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ANALYSIS OF MONTHLY GLOBAL SOLAR RADIATION IN ERBIL-IRAQ

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ABSTRACT:

Solar energy is a crucial and sustainable source of electricity that may be harnessed for a long duration without causing pollution. Moreover, it reduces pollution, thus improving the quality of life and reducing the cost of energy in the long term. This study analyzes and uses the modified Angstrőm–Prescott equation to estimate the monthly average global solar radiation in the Erbil governorate depending on latitude and daylight hours. The data is collected from the Agriculture Directorate in Erbil for ten stations in different locations for the period (2016-2023). Results show that the global solar energy in the region reaches a maximum of 8.4 kW.day^{-1}.m^{-2} in the summertime and descends to a minimum of 1.6 kW.day^{-1}.m^{-2} in winter. The equation used to estimate global solar energy is in strong agreement with measured data from the ground base weather station, and to validate the results, mean absolute percentage error (MAPE) and residual mean square error (RMSE) were used. They found the value of MAPE = 4.34 -7.98 and RMSE= 0.183-0.426, indicating that the model is suitable for estimating solar radiation.

KEYWORDS: Estimation, Erbil, Extraterrestrial, Global, Solar energy.

1. INTRODUCTION

Solar energy now seems more important than other forms of alternative energy and has become a vital resource worldwide. Thus, solar energy can be considered a major factor in air pollution reduction and environmental safety (Kassem et al., 2018). The decline in other fuels led to a direction towards renewable energy sources such as solar radiation because renewable energy, like solar energy, is environment-friendly. Renewable energy is an alternative to fossil fuels and nuclear energy. (Vecan, 2011). The solar radiation received at a given location on the earth's surface depends on two main factors: external solar radiation and atmospheric conditions. External solar radiation is the amount of solar energy that reaches a horizontal surface at the top of the atmosphere. The site's latitude determines this: the distance of the earth from the sun and the time of year. The sun's daily cycle goes from zero at sunrise to maximum noon light and back to zero in the evening and sunset. Angstrom made the first attempt to calculate the total solar radiation, the monthly average daily solar radiation, the average proportion of potential sunshine hours, and precise day radiation at the site are all related to the original Angstrom-type regression equation (Duffie et al., 1980). Many researchers have attempted to adapt or alter the original Angstrom model to estimate the amount of solar radiation from other meteorological data at different locations worldwide due to the absence of dependable solar radiation (Muhammad et al., 2014).

Five theoretical models that currently forecast global solar radiation in Sokoto using relative humidity and maximum/minimum temperature as input factors were assessed for accuracy by Aliyu and Sambo (Aliyu et.al., 1991).

If the coefficients of temperature-based empirical models were appropriately modified, the models produced superior forecasts at all locations. Moreover, the recently proposed models were the most precise in estimating temperature for every station (Aksoy, 1997). AL-Salihi et al. Estimated global solar radiation on horizontal surfaces using a model based on temperature and relative humidity for different locations in Iraq and concluded that the resulting models reasonably predict the global solar radiation received on horizontal surfaces and the expected solar radiation behavior (AL-Salihi et al., 2010). Values of extraterrestrial radiation and global solar radiation were calculated (Abd et al.,2019) using the data on sunshine duration and geographic location (latitude), applying the Angstrom equation. The FAO values of the constant's dependent on the station's location within Iraqi territory were determined using the regression constants and b values.

A study using Artificial Neural Networks (ANNs) to forecast the daily average solar radiation (DASR) and examine the impact of meteorological factors on DASR in Duhok City, Iraq, was conducted. The input variables utilized were the daily average of the relative humidity (RH), lowest temperature (T min), maximum temperature (T max), wind speed (WS), cloud layer (CL), atmospheric pressure (AP), and ultraviolet (UV) levels in order to determine DASR. For certain models, the reported findings demonstrate superior predictive accuracy compared to others. The study suggests that different meteorological conditions might greatly impact the prediction of solar radiation (Mahdi et al., 2020). The solar direct irradiance in Iraq was forecasted for three locations (Erbil, Bagdad, and Basra) using an artificial neural network. The prediction was based on seven input variables: Temperature, Precipitation, Humidity, Wind speed, Wind direction, Sunshine duration, and Date. They reported a Root Mean Square Error (RMSE) ranging from 2.5 to 3 (Saleem et al.,2021). The solar data obtained from meteorological stations and satellite-derived models were examined and compared using the PVGIS-5 geo-temporal irradiance database. The findings unveiled substantial regional disparities in sun radiation throughout the Iraqi Kurdistan Region. The solar radiation map indicated places with abundant solar potential, particularly in the southern and western regions, while also highlighting areas with limited solar energy availability, such as mountainous or forested regions (Keya et al., 2022).

There are many weather stations in Erbil governorate, but most do not measure solar radiation; the ones that suffer from significant records gaps and missing data are common among them. Therefore, we suggest a simple model to estimate data depending on latitude and sunlight duration. The global solar

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radiation data estimated here can benefit solar power designers, researchers, and any field that uses solar energy data.

2. METHODOLOGY

2.1 Study area

Erbil is a governorate located in the Kurdistan region of Iraq, situated in the northern part of the country. The Geographical location shown in Fig.1 is between latitudes (35° 25'N - 37° 18'N) and longitudes (43° 19'E - 45° 08'E). The governorate consists of three regions starting from south to northeast (a broad plane, low mountains, and a high mountain) areas that affect the amount of rainfall that increases as it moves north-eastward in the region as altitude increases.

Erbil is hot and dry in summer with plenty of sunshine, daylight reaching 13 hours, and cold and wet in winter, with daylight decreasing to around 4.5 hours, with short spring and autumn seasons compared to summer and winter.

2.2 Data and Software

The solar energy recording of 10 stations in Erbil governorate was obtained from the Directorate of Agriculture in Erbil from 2016-2023. All calculations and plots were performed with Microsoft Excel and map drawing with GIS Pro 3.5.

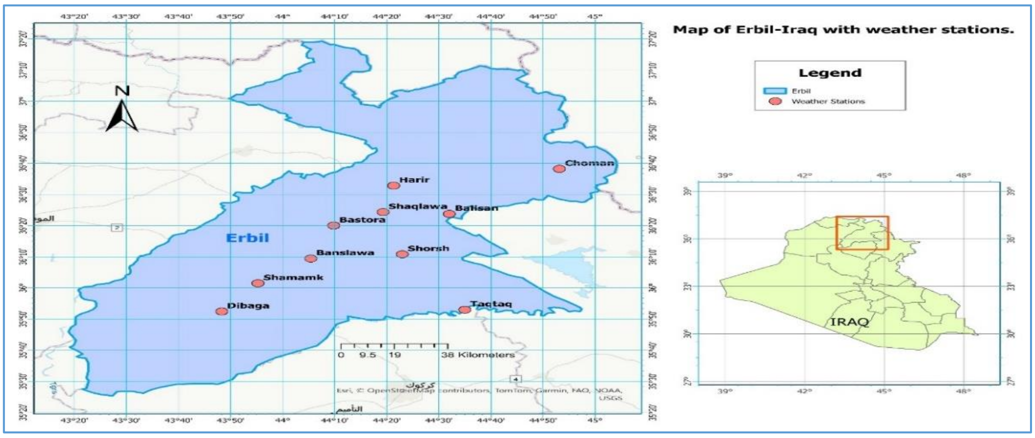

Figure 1: Map of Erbil-Iraq governorate.

2.3 Solar Radiation

The theoretical extraterrestrial solar radiation I_o on a horizontal surface can be calculated from the following equation (Duffieet. al., 1980):

$$I_0 = \frac{24}{\pi} \cdot I_{SC} \cdot \left\{ \left[1 + 0.033 \cdot cos\left(\frac{360 \cdot n}{365}\right) \right] \cdot \left[cos\,\phi \cdot cos\,\delta \cdot sin\,\omega_S + \frac{2\pi \cdot \omega_S}{360} sin\,\phi \cdot sin\,\delta \right] \right\} \ldots (1)$$

Where I_{sc} is the solar constant and equal to 1367 $W.m^{-2}$ (Frolich et al., 1981), n is the day of the year from January 1 to December 31, ϕ is the latitude of the location, δ is solar declination angle, and w_s the hour angle for the horizontal surface is given as (Duffieet. al., 1980):

$$w_s = cos^{-1} - tan(\phi) \cdot tan(\delta) \ldots (2)$$

Declination is calculated as (Cooper, 1969):

$$\delta = 23.45 \times sin\left(\frac{360}{365} \cdot (284 + n)\right) \ldots (3)$$

The day length N is the number of hours of sunshine or darkness within 24 hours on a given day. For a horizontal surface, it is given by (Duffieet. al, 1980):

$$N = \frac{2}{15} w_s = \frac{2}{15}\, cos^{-1}(-tan(\varphi) \cdot tan(\delta)) \ldots (4)$$

Empirical relations have been developed to forecast the monthly average global radiation using various meteorological data. In many countries, sunshine duration data are readily available among existing correlations. Several algorithms have been developed based on these data to calculate solar radiation from sunshine duration. Angstrťm created the most frequently used approach, while Prescott later made modifications. The most practical and extensively used correlation for estimating worldwide radiation has been the modified Angstrőm–Prescott version. The formula is (Duffie et al., 1994):

$$\frac{I_g}{I_o} = a + b\frac{dn}{N} \ldots (5)$$

Here, d_n is the actual monthly average daily number of hours of bright sunshine, and I_g and I_o are the monthly average daily global and extraterrestrial radiation on a horizontal surface, respectively, measured in $kWm^{-2}day^{-1}$, a and b are Angstrom coefficient (also called regression coefficient) The values of *a* and *b* are obtained from monthly averaged data of all months of the year for a location. There are many models that use different values of regression coefficients and equations that are suitable for different locations and altitudes; in this research, we calculated our own values of the regression coefficient for each location based on solar radiation data recorded in our region that proved to be more accurate and suitable for our purpose as will be seen in the results.

Microsoft Excel is used to calculate $\boldsymbol{I_o}$ for each day (365 days of the year). The procedure is applied on all stations; the only difference is the latitude variable that changes each station's outcome (higher latitudes receive less solar radiation than lower latitudes). Moreover, the theoretical day length *N* is calculated from Eq. (4). Then, the monthly average extraterrestrial solar radiation is determined. Two measurements were taken from the station's data: the monthly average solar radiation and the monthly average daily number of hours of bright sunshine. To find the monthly regression coefficients for the selected station, Eq. (5) is used by plotting between I_g/I_o versus dn/N; the linear fitting equations can be added to the scatter plot to find regression constants a and b; Excel also provides the regression coefficient R^2. The regression constants *a* and *b* calculated from the previous step can now be used to estimate the solar radiation at each station.

2.4 Model Validation

To evaluate the model's accuracy, we compared our model's estimated solar radiation values with the measured solar radiation I_g values for each station in order to evaluate the accuracy of the model. We validated the models using the methods of residual mean square error (RMSE), mean absolute percentage error (MAPE), and coefficient of determination (R^2).

To compare estimated and measured values of solar radiation, the acceptable ranges for Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE) are 0% to 10% for MAPE and 0 kW/m^2 to 10 MJ/m^2 for RMSE. The evaluation methods commonly employed to analyze empirical models are those described by (Nwokolo et. al. 2022) and (Ghazouani et. al. (2022).

A good precision model is indicated by MAPE values of less than 10% (Djoman et al., 2021) and (Zirebwa et al., 2014). The model is more accurate when its RMSE values are closer to zero, and the optimal value is when RMSE equals zero.

The mean absolute percentage error (MAPE) can be determined from the equation (Ghazouani et al. (2022):

$$MAPE = \frac{1}{N}\left[\sum\left(\frac{S_c - S_m}{S_m}\right) \times 100\right] \ldots (6)$$

Where Sc and S_m are the values of predicted and measured global solar radiation, respectively and N is the total number of values.

And the residual mean square error (RMSE) can be determined from the equation (Ghazouani et al. (2022):

$$RMSE = \sqrt{\frac{1}{N}\sum(S_c - S_m)^2} \ldots (7)$$

3. RESULTS AND DISCUSSION

The fitting curve between vs for each station is shown in Fig. (2); the linear equation fits are acceptable, with regression coefficients R^2 ranging from 0.68 to 0.9; the purpose of these graphs in Fig. (2) is to reconstruct Eq. (5) with custom equations for each station to be used later to estimate the solar energy.

The monthly regression coefficients for the chosen sites are displayed in Table 1. These coefficients were derived from each station's monthly clearness index versus sunshine duration fractions using Eq. (5), which expressed the regression coefficients, *a* and *b*, as the linear y-intercept and gradient of each line, respectively. The value of *a*, which is the intersection with the y-axis or I_g/I_o, is quite small, ranging from -0.2772 to +0.0038, while coefficient b, or the slope of the line, ranges from 0.75 to 1.17. Differences in the values of *a* and *b* can be due to the location factors of each station, such as altitude and neighboring buildings and trees, in some cases, to instrument accuracy.

The use of the estimated equation listed in Table (1) enables us to calculate the solar energy at each station location and compare it with measured values; these graphs are useful to show how close our results are close to real values, which can be seen in Fig. (3). The compression is made for the year of each station for the years that have best and complete data. We can see from the graphs that the best results are obtained in months that have low values of solar energy, such as the months of (Oct, Nov, Dec, Jan, Feb, and Mar) where solar energy is most affected by cloud cover while in other months when the solar energy is high, the estimated values become less accurate but within reasonable ranges.

Finally, to evaluate our results, mean absolute percentage error (MAPE) and residual mean square error (RMSE) are used. The value of MAPE ranges from 4.34 to 7.98; as mentioned earlier, MAPE values less than 10 % indicate good precision; therefore, according to our results which are much less than 10% our estimation can be considered in good accordance with the real values, to validate our estimate the values of RMSE is calculated which ranges from 0.183 to 0.426 as shown in Table (2) these values are close enough to zero to indicate the good agreement with measured values.

Table 1: Monthly regression equations and coefficients developed for selected locations.

	Station	Long.	Lat.	Altitude	Equation	R^2
1	Balisan	44.5333	36.3959	885	y = 0.7905x - 0.0430	0.800
2	Banslawa	44.0900	36.1571	530	y = 1.1768x - 0.2772	0.807
3	Taqtaq	44.5830	35.8830	387	y = 0.7148x + 0.0038	0.875
4	Harir	44.3550	36.5475	655	y = 0.9083x - 0.1030	0.684
5	Dibaga	43.8050	35.8737	348	y = 0.9695x - 0.1772	0.796
6	Shaqlawa	44.3214	36.4056	980	y = 0.7494x - 0.0183	0.724
7	Shorsh	44.3828	36.1797	760	y = 0.8446x - 0.0772	0.886
8	Bastora	44.1636	36.3336	663	y = 0.8554x - 0.0995	0.856
9	Shamamk	43.9210	36.0246	345	y = 0.8493x - 0.0595	0.901
10	Choman	44.1267	36.6371	1174	y = 0.8561x - 0.0630	0.906

Table 2: Validating the estimated results with MAPE and RMSE.

	Station	**MAPE**	**RMSE**
1	Balisan	5.420	0.223
2	Banslawa	6.481	0.426
3	Taqtaq	5.628	0.248
4	Harir	7.652	0.363
5	Dibaga	5.136	0.250
6	Shaqlawa	7.983	0.325
7	Shorsh	4.340	0.228
8	Bastora	5.076	0.279
9	Shamamk	5.141	0.183
10	Choman	6.638	0.350

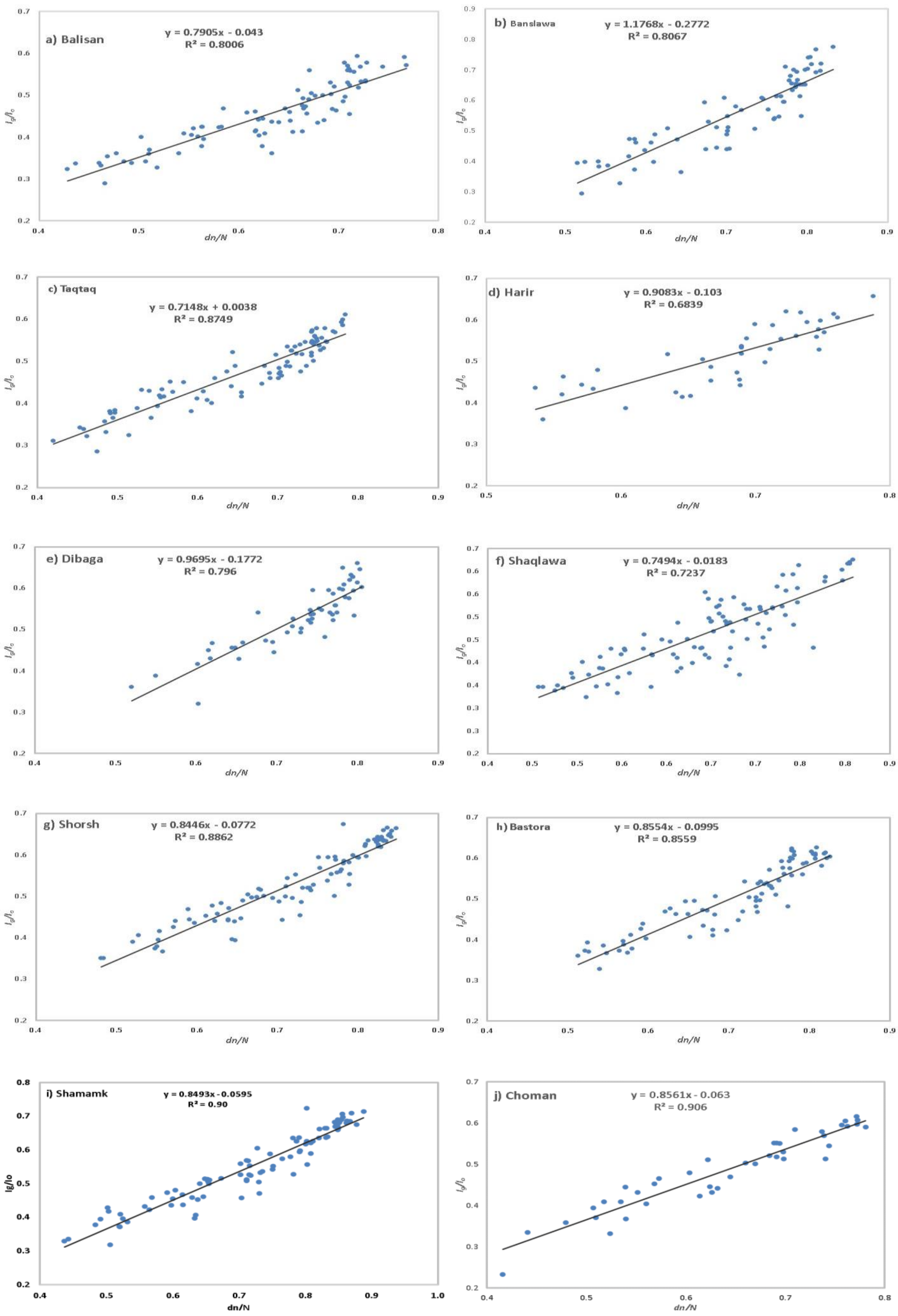

Figure 2: Fitting curve between I_g/I_o vs *dn/N* to find the regression coefficients a and b of all stations.

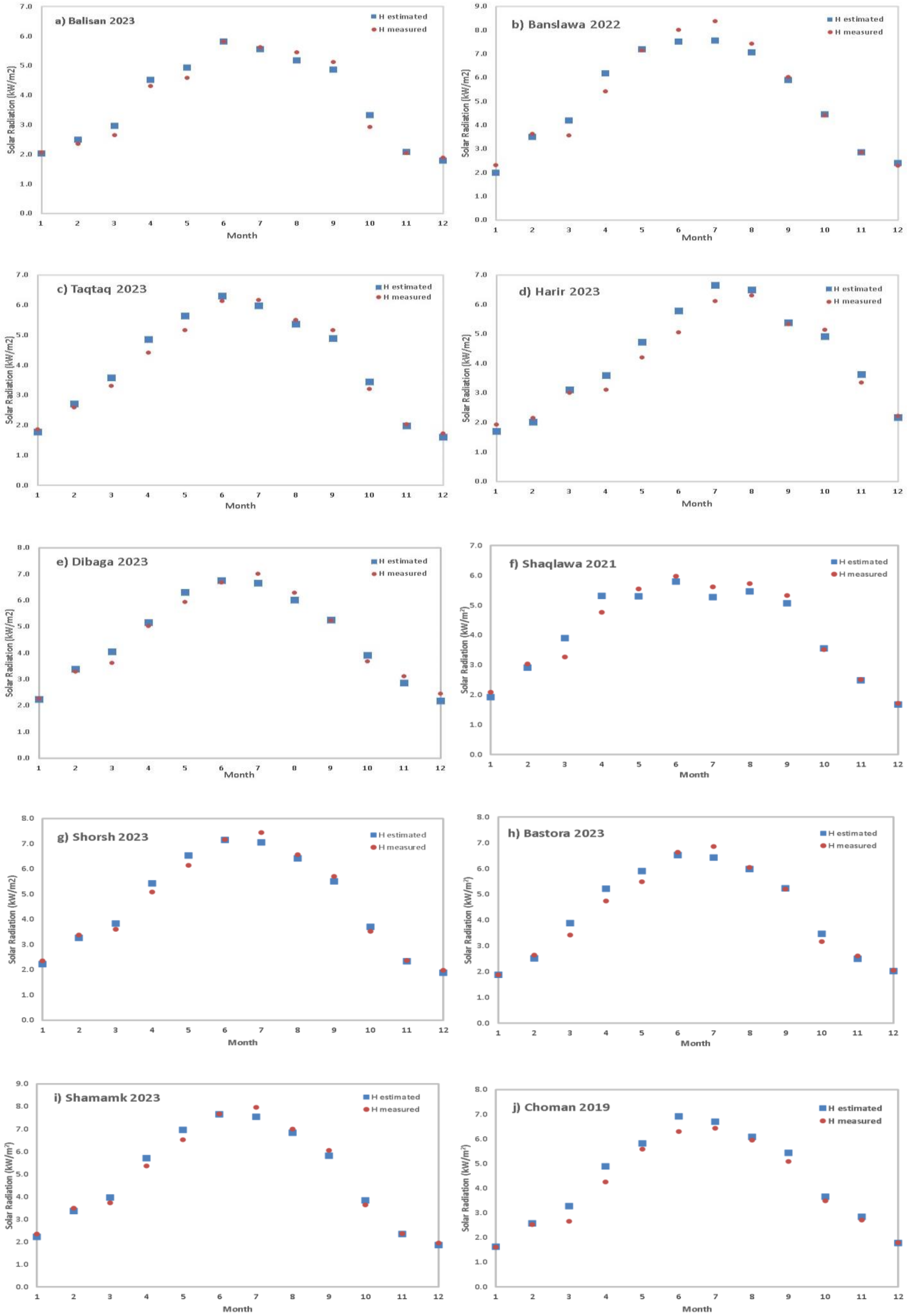

Figure 3: Measured global solar energy versus estimated.

CONCLUSION

This study uses a modified Angstrőm–Prescott model for global solar radiation at selected stations in the Erbil governorate with a calculated Angstrom coefficient suitable for each station in the study area. The main parameters used were latitude and daylight hours for each station. The effectiveness of the model was assessed using two common parameters, namely MAPE and RMSE. The values of MAPE varied between 4.34 to 7.98, whereas RMSE ranged from 0.183 to 0.426. This indicates that the model is of high accuracy in the estimation of solar radiation in the area.

It is also noteworthy that the Erbil governorate has high solar radiation energy of up to 8.4 kW.day^{-1}.m^{-2}, which may occur in summer and is as low as 1.6 kW.day^{-1}.m^{-2} in winter. The modified Angstrőm–Prescott model, with its calculated Angstrom coefficient that suits the study region in particular, can be applicable to nearby regions also, with consideration of site environments that can affect the solar energy available, such as vicinity to mountains, buildings, trees, and such barriers that reduce the amount of solar energy received at site location. The model can be effectively used in the design, analysis, and performance estimation of solar energy systems and may contribute to its enhancement and optimization in the area.

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