Global Solar Radiation Estimation over Jazan, the Kingdom of Saudi Arabia

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Abstract: ***Empirical models offer precise and cost-effective insights into solar energy assessment. Our research was conducted in Jizan (17°30'N, 42°30'E, Elev: 7 m), situated in the southwest of the Kingdom of Saudi Arabia. The dataset encompasses monthly average values of global, diffuse, and direct solar radiation, along with the clearness index, alongside data on cloud cover percentage, air temperature, and relative humidity for the years 1983-2005.The distribution of monthly average values for solar radiation components was highest during the summer months, with the lowest values occurring in the winter months. Estimation of the monthly averaged value of global solar radiation using other parameters was performed for the same period. A strong direct correlation was observed between G and D, I, Kt, and T. Conversely, an inverse correlation was noted between G and RH% and Cl%.***

Keywords: Global (G), diffuse (D) and direct (I) solar radiation, clearness index (Kt), air temperature (T), relative humidity (RH) and cloud cover (Cl) %.

1. Introduction

Fossil fuels such as natural gas, petroleum, and coal meet the majority of the world's energy demand. When burned, they produce harmful gases, and their limited supplies cannot be replaced. Renewable energy sources play a crucial role in reducing CO_2 emissions and mitigating dependence on fossil fuel energy. One of the most important options for developing renewable energy production is solar power, which has a minimal environmental impact (Sheik Mujabar et al., 2021). The continuous measurement of global solar radiation data holds a vital and leading position for the effective implementation and consumption of resources, as discussed by Mohandas et al. (2021). Models based on meteorological data are the most commonly inspected and widely utilized models globally (Besharat et al., 2013). The development of a model for solar radiation energy and its relation with sunshine hours was undertaken by Wong Chow WK (2001). The primary perpetual energy source is solar energy, providing the Earth with about 170 trillion kW. The study of solar radiation provides important information for the assessment and design of solar energy projects (Fathy A.M., 2008). The Atlas of Solar Radiation for KSA contains measured data collected for the years 1971-1980 by the Ministry of Agriculture and Water and the Meteorological and Environmental Protection Agency of KSA. This data, used in the CSR model, provides resulting data grids and maps as climatological monthly and annual averages (Solar Radiation Atlas for KSA, 1998), using a thirty-year record data to deduce climatological weather parameters.

2. Data

This work is directed to study the solar radiation component distributions over Jazan, Saudi Arabia, (17o 30' N, 42o 30' E, Elev: 7 m) which lie in the Southwest of KSA for the years (1983-2005). This data used to estimate a regression model of global solar radiation using the other (D, Iand Kt) solar radiation beside the metrological parameters (Cl%, RH%, T and P) (Fathy A.M., 2023)

3. Results and Discussion

3.1 Monthly averaged values of (G, D and I) solar radiation:

Monthly mean (G) values on a horizontal surface has been studied, where the highest values were in summer months with value 7.78 (kWh/m2/day) in July, while the lowest values in winter months with value 5.01 (kWh/m2/day) in January. Monthly mean (D) valuesshow highest values in summer months with value 2.06 (kWh/m2/day) in July, while lowest values in winter months with a value of 1.08 (kWh/m2/day) in December. Monthly mean (I) shows highest value in July with value of 7.78 (kWh/m2/day), while lowest value was in January with value of 5.63 (kWh/m2/day), see figure 1.

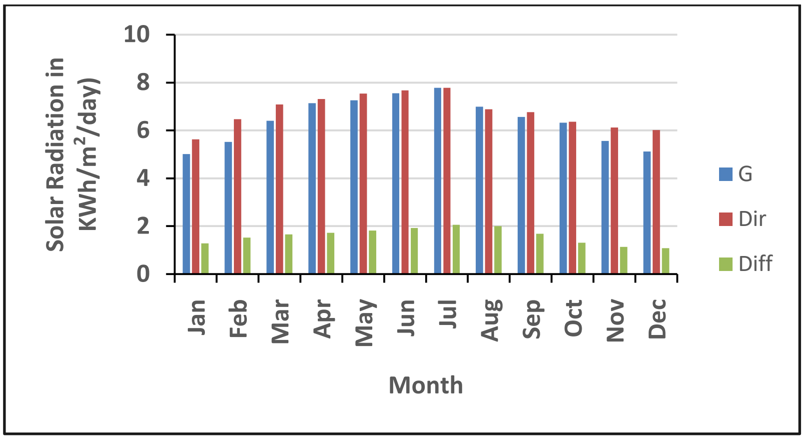


Figure 1: Monthly average values of Global, Direct and Global solar radiation in (kWh/m^2/day)

3.3.1 Statistical error estimation:

To assess the accuracy and performance of the estimated empirical models, they undergo techniques of statistical error estimation. Error estimation is valuable for statistically organizing the models and identifying the leading predictive model.

Various statistical techniques have been employed to validate the precision and effectiveness of the models. In this study, we utilized two statistical techniques: the correlation coefficient (r) and the coefficient of determination (R^2). The correlation coefficient (r) and the coefficient of determination (R^2) indicate how successful the developed models are, and they can be calculated using Eqs. (1) and (2). A correlation coefficient (r) close to 1 demonstrates the excellence and superior fit of the model.

3.2 Monthly average values of (Cl%, RH%, P and T):

Studying of the monthly mean values of (T)in (°C) shows highest values were in summer months with value 31°C in June, while lowest values were in winter months with value 24.2°C in January. Monthly mean values of (RH%) shows highest values were in winter months with value 63.7% in January, while the lowest values were in summer months with value 48.31 in December. Monthly average values of the (P) in (kPa) shows no differences between values from month to month. The values of atmospheric pressure are ranged from 96.6 kPa to 97.5 kPa.Monthly mean values of (Cl%) shows highest values were in winter months with value 54.3% in December, while lowest values were in summer months with value 43.3% in July, see figure 2.

3.3 Correlations between G against D, I and Kt over Gazan:

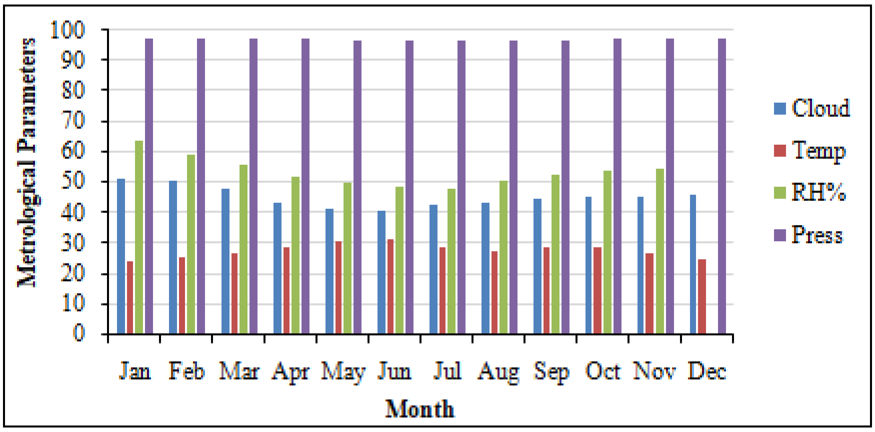


Figure 2: Monthly average values of meteorological parameters over Jazan.

$$\text{Correlation coefficient(r)} = 1 - \frac{\sum_{i=1}^{n}\left(G_{gm}^{i} - G_{gp}^{i}\right)^2}{\sum_{i=1}^{n}\left(G_{gm}^{i} - \overline{G}_{gm}\right)^2} \quad (1)$$

$$\text{Coefficient of determination } (R^2) = \frac{SSR}{SST} \quad (2)$$

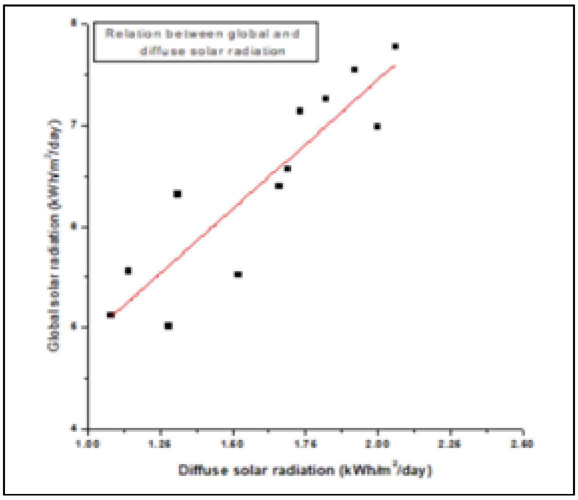
Where G_{gm}^{i} is the th measured value, G_{gp}^{i} is the th predicted value, and n is the total number of observations. Also, SSR and SST are given by the following two equations (Sheik Mujabaret al., 2021):

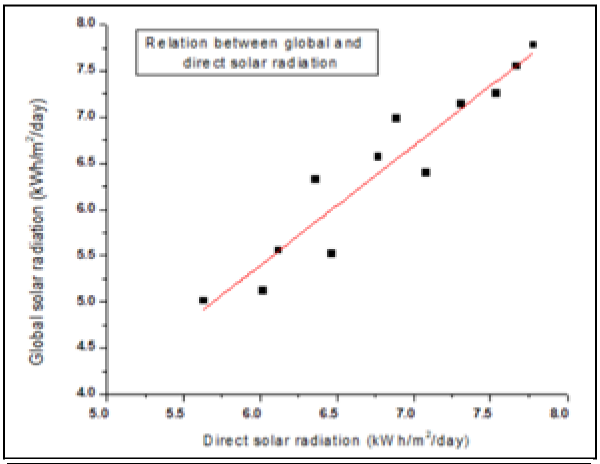
$$\text{Total Sum of Squares (SST)} = \sum_{i=1}^{n}\left(\bar{G}_{gm}^{i} - G_{gm}^{i}\right)^2 \quad (3)$$

$$\text{Sum of Squares of Regression (SSR)} = \sum_{i=1}^{n}\left(\bar{G}_{gm}^{i} - G_{gp}^{i}\right)^2 \quad (4)$$

All the regression models appeared a great degree of precision in the estimation of global solar radiation using diffuse, direct solar radiation beside the clearness index. The same results given in estimating the global solar radiation using the meteorological parameters as Relative humidity%, cloud cover % and air temperature.

Table 1, shows the regression models and their statistical parameters (r) and (R2), where a good correlation coefficients and coefficients of determination between G against the other parameters as shows in figures 3 and 4.





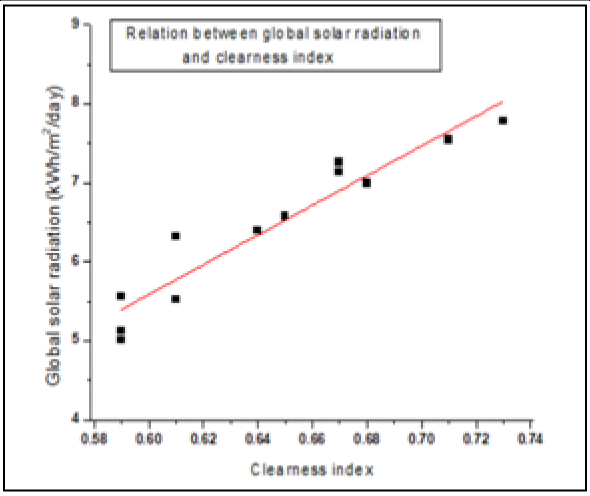
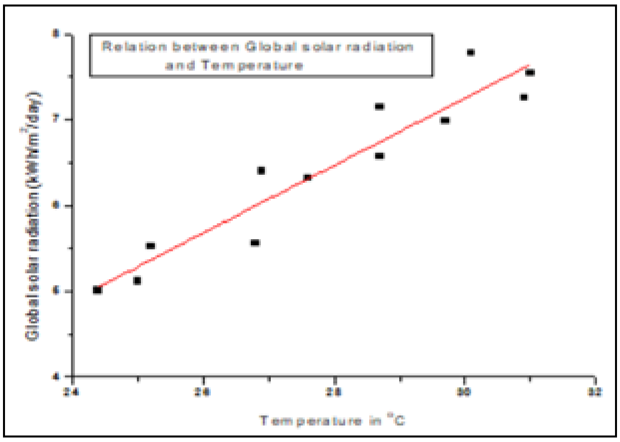
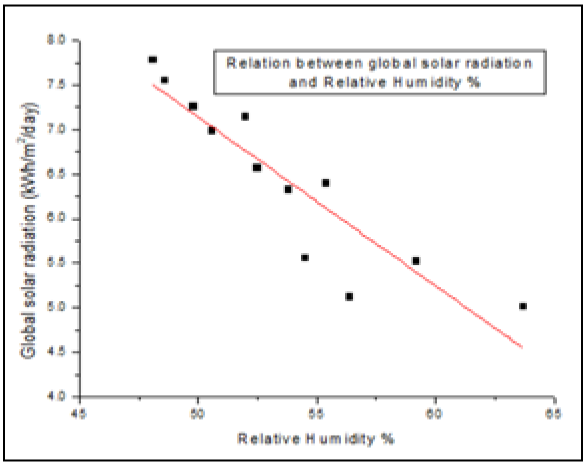


Figure 3: Correlations between G values against D, I and Kt over Jazan





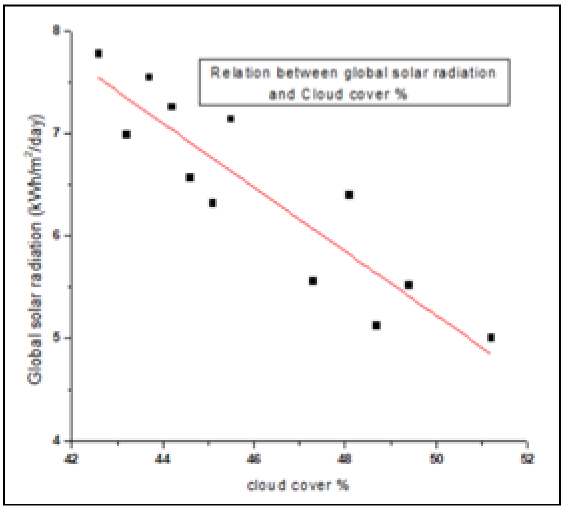


Figure 4: Correlations between G against Cl%, RH% and T over Jazan.

Using this work helping us to estimate the monthly average global solar radiation using the diffuse, direct solar radiation, clearness index and meteorological parameters (RH%, Cl% and T) using the regression models mentioned in table 1. From this study, there are a direct proportional between global solar radiation against diffuse, direct solar radiation, clearness index, air temperature, or by increasing any of these parameters, global solar radiation will increase.

The study also implies that the global solar radiation is decreasing with increasing the values of relative humidity and cloud cover. The presence of moisture and water vapor content in the hot air, increases more scattering of global solar radiation andthereby reduces the incoming solar radiation. Finally, the increase in average relative humidity and cloud cover gives rise to a decrease in solar radiation and vice versa. This depicts an inverse relationship between average relative humidity and cloud cover against solar radiation intensity.

Table 1: Models for estimation global solar radiation against D, I, Kt, RH%, Cl% and T

Relation	Regression equations	R^2	R
G&D	G = 2.553 D +2.348	0.785	0.897
G&I	G = 1.295 I - 2.376	0.895	0.950
G&Kt	G = 18.83 Kt – 5.711	0.901	0.954
G&Cl	G = - 0.313 Cl + 20.87	0.798	-0.903
G&T	G = 0.392 T – 4.529	0.894	0,951
G&RH	G = -0.198 RH – 16.61	0.510	-0.907

4. Conclusions

In this study, we discuss solar radiation and meteorological parameters as monthly average values over Jazan, Saudi Arabia, leading to the following conclusions:

- The highest monthly mean values of G, D, and I occurred during summer months, while their minimum values were recorded in winter months.
- The highest monthly average Kt values were observed in winter and spring months, whereas the lowest value was in summer due to dust storms in Jazan during that season.
- The highest monthly average air temperature was found in summer, while the lowest values were in winter.
- The highest RH% and Cl% values were noted in winter months, while the lowest values were in summer.
- There is a strong direct correlation between G and D, I, Kt, and T, with high correlation coefficients and coefficients of determination.
- Additionally, there is a notable inverse correlation between G and RH% and Cl%, supported by high correlation coefficients and coefficients of determination

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