside the present work. For all models, the absolute values of the (MPE) giving suggest excellent agreement between measured and calculated values of the diffuse solar fraction (H_d/H) or the diffuse solar transmittance (H_d/H_o) and clearness index K_t, relative wide variety of light hours (S/S_o) and the mixture of them.

Also from **Table 6**, the t-Test of the models in Equations (17) and (20) given the smallest values, and then it is considered as the best models for estimating the diffuse solar radiation at selected sites in Saudi Arabia and Egyptian sites respectively with an acceptable error.

The analysis of statistical indicator results of the relative ability of the Olmo *et al.* model to determine the solar global irradiation on the inclined surface are presented in **Table 7**. The Olmo *et al.* [3] [10] [44], model was applied to the database corresponding to the horizontal solar total irradiation to determine values for a south facing surface, tilted at latitude angle for all sky conditions.

Table 6. Comparison between measured ($H_{d,m}$) and calculated ($H_{d,c}$) values (MJ/m²·day) with the metrological variable selected locations in the present research.

El-Kharga							Hurghada						
No. of model	$G_{d,m}$	$G_{d,c}$	MBE	RMSE	MPE%	t-Test	No. of model	$G_{d,m}$	$G_{d,c}$	MBE	RMSE	MPE%	t-Test
Equation (16)	28.29	28.75	−2.15	2.89	−1.25	2.24	Equation (16)	27.68	27.84	2.78	2.12	−2.78	3.12
Equation (17)	29.42	29.12	3.47	1.54	1.15	1.27	Equation (17)	28.45	28.77	−3.27	1.86	1.68	1.63
Equation (18)	28.71	29.55	3.12	3.24	1.38	1.84	Equation (18)	28.12	28.63	4.35	2.67	3.45	2.56
Equation (19)	28.62	28.86	2.63	2.78	1.89	2.31	Equation (19)	27.34	27.14	2.89	3.14	−2.78	1.78
Equation (20)	29.15	29.74	−2.24	1.85	2.35	1.62	Equation (20)	28.65	28.24	−2.78	2.68	2.78	1.92
Equation (21)	29.54	30.21	−1.89	2.28	−2.15	1.69	Equation (21)	28.17	27.97	−1.23	1.47	1.83	2.52
Dammam							Hail						
No. of model	$G_{d,m}$	$G_{d,c}$	MBE	RMSE	MPE%	t−Test	No. of model	$G_{d,m}$	$G_{d,c}$	MBE	RMSE	MPE%	t−Test
Equation (16)	29.65	29.15	−2.86	2.34	−1.67	2.78	Equation (16)	28.75	29.11	−2.25	2.87	−1.97	2.35
Equation (17)	29.89	29.32	3.11	1.89	2.85	2.21	Equation (17)	29.14	29.65	3.67	2.31	2.25	2.81
Equation (18)	30.21	29.74	3.68	3.56	1.91	1.65	Equation (18)	29.85	29.33	3.14	3.85	1.63	1.92
Equation (19)	29.14	28.98	2.14	2.16	1.42	2.78	Equation (19)	29.54	28.18	2.78	2.39	1.87	2.25
Equation (20)	29.68	29.16	−2.87	1.38	1.34	1.38	Equation (20)	29.15	29.58	−2.23	1.82	1.49	1.74
Equation (21)	29.11	29.45	−1.25	2.47	−2.69	1.84	Equation (21)	29.73	29.34	−1.82	2.68	−2.27	2.14

Table 7. The analysis of statistical indicator for Olmo *et al.*, at the selected sites in the present study.

El-Kharga						Hurghada					
Month	MBE	RMSE	MPE%	R^2	t-Test	Month	MBE	RMSE	MPE%	R^2	t-Test
J.	15.32	22.35	7.32	0.957	5.36	J.	13.24	17.68	6.58	0.958	4.32
F.	19.32	25.47	8.56	0.963	6.32	F.	15.85	21.34	9.45	0.978	7.65
M.	11.45	28.56	9.31	0.987	4.32	M.	16.84	23.75	8.56	0.969	5.31
A.	11.27	18.32	6.54	0.974	3.45	A.	8.65	15.98	7.35	0.957	4.89
M.	−8.79	15.47	7.34	0.962	3.21	M.	6.58	14.32	6.25	0.972	5.64
J.	7.38	28.32	5.48	0.982	2.95	J.	−5.32	19.74	7.21	0.959	3.65
J.	9.34	16.32	4.32	0.992	2.24	J.	7.32	15.86	4.69	0.975	3.89
A.	5.24	11.27	2.35	0.985	2.95	A.	6.57	13.24	3.45	0.963	2.15
S.	6.47	15.47	8.32	0.973	3.48	S.	4.35	9.35	6.89	0.954	1.89
O.	12.35	17.36	9.65	0.968	4.68	O.	8.36	14.25	5.78	0.948	3.65
N.	15.78	24.35	7.65	0.957	3.56	N.	9.57	16.38	4.32	0.957	2.45
D.	18.25	26.59	9.37	0.949	5.64	D.	11.28	19.57	8.32	0.966	3.78
Dammam						Hail					
Month	MBE	RMSE	MPE%	R^2	t-Test	Month	MBE	RMSE	MPE%	R^2	t-Test
J.	17.35	21.32	6.32	0.976	6.89	J.	−9.26	18.36	5.21	0.952	5.32
F.	20.65	23.54	9.56	0.982	5.21	F.	15.32	22.34	8.32	0.969	4.38
M.	15.47	25.78	7.25	0.991	3.21	M.	11.32	24.21	6.47	0.975	2.36
A.	13.65	21.32	5.32	0.954	4.26	A.	−15.32	19.65	7.69	0.964	3.48
M.	−7.25	17.32	6.78	0.962	5.28	M.	8.32	15.41	5.24	0.951	4.24
J.	−9.65	19.32	8.32	0.958	4.69	J.	13.45	18.32	4.32	0.969	4.83
J.	11.32	17.32	6.18	0.969	3.65	J.	7.35	14.28	4.98	0.987	2.68
A.	8.32	14.89	4.32	0.957	3.21	A.	6.45	11.82	3.26	0.973	5.36
S.	14.35	18.32	4.36	0.948	5.24	S.	9.34	9.32	5.32	0.962	6.47
O.	15.72	19.65	5.68	0.963	3.62	O.	11.47	14.75	6.89	0.951	4.28
N.	12.68	22.78	4.12	0.969	4.22	N.	14.59	17.39	8.45	0.978	2.31
D.	16.35	23.24	7.29	0.972	6.58	D.	10.45	19.84	6.18	0.956	5.11

The hourly daily solar irradiation data used in this study and the statistical coefficients have computed because of the experimental data. It is evident from Table 7, it is clear that, the mean percentage error (MPE %) is in the range of varies from 2.35% to 9.45% and from 3.26 to 9.56 at the selected sites in Egypt and Saudi Arabia respectively in the present work. The values of root mean square error (RMSE) varies from 11.27 to 28.56 in Egypt sites. However, varies from 11.82 to 25.78 in Saudi Arabia sites. Also from this table, we notice that all values of (MBE and RMSE) in all months are nearest them it, with exception summer months at all selected sites in the present research. The model provides a good estimation tool for the other months. In general, considering the statistics as a whole, the total solar irradiation data estimated by Olmo *et al.* model are in good agreement with the measured values at all selected locations in the present work. Therefore, Olmo *et al.* model recommended estimating the total solar radiation on an inclined surface in this research, due to its accuracy, input requirements and simplicity.

The monthly mean daily values of the mean bias error, (MBE %) for global solar irradiation received on inclined surface at different slope during the period time 1980-2020 at selected sites in the present work are clear in **Figures 4-8**. From these figures, it is clear that, fifth solar irradiance models are considered in this work; Koronakis, Badescu, Reindle *et al.*, Hay and Davies and Tian *et al.* models. For each model, the measured values of diffuse solar radiation and horizontal values of total solar radiation used to calculate the solar radiation on surface tilted at different slope varies from 15˚ to 90˚ above the horizon at all selected sites in the present research. The results compared with the solar irradiances monitored and presented in terms of usual statistics; the mean base error (MBE) and the root mean square error (RMSE). Also from these figures, it is seen that, the values of MBE varies from −2.58 to −8.63, −3.25 to −8.29, −3.39 to −9.17, −3.15 to −7.86 and −2.75 to −8.11 for; Koronakis, Badescu, Reindle *et al.*, Hay and Davies and Tian *et al.* models respectively for all selected locations in

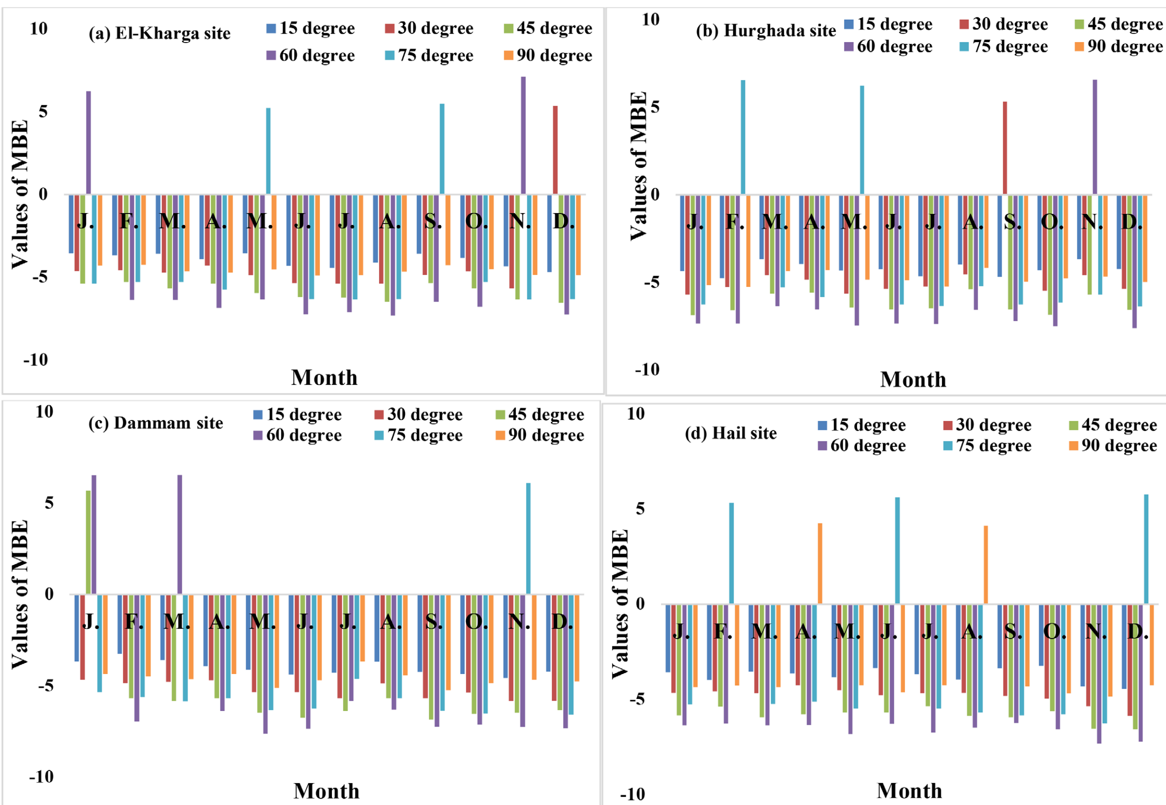

Figure 4. Monthly mean daily values of mean bias error (MBE %) for solar energy received on inclined surface by using Koronakis model at different slope at selected sites in the present work.

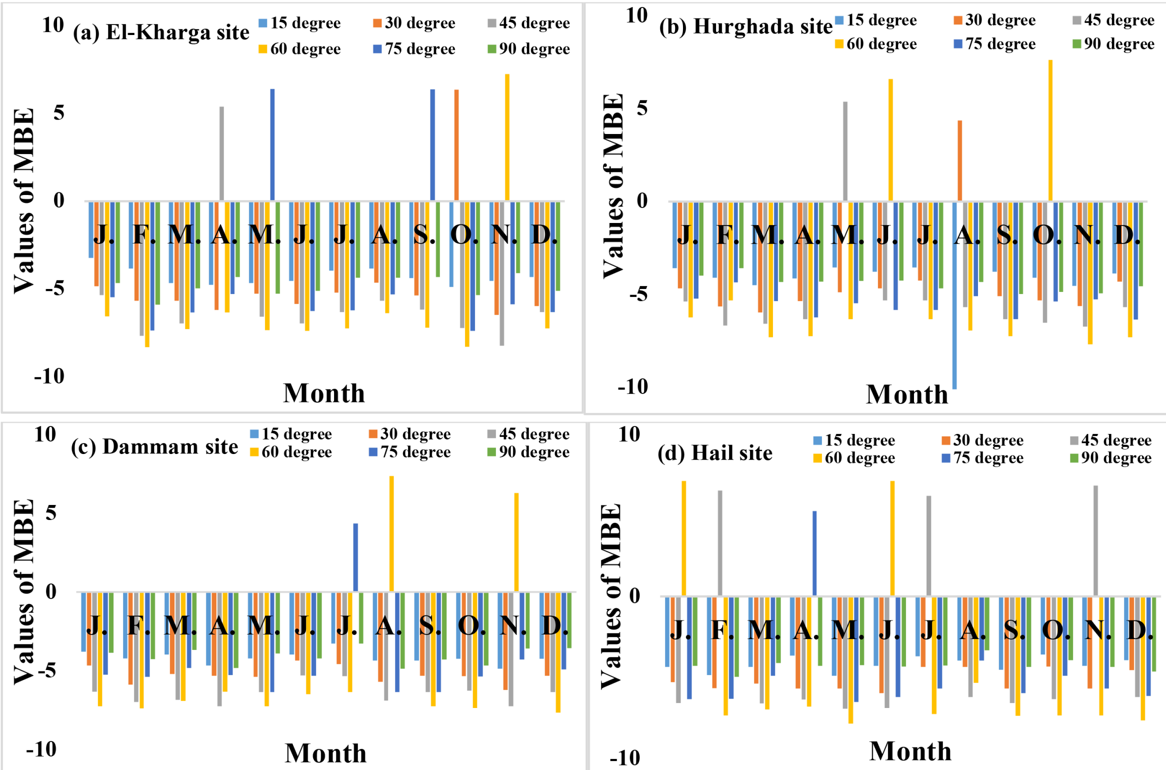

Figure 5. Monthly mean daily values of mean bias error (MBE %) for solar energy received on inclined surface for Badescu model at different slope at selected sites in the present work.

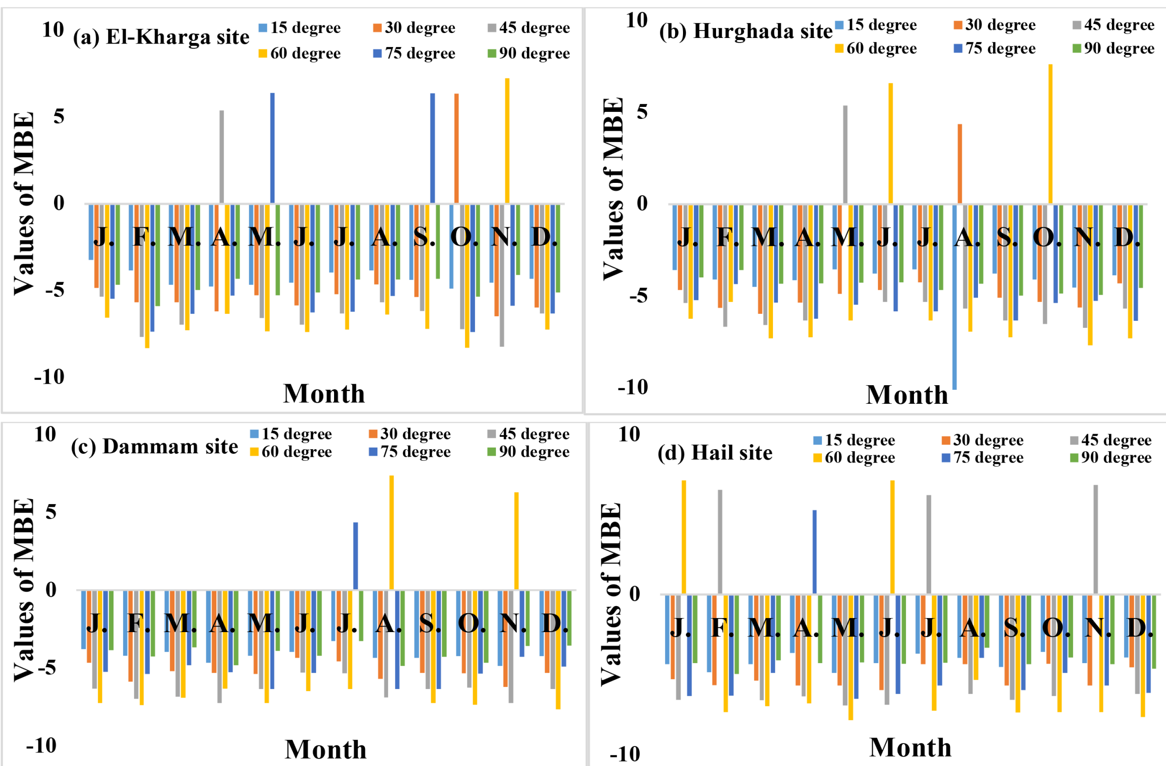

Figure 6. Monthly mean daily values of mean bias error (MBE %) for solar energy received on inclined surface for Reindle *et al.* model at different slope at selected sites in the present work.

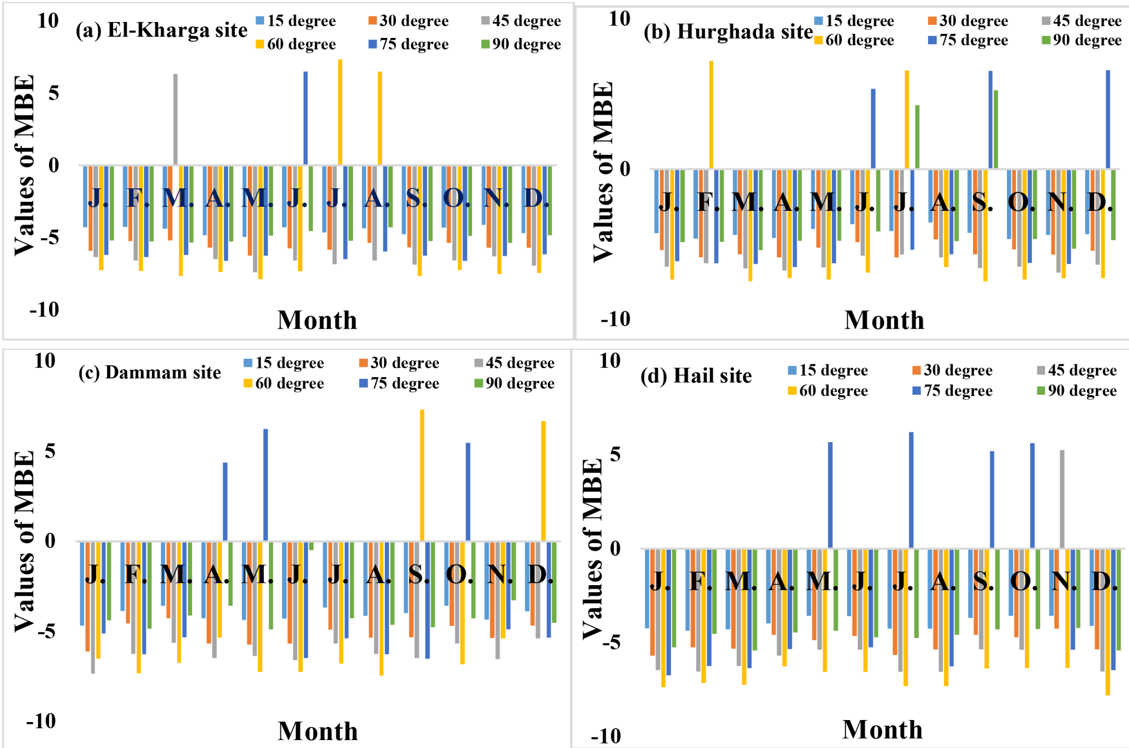

Figure 7. Monthly mean daily values of mean bias error (MBE %) for solar energy received on inclined surface for Hay and Davies model at different slope at selected sites in the present work.

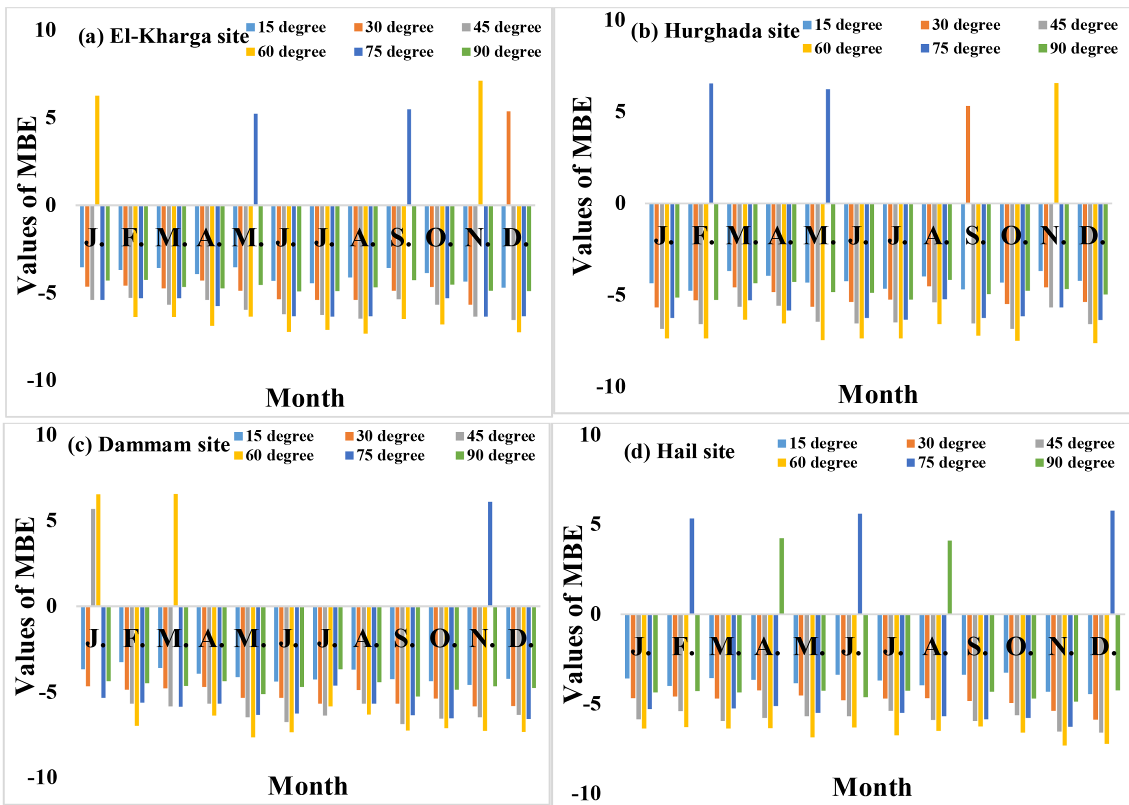

Figure 8. Monthly mean daily values of mean bias error (MBE %) for solar energy received on inclined surface for Tian *et al.* model at different slope at selected sites in the present work.

the present study. The values of MBE results show that, the all models are substantially under predicts the irradiance incident on an inclined surface, and with exception for some slope considerably over predicts irradiance incident on an inclined surface on an overall basis.

Tables 8-11, shows the results for south facing surfaces of the root mean

Table 8. Monthly mean daily values of the root mean square error (RMSE %) for solar energy received on inclined surface at different slope at El-Kharga site in the present work.

Model	Slope	J.	F.	M.	A.	M	J.	J.	A.	S.	O.	N.	D.
Koronakis Model	15˚	11	9	8	9	5	7	3	5	9	11	6	8
	30˚	12.5	13	10	8	6	9	8	6	8.5	10	9	6.5
	45˚	14	11	8	6.5	9	11	6	8	9.5	8	7.5	8
	60˚	9	8	6.5	7	11	7.5	7.5	5	6	9.5	11	4.5
	75˚	10	9	9	12	7.5	8.5	10	7	7	7	8	7
	90˚	7	11	7	13	4.5	6.5	4.5	4	11	8.5	9	10
Badescu Model	15˚	5	10	4.5	8.5	8.5	8.5	8	9	12	6.5	7.5	9
	30˚	9	6	8	9	10	9	9.5	3	4.5	9.5	8.5	12
	45˚	11	6	9	3.5	11	10	11	5.5	8.5	7	6	8
	60˚	13	12	6.5	6	7.5	7	10	8.5	6	4.5	7	7
	75˚	7	6	9	8	9.6	9.5	7.5	4.5	9	6	9	6.5
	90˚	8	13.5	7.5	9	5.5	6.5	8.5	7	8.5	8.5	7.5	8
Reindle *et al.* Model	15˚	5.5	6	11	7	8	8	6	6	7	6	7	9
	30˚	7	8	6.5	8.5	7	9	9	8	12	5.5	9	11
	45˚	9	5.5	9	11	9.5	10	11	9.5	6.5	4.5	11	6.5
	60˚	11	8	4.5	10.5	6.5	7	8.5	7	9	8.5	7.5	8
	75˚	8.5	9	7	6.8	8	6.5	7	6.5	8.5	6.	8.5	9
	90˚	7	7.5	9	9	7.5	5	9	4.5	7	7	9	7.5
Hay and Davies Model	15˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11.8
	30˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	17.2
	45˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	60˚	9	6	8	9	10	9	9.5	3	4.5	9.5	8.5	12
	75˚	11	6	9	3.5	11	10	11	5.5	8.5	7	6	8
	90˚	13	12	6.5	6	7.5	7	10	8.5	6	4.5	7	7
Tian *et al.* Models	15˚	7	6	9	8	9.6	9.5	7.5	4.5	9	6	9	6.5
	30˚	8	13.5	7.5	9	5.5	6.5	8.5	7	8.5	8.5	7.5	8
	45˚	5.5	6	11	7	8	8	6	6	7	6	7	9
	60˚	7	8	6.5	8.5	7	9	9	8	12	5.5	9	11
	75˚	9	5.5	9	11	9.5	10	11	9.5	6.5	4.5	11	6.5
	90˚	7.5	6	9	8.5	7	7.5	9	8	6.5	9	8	7.5

Table 9. Monthly mean daily values of the root mean square error (RMSE %) for solar energy received on inclined surface at different slope at Hurghada site in the present work.

Model	Slope	J.	F.	M.	A.	M	J.	J.	A.	S.	O.	N.	D.
Koronakis Model	15˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8
	30˚	11.5	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	7.5
	45˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	8.5
	60˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	75˚	13	16	11	12	7	9	7	10.6	10	12.6	10.4	13.5
	90˚	16	19	13	9	11.5	10.4	8.7	12	13	15.2	12	12.2
Badescu Model	15˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8
	30˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	6.5
	45˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	7.5
	60˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	75˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	10
	90˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	17.2
Reindle *et al.* Model	15˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	30˚	13	16	11	12	7	9	7	10.6	10	12.6	10.4	11
	45˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	8.5
	60˚	9.5	8	12	5	6	4.3	5	6.2	4.3	7.5	10	7.5
	75˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	90˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	6.5
Hay and Davies Model	15˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	11
	30˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	12
	45˚	13	16	11	12	7	9	7	10.6	10	12.6	10.4	13.5
	60˚	16	19	13	9	11.5	10.4	8.7	12	13	15.2	12	9.5
	75˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11
	90˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	8.5
Tian *et al.* Models	15˚	8.5	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	10
	30˚	13	16	11	12	7	9	7	10.6	10	12.6	10.4	11
	45˚	7.5	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	9.5
	60˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	8
	75˚	6.5	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	7.5
	90˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	9

Table 10. Monthly mean daily values of the root mean square error (RMSE %) for solar energy received on inclined surface at different slope at Dammam site in the present work.

Model	Slope	J.	F.	M.	A.	M	J.	J.	A.	S.	O.	N.	D.
Koronakis Model	15˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	30˚	13	16	11	12	7	9	7	10.6	10	12.6	10.4	13.5
	45˚	16	19	13	9	11.5	10.4	8.7	12	13	15.2	12	12.2
	60˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8
	75˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11.8
	90˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	17.2
Badescu Model	15˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	30˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8
	45˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11.8
	60˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	17.2
	75˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	90˚	13	16	11	12	7	9	7	10.6	10	12.6	10.4	13.5
Reindle *et al.* Model	15˚	16	19	13	9	11.5	10.4	8.7	12	13	15.2	12	12.2
	30˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8
	45˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11.8
	60˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	17.2
	75˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	90˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8
Hay and Davies Model	15˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11.8
	30˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11.8
	45˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	17.2
	60˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	75˚	13	16	11	12	7	9	7	10.6	10	12.6	10.4	13.5
	90˚	16	19	13	9	11.5	10.4	8.7	12	13	15.2	12	12.2
Tian *et al.* Models	15˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8
	30˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11.8
	45˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	17.2
	60˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	75˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8
	90˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11.8

Table 11. Monthly mean daily values of the root mean square error (RMSE %) for solar energy received on inclined surface at different slope at Hail site in the present work.

Model	Slope	J.	F.	M.	A.	M	J.	J.	A.	S.	O.	N.	D.
Koronakis Model	15˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	17.2
	30˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	45˚	13	16	11	12	7	9	7	10.6	10	12.6	10.4	13.5
	60˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	17.2
	75˚	11	19	13	9	11.5	10.4	8.7	12	13	15.2	12	12.2
	90˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8
Badescu Model	15˚	16	19	13	9	11.5	10.4	8.7	12	13	15.2	12	12.2
	30˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8
	45˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11.8
	60˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	17.2
	75˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	90˚	13	16	11	12	7	9	7	10.6	10	12.6	10.4	13.5
Reindle *et al.* Model	15˚	16	19	13	9	11.5	10.4	8.7	12	13	15.2	12	12.2
	30˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8
	45˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11.8
	60˚	16	19	13	9	11.5	10.4	8.7	12	13	15.2	12	12.2
	75˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11.8
	90˚	16	19	13	9	11.5	10.4	8.7	12	13	15.2	12	12.2
Hay and Davies Model	15˚	13	16	11	12	7	9	7	10.6	10	12.6	10.4	13.5
	30˚	16	19	13	9	11.5	10.4	8.7	12	13	15.2	12	12.2
	45˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8
	60˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11.8
	75˚	16	19	13	9	11.5	10.4	8.7	12	13	15.2	12	12.2
	90˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8
Tian *et al.* Models	15˚	11	15	9	8	6.5	3.7	2.3	3.3	6	9	8.4	11.8
	30˚	9	8	12	5	6	4.3	5	6.2	4.3	7.5	10	17.2
	45˚	8	14	8.5	9	9	6	3.7	7.8	6.4	6.7	7.8	14
	60˚	13	16	11	12	7	9	7	10.6	10	12.6	10.4	13.5
	75˚	16	19	13	9	11.5	10.4	8.7	12	13	15.2	12	12.2
	90˚	9	12	7	6	4	5	3.4	4.2	4.8	5.3	5.2	6.8

square error (RMSE) for different slope at different models in the present work. From these tables, we conclude that, the RMSE values for the most fifth models increases as the slop of the collector increase, but remain in a domain of error for which these relations can applied with good accuracy. Inspecting the results, it is apparent that the models agree quit well with each other during the summer months. They deviate from each other in the winter months, when the effect of the difference in the diffuse solar radiation parameterization is at its maximum. The RMSE results indicate that the anisotropic models show similar performance on an overall basis, but isotropic model exhibit much larger error. In general, we confirm that, the observation of the Reindle, Hay and Davie models describe the irradiance on inclined plane more accurately than anther models. These results in the present work are good agreement with other work that found in [3] [107].

The models used to estimate the diffuse solar radiation on a tilted surface are broadly classified as isotropic and anisotropic sky models. Several isotropic and anisotropic models are available in literature. For this work, total nine models chosen. Out of nine, four isotropic models namely: Koronakis 1986 (Kr) [91], Badescu 2002 (Ba) [89], Tian *et al.* 2001 (Ti) [90], and Liu and Jordan 1962 (LJ) [86]. In addition, five anisotropic models namely, Skartveit and Olseth 1986 (SO) [94], Reindl *et al.* 1990 (Re) [93], Klucher 1979 (Kl) [96], Hay 1979 (Ha) [84] and Stevenand Unsworth 1980 (SU) [95] model were investigated. For more information about models and mathematical relationships between these models and the comparison of regression constants. Mean bias error (MBE), root mean square error (RMSE), mean percentage error (MPE), correlation coefficient (R^2) and t-Test statics of different hourly models for south–facing and west–facing in this work are referred to **Tables 12-19** respectively. The evaluation carried out on a semi-hourly basis. The total solar irradiation component on the tilted surface was determined from measured horizontal data using different models and compared with the measured tilted data of the same period at selected sites in the present work. **Tables 12-19**, reports a summary of the statistical indicators results of the models for south facing and west facing surface in the present study respectively. It is seen that from **Tables 12-15**, the absolute relative values of the root mean square error (RMSE), for the south-facing surface ranges from 7 to 41.3 at El-Kharga and Hurghada sites, Egypt in the present work for Koronakis and Stevenand Unsworth (SU) models respectively. These results are good agreement with the values of t-Test statistics for the same models and the correlation coefficient is clear that the higher value too for self-models. The values of (RMSE), for the south-facing surface ranges from 9.3 to 39.7 at Dammam and Hail sites, Saudi Arabia in the present work for Koronakis and Klucher models respectively. These results are good agreement with the values of t-Test statistics for the same models and the correlation coefficient is clear that the higher value too for self-models..For west-facing surface show in **Tables 16-19**, the values of root mea square error range from 11.2 to 47.3 for Badescu and Koronakis models at El-Kharga and Hurghada sites, Egypt respectively in the present research,

Table 12. The results of statistical indicator of the models for the south-facing surface at El-Kharga, Egypt in the present work

Model	Abbreviation	*a*	*b*	MBE	RMSE	MPE	R^2	t−Test
Koronakis (1986)	Kr (ISO)	0.347	0.432	16.3	14	8.5	0.947	6
Badescu (2002)	Ba (ISO)	0.652	0.207	−17.2	11	−11	0.969	3.7
Tian *et al.* (2001)	Ti (ISO)	0.425	0.358	15.3	10	−7.5	0.948	6.5
Liu and Jordan (1962)	LJ (ISO)	0.165	0.534	−11.5	22	−6.9	0.965	3.5
Skartveit and Olseth (1986)	SO (ANISO)	0.281	0.498	11	9	12	0.968	3.5
Reindl *et al.* (1990)	Re (ANISO)	0.623	0.265	21.8	12	10	0.987	4
Klucher (1979)	Kl (ANISO)	0.458	0.378	15.6	15	13	0.982	3
Hay (1979)	Ha (ANISO)	0.487	0.361	−18.6	14	−7.5	0.969	4
Stevenand Unsworth (1980)	SU (ANISO)	0.195	0.604	−13.3	7	11	0.991	1.8

(ISO, means isotropic and ANI means anisotropic).

Table 13. The results of statistical indicator of the models for the south-facing surface at Hurghada, Egypt in the present work

Model	Abbreviation	*a*	*b*	MBE	RMSE	MPE	R^2	t-Test
Koronakis (1986)	Kr (ISO)	0.154	0.425	19.6	8.7	12.4	0.991	3.64
Badescu (2002)	Ba (ISO)	0.294	0.656	−15.8	19.5	−9.3	0.974	5.55
Tian *et al.* (2001)	Ti (ISO)	0.345	0.511	18.7	24.2	12.8	0.985	7.89
Liu and Jordan (1962)	LJ (ISO)	0.534	0.632	−22.4	29.5	11.6	0.942	8.47
Skartveit and Olseth (1986)	SO (ANISO)	0.674	0.341	−13.6	16.7	−9.3	0.974	5.55
Reindl *et al.* (1990)	Re (ANISO)	0.127	0.425	25.3	41.3	16.7	0.981	11.74
Klucher (1979)	Kl (ANISO)	0.558	0.655	−11.4	18.4	−9.3	0.974	5.55
Hay (1979)	Ha (ANISO)	0.621	0.371	−21.2	26.1	11.6	0.942	8.47
Stevenand Unsworth (1980)	SU (ANISO)	0.192	0.485	−17.5	15.2	−9.3	0.974	5.55

(ISO, means isotropic and ANI means anisotropic)

Table 14. The results of statistical indicator of the models for the south–facing surface at Dammam, Saudi Arabia in the present work.

Model	Abbreviation	*a*	*b*	MBE	RMSE	MPE	R^2	t-Test
Koronakis (1986)	Kr (ISO)	0.345	0.511	−30.4	9.3	14.6	0.989	4.61
Badescu (2002)	Ba (ISO)	0.281	0.524	18.9	17.9	16.9	0.958	8.87
Tian *et al.* (2001)	Ti (ISO)	0.319	0.511	−28.7	10.5	18.7	0.972	9.11
Liu and Jordan (1962)	LJ (ISO)	0.437	0.411	−24.2	11.2	11.3	0.972	6.16
Skartveit and Olseth (1986)	SO (ANISO)	0.334	0.532	25.8	37.8	16.7	0.981	11.74
Reindl *et al.* (1990)	Re (ANISO)	0.474	0.341	−13.6	19.4	−11.7	0.974	6.47
Klucher (1979)	Kl (ANISO)	0.165	0.653	−27.9	25.9	13.7	0.962	8.51
Hay (1979)	Ha (ANISO)	0.257	0.624	14.7	16.3	15.4	0.958	6.47
Stevenand Unsworth (1980)	SU (ANISO)	0.318	0.549	15.6	13.7	12.8	0.958	7.35

(ISO, means isotropic and ANI means anisotropic).

Table 15. The results of statistical indicator of the models for the south-facing surface at Hail, Saudi Arabia in the present work.

Model	Abbreviation	*a*	*b*	MBE	RMSE	MPE	R^2	t-Test
Koronakis (1986)	Kr (ISO)	0.534	0.432	25.8	39.7	16.7	0.981	11.74
Badescu (2002)	Ba (ISO)	0.194	0.625	12.6	28.7	−8.4	0.957	7.57
Tian *et al.* (2001)	Ti (ISO)	0.185	0.693	−27.9	25.9	13.7	0.962	8.11
Liu and Jordan (1962)	LJ (ISO)	0.281	0.524	18.4	18.7	16.4	0.958	9.87
Skartveit and Olseth (1986)	SO (ANISO)	0.674	0.241	−13.6	19.4	−11.7	0.974	10.35
Reindl *et al.* (1990)	Re (ANISO)	0.163	0.753	−27.9	25.9	16.3	0.962	7.61
Klucher (1979)	Kl (ANISO)	0.321	0.564	18.4	11.4	13.6	0.995	5.87
Hay (1979)	Ha (ANISO)	0.368	0.443	−27.9	24.6	15.1	0.962	9.66
Stevenand Unsworth (1980)	SU (ANISO)	0.489	0.341	−13.6	19.4	−14.7	0.974	10.56

(ISO, means isotropic and ANI means anisotropic).

Table 16. The results of statistical indicators of the models for the west-facing surface at El-Kharga, Egypt in the present work.

Model	Abbreviation	*a*	*b*	MBE	RMSE	MPE	R^2	t-Test
Koronakis (1986)	Kr (ISO)	0.423	0.342	−12.4	21.2	−13.5	0.974	8.45
Badescu (2002)	Ba (ISO)	0.497	0.367	14.7	11.2	−14.9	0.985	4.34
Tian *et al.* (2001)	Ti (ISO)	0.312	0.487	−15.2	46.3	15.6	0.949	11.54
Liu and Jordan (1962)	LJ (ISO)	0.546	0.343	17.3	47.3	10.8	0.953	13.76
Skartveit and Olseth (1986)	SO (ANISO)	0.497	0.367	19.5	21.7	−12.3	0.965	6.28
Reindl *et al.* (1990)	Re (ANISO)	0.411	0.398	−25.7	31.8	17.5	0.971	8.94
Klucher (1979)	Kl (ANISO)	0.312	0.487	−16.28	39.5	16.4	0.949	12.54
Hay (1979)	Ha (ANISO)	0.546	0.349	15.7	22.7	11.8	0.953	14.92
Stevenand Unsworth (1980)	SU (ANISO)	0.497	0.334	11.5	29.5	−12.6	0.965	10.85

(ISO, means isotropic and ANI means anisotropic).

Table 17. The results of statistical indicators of the models for the west-facing surface at Hurghada, Egypt in the present work.

Model	Abbreviation	*a*	*b*	MBE	RMSE	MPE	R^2	t–Test
Koronakis (1986)	Kr (ISO)	0.396	0.456	−12.6	12.4	11.2	0.992	3.76
Badescu (2002)	Ba (ISO)	0.432	0.325	11.2	30.8	15.8	0.985	6.54
Tian *et al.* (2001)	Ti (ISO)	0.532	0.387	−22.4	33.6	19.2	0.974	10.76
Liu and Jordan (1962)	LJ (ISO)	0.497	0.367	14.7	22.5	−14.9	0.965	6.34
Skartveit and Olseth (1986)	SO (ANISO)	0.411	0.398	−25.4	31.2	17.6	0.971	8.94
Reindl *et al.* (1990)	Re (ANISO)	0.571	0.332	16.9	25.8	16.4	0.978	7.23
Klucher (1979)	Kl (ANISO)	0.478	0.322	−19.3	19.7	13.8	0.983	6.64
Hay (1979)	Ha (ANISO)	0.396	0.456	−13.7	21.6	12.4	0.972	4.76
Stevenand Unsworth (1980)	SU (ANISO)	0.411	0.325	15.3	27.8	17.8	0.985	6.54

(ISO, means isotropic and ANI means anisotropic).

Table 18. The results of statistical indicators of the models for the west-facing surface at Dammam, Saudi Arabia in the present work.

Model	Abbreviation	*a*	*b*	MBE	RMSE	MPE	R^2	t-Test
Koronakis (1986)	Kr (ISO)	0.482	0.325	11.2	30.8	15.4	0.985	6.54
Badescu (2002)	Ba (ISO)	0.532	0.387	−22.4	33.6	19.2	0.974	10.76
Tian *et al.* (2001)	Ti (ISO)	0.561	0.332	16.9	25.8	17.8	0.968	8.23
Liu and Jordan (1962)	LJ (ISO)	0.478	0.342	−19.3	19.7	13.1	0.983	6.64
Skartveit and Olseth (1986)	SO (ANISO)	0.419	0.382	−17.6	15.4	11.6	0.987	6.64
Reindl *et al.* (1990)	Re (ANISO)	0.396	0.456	−12.9	12.4	12.4	0.962	4.76
Klucher (1979)	Kl (ANISO)	0.462	0.395	16.8	6.5	15.2	0.991	3.7
Hay (1979)	Ha (ANISO)	0.516	0.364	−21.3	10.4	17.8	0.976	10.76
Stevenand Unsworth (1980)	SU (ANISO)	0.438	0.376	−15.7	19.7	13.6	0.981	6.64

(ISO, means isotropic and ANI means anisotropic).

Table 19. The results of statistical indicators of the models for the west-facing surface at Hail, Saudi Arabia in the present work.

Model	Abbreviation	*a*	*b*	MBE	RMSE	MPE	R^2	t-Test
Koronakis (1986)	Kr (ISO)	0.511	0.365	15.6	25.8	19.4	0.978	8.23
Badescu (2002)	Ba (ISO)	0.478	0.376	−17.3	19.7	15.8	0.983	6.64
Tian *et al.* (2001)	Ti (ISO)	0.396	0.322	−12.6	12.4	12.4	0.992	4.76
Liu and Jordan (1962)	LJ (ISO)	0.572	0.347	−22.4	38.5	16.2	0.974	10.76
Skartveit and Olseth (1986)	SO (ANISO)	0.534	0.353	14.3	15.7	13.6	0.963	5.97
Reindl *et al.* (1990)	Re (ANISO)	0.421	0.298	11.2	8.3	15.8	0.996	4.21
Klucher (1979)	Kl (ANISO)	0.358	0.432	16.9	16.5	11.5	0.978	7.45
Hay (1979)	Ha (ANISO)	0.519	0.316	−19.3	16.2	18.4	0.953	8.32
Stevenand Unsworth (1980)	SU (ANISO)	0.437	0.456	−11.7	14.8	11.2	0.996	6.57

(ISO, means isotropic and ANI means anisotropic).

while values of RMSE range from 6.5 to38.5 for Klucher and Reindl *et al.* models at Dammam and Hail sites, Saudi Arabia. From Tables 12-19, we can concluded to the models Koronakis, Klucher and Stevenand Unsworth (SU) models are given the most accurate predictions for the south-facing surface, and Badescu, Koronakis, Klucher and Reindl *et al.* models are good performs better estimated for the west-facing surface.

10. Conclusions

The monthly average daily of total solar radiation (*H*), beams (*B*) and diffuses (*D*) solar radiation on a horizontal surface at four selected sites (El-Kharga and Hurghada in Egypt and Dammam and Hail in Saudi Arabia) in the present work during the period time from 1980 to 2020. The highest values of solar radiation components are lies in summer months, while the lowest values indicate in winter months, but the values of solar radiation components in spring and autumn months are lies between highest and lowest values at all selected sites in the present work. Generally, the beam component is more dominant than diffuse component and winter months, the beam radiation represents nearly vary from 62% to 71% of total radiation, while diffuse radiation represents nearly vary from 23% to 34% of total radiation at all selected locations in the present research.

The empirical equations between (H/H_o) and meteorological variables along with the values of (MBE), (RMSE), MPE, R^2 and the t-Test statics are show in the present work. Empirical models for estimation of total solar radiation on horizontal surface in the form of equations from (6) to (14) proposed for at selected sites using the meteorological data during the period time in the present work. From the analysis of the measured and estimated values of the total solar radiation (H), it is clear that, the values of correlation coefficients (R^2) are higher than 0.96 and the values of the RMSE are found varies from 1.98 to 5.89, at all selected locations in the present research. This indicating good agreement between measured and estimated values of total solar radiation (H).

The differences between the measured ($H_{d,m}$) and estimated ($H_{d,c}$) values of the diffuse solar radiation at al selected sites in the present research along with the values of mean base error (MBE), root mean square error (RMSE), mean percentage error (MPE), and t-Test statics shown in **Table 6**. It is clear that, the low values of the (RMSE) for all models indicate a good agreement between measured and estimated values of diffuse solar radiation (H_d) at selected locations. The negative values of (MPE) indicate that the proposed correlations slightly overestimate (H_d) at all sites in the present work. For all models, the absolute values of the (MPE) giving indicate very good agreement between measured and calculated values of the diffuse solar fraction (H_d/H) or the diffuse solar transmittance (H_d/H_o) and clearness index K_t, relative number of sunshine hours (S/S_o) and the combination of them. The t-Test of the models in Equations (17) and (20) given the smallest values, and then it is considered as the best models for estimating the diffuse solar radiation at selected sites in Saudi Arabia and Egyptian sites respectively with an acceptable error.

The results for south facing surfaces of the root mean square error (RMSE) for different slope at different models in the present work. It is clear that, the RMSE values for the most fifth models increases as the slop of the collector increase, but remain in a domain of error for which these relations can applied with good accuracy. Inspecting the results, it is apparent that the models agree quit well with each other during the summer months. They deviate from each other in the winter months, when the effect of the difference in the diffuse solar radiation parameterization is at its maximum. The RMSE effects suggest that the anisotropic models show comparable overall performance on a standard basis, but isotropic version show off a good deal large blunders. In trendy, we verify that, the remark of the Reindle, Hay and Davie models describe the irradiance on inclined aircraft more as it should be than anther models.

Nine isotropic and anisotropic models used to estimate the diffuse sun radiation on a tilted floor. The absolute relative values of the basis suggest rectangular errors (RMSE), for the south dealing with floor ranges from 7 to 41.Three at El-Kharga and Hurghada sites, Egypt in the present paintings for Koronakis and Stevenand Unsworth (SU) models respectively. These results are good agreement with the values of t-Test statistics for the same models and the correlation coefficient is clear that the higher value too for self-models. The values of (RMSE), for the south-facing surface ranges from 9.3 to 39.7 at Dammam and Hail sites, Saudi Arabia in the present work for Koronakis and Klucher models respectively. These results are good agreement with the values of t-Test statistics for the same models and the correlation coefficient is clear that the higher value too for self-models. For west-facing surface the values of root mea square error range from 11.2 to 47.3 for Badescu and Koronakis models at El-Kharga and Hurghada sites, Egypt respectively in the present research, while values of RMSE range from 6.5 to38.5 for Klucher and Reindl *et al.* models at Dammam and Hail sites, Saudi Arabia. The models Koronakis, Klucher and Stevenand Unsworth (SU) models given the most accurate predictions for the south-facing surface, and Badescu, Koronakis, Klucher and Reindl *et al.* models are good performs better estimated for the west-facing surface.

Conflicts of Interest

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

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