QUANTIFYING SOLAR RADIATION OVER NORTHERN INDIA AND VALIDATING WITH CROPWAT

Abstract

Precise computation of global solar energy is crucial for many fields of investigation such as renewable energy, meteorology, and agricultureespecially crop water requirement and irrigation requirement. This paper presents the quantification of solar radiation using weather data during the years from 2020-21. The results obtained were validated with the solar radiation estimated with the help of CROPWAT during the year. Statistical and visual approaches were adopted to validate the quantified results.Analysis revealedthe high degree of similarity between simulated and CROPWAT determined daily solar radiation during the year 2020-21 over the study area. Very high values of Willmot index of agreement (1.0), Nash-Sutcliffe efficiency (0.999), and Pearson correlation coefficient (0.998), and low values of mean absolute error (0.138), mean bias error (-0.024), and root mean square error (0.182)between them was observedduring the year 2020-21 in the area. The minimum solar radiation reaching over the region were observed to be around 5.71 MJ/m^2/day during winter season (January) with a normal value of 13.50 MJ/m^2/day, while the maximum value of 24.5 MJ/m^2/day was observed during the summer season (June) with a normal value of 24.13 MJ/m^2/day over the region.The use of these data for further study is recommended as it is worthful quantification over the region.

Keywords : Global solar radiation, Food and Agriculture Organisation, statistical analysis irrigation requirement.

1. INTRODUCTION

On Earth, global solar radiation is a most common renewable and uniformly distributed energy source [5]. It is the total amount of solar energy received by the Earth's surface. This energy is essential for various natural processes, including photosynthesis, climate regulation, and the hydrological cycle. Understanding global solar radiation is crucial for many fields such as agriculture, meteorology, and renewable energy. Solar power not only offers a clean alternative to fossil fuels but also enhances efficiency, productivity, and sustainability in agricultural operations. In agriculture, it is increasingly being integrated through several innovative applications that are transforming traditional farming practices. Irrigation is a critical aspect of agriculture, particularly in a region which is prone to water scarcity. Solar-powered irrigation systems use photovoltaic panels to generate electricity that pumps water from underground sources, rivers, or reservoirs to irrigate crops. These systems are highly effective in off-grid and remote areas, where access to electricity is limited or non-existent. Solar irrigation reduces reliance on diesel-powered pumps, cutting down on fuel costs and greenhouse gas emissions. Solar drip irrigation systems are particularly beneficial in arid regions, allowing for efficient water usage and reducing losses.

The future of solar energy in agriculture is promising, driven by technological advancements, supportive policies, and increasing awareness of sustainable practices. Several innovations and trends are shaping the integration of solar energy into agricultural practices. The integration of solar energy with smart farming technologies, such as Internet of Things (IoT) devices, sensors, and automated systems, can enhance precision agriculture. Solar-powered sensors can monitor soil moisture, weather conditions, and crop health, enabling data-driven decision-making and resource optimization. By harnessing the power of the sun, the agricultural sector can transit towards more resilient and sustainable practices, addressing the pressing demands of food security and environmental stewardship in the face of a growing global population and climate change.

There are several empirical models such as Hargreaves and Samani (1985) model, Davies and Mckay (1982) model which determines solar radiation in cloud condition, Angstrom-Prescott model for determination of monthly average daily total solar radiation [1] and Food and Agriculture Organization developed model which is primarily designed for estimating reference evapotranspiration but also computing solar radiation. Empirical quantification also involves satellite data to estimate solar radiation. Satellites measure reflected solar radiation and cloud cover, which can then be used to estimate the solar radiation reaching the Earth's surface. This method is useful for quantification of solar radiation on large-scale and remote areas. These methods, when direct measurements are not available, are useful to quantify solar radiation that provide valuable estimates. They vary in complexity and data requirements, with the choice of model often depending on the available meteorological data and the specific application. Applying these empirical methods for solar radiation quantification allows researcher, planners, and policymakers for better planning and optimization in fields such as agriculture, renewable energy, and environmental management.

The current study presents the quantification of daily solar radiation over Prayagraj district of Uttar Pradesh, India. It also validates the computed solar radiation with that estimated by CROPWAT using ground observations recorded at weather station located in the campus of Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj for the duration 3 years from 2020 to 2022.

2. METHODOLOGY

2.1 Study Area and Weather Data Used

The study area, the research farm of Sam Higginbottom University of Agriculture, Technology, and Science (SHUATS), Prayagraj district of Uttar Pradesh, is located at a latitude of 25° 34' 12" N, a longitude of 87° 11' 24" E, and an altitude of 98.0 m above mean sea level. The region has a hot and dry summer, a chilly and severing winter, and a warm, humid rainy seasons. It receives an annual normal rainfall of 1207.0 mm. The maximum temperature in the region varies from 40 °C to 45 °C during the summer. The weather data, such as daily maximum and minimum temperature, daily maximum and minimum relative humidity, daily wind speed, and bright sunshine of duration three years from 2020 to 2022, were collected from the meteorological observatory located in the campus of SHUATS, Prayagraj, Uttar Pradesh, and used for the computation and validation of solar radiation.

2.2 FAO-56 Model of Solar Radiation Estimation

The Food and Agriculture Organisation developed equation to estimate solar radiation was used and is written as [2]:

$$R_S = \frac{180}{\pi}\left[\omega_s \, Sin(\delta)\, Sin(\varphi) + Sin(\omega_s)\, Cos(\delta)\, Cos(\varphi)\right] G_{SC} d_r \left(1 + \frac{2\,n}{N}\right) \ldots (1)$$

Where, ω_s is the angle of sunset hour (radian), φ is the latitude of the location (radian), δ is the solar declination (radian), G_{SC} is a solar constant (0.082 MJ/m^2/min), d_r is the inverse relative distance between the sun and the earth, n is the actual duration of bright sunshine (hr), and N is the maximum possible duration of bright sunshine (hr) over the area.

2.3 Statistical Approach of Validation

Statistical analysis based on error quantification and association between the simulated and CROPWAT estimated solar radiation was used to test the goodness-of-fit. Mean absolute error (MAE), mean bias error (MBE), root mean square error (RMSE), Willmot index of agreement (d), Pearson correlation coefficient (PCC), and Nash-Sutcliffe efficiency (NSE),were used to quantify the error between them. Moreover, following the suggestions of [6], the slope (*m*) and the intercept (*c*) of the straight line fitted to the observed and the simulated series of reference evapotranspiration were used as evidence of closeness between them.

3. RESULTS AND DISCUSSION

The daily estimates of solar radiation (R_S) were simulated using weather observations over the study area, and the performance of the simulation was evaluated by comparing the simulated solar radiation with that determined by CROPWAT version 8.0, a decision-support tool developed by the Food and Agriculture Organization. It assists to agricultural planners, engineers, and water managers in the calculation of crop water requirements and the planning of irrigation schemes. CROPWAT helps to optimize the use of water resources in agriculture by integrating various climatic, crop, and soil data.

The solar radiation reaching over the region was computed using eq. No. (1) using weather data for a period of three years from 2020 to 2022. The same parameters were estimated using CROPWAT for the same period of three years from 2020 to 2022 over the region. The general characteristics of the simulated and CROPWAT determined solar radiation over the study area were computed to compare and presented in Table 1.

Table 1 :General statistics of simulated and CROPWAT determined solar radiation over the study area during the year 2020-22.

General Statistics	Simulated R_S	CROPWAT R_S
Minimum (MJ/m2/day)	5.59	5.60
Maximum (MJ/m2/day)	24.94	24.50
Mean (MJ/m2/day)	17.56	17.53
Std. (MJ/m2/day)	4.71	4.67
CV	0.27	0.27

The daily simulated minimum and maximum amount of solar radiation of 5.59 to 24.94 MJ/m2/day, respectively were observed over the region during the years while that estimated by using CROPWAT were 5.60 to 24.50 MJ/m2/day, respectively over the region. The average daily solar radiation reaching over the region was simulated 17.56 MJ/m2/day against the CROPWAT determined value of 17.53 MJ/m2/day during the year. The minimum variability in daily solar radiation amounting to 0.27 which was same in both the series *i.e.* simulated and CROPWAT estimated daily solar radiation were noticed over the region (Table 1).

The high agreement between these two series determined during the year was clearly depicted by visualising the plotting the values of simulated and CROPWAT estimated solar radiation on daily time scale which was shown in Fig. 1. During the winter season in which January is the coldest, the minimum solar radiation reaching over the region were observed to besimulated as 5.59 MJ/m^2/day while that of CROPWAT determined was noted to be 5.83 MJ/m^2/day during the year. The normal simulated value of solar radiation during winter season was found to be 13.52 MJ/m^2/day while that of CROPWAT simulated was 13.48 MJ/m^2/day. Whereas, the highest values of solar radiation were found to be 19.87 MJ/m^2/day during simulation and that of CROPWAT determined was 19.70 MJ/m^2/day was estimated during the winter season of the years of study (Fig. 1).

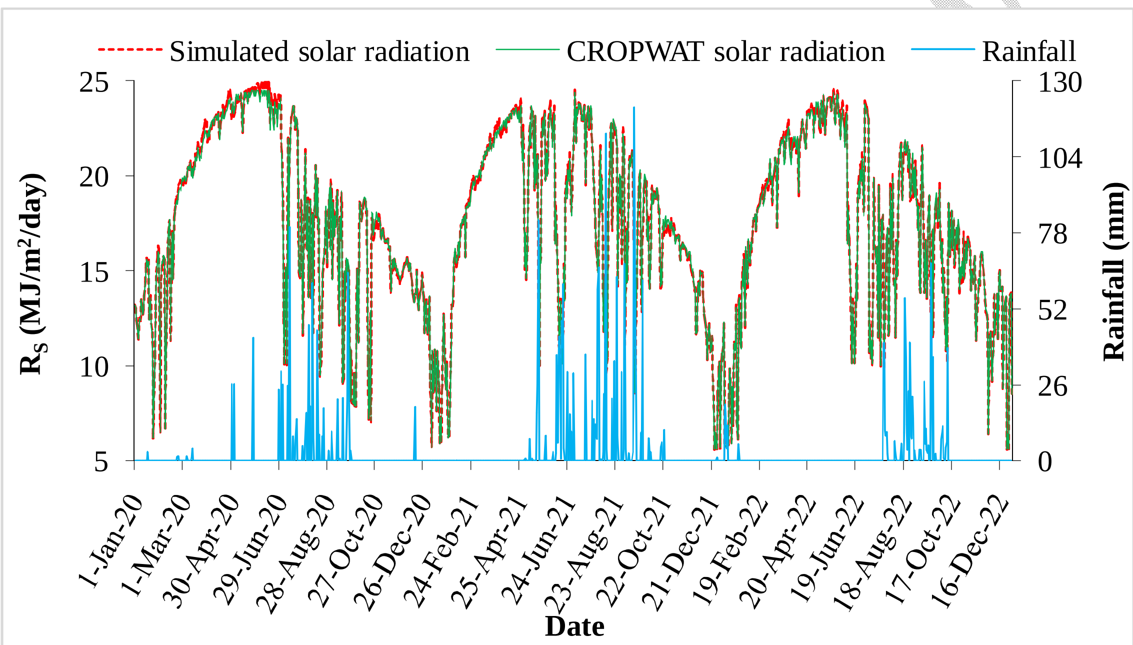

Fig. 1: Daily time series of simulated and CROPWAT estimated solar radiation during the years from 2020 to 2022 over the study area.

However, the value of solar radiation reaching over the region attains a peak value of 24.48 MJ/m^2/day and 24.20 MJ/m^2/day which are simulated and CROPWAT estimated values, respectively during the summer season and generally fall on mid of June, after which it is observed fluctuating due to the presence of cloud (Fig. 1).

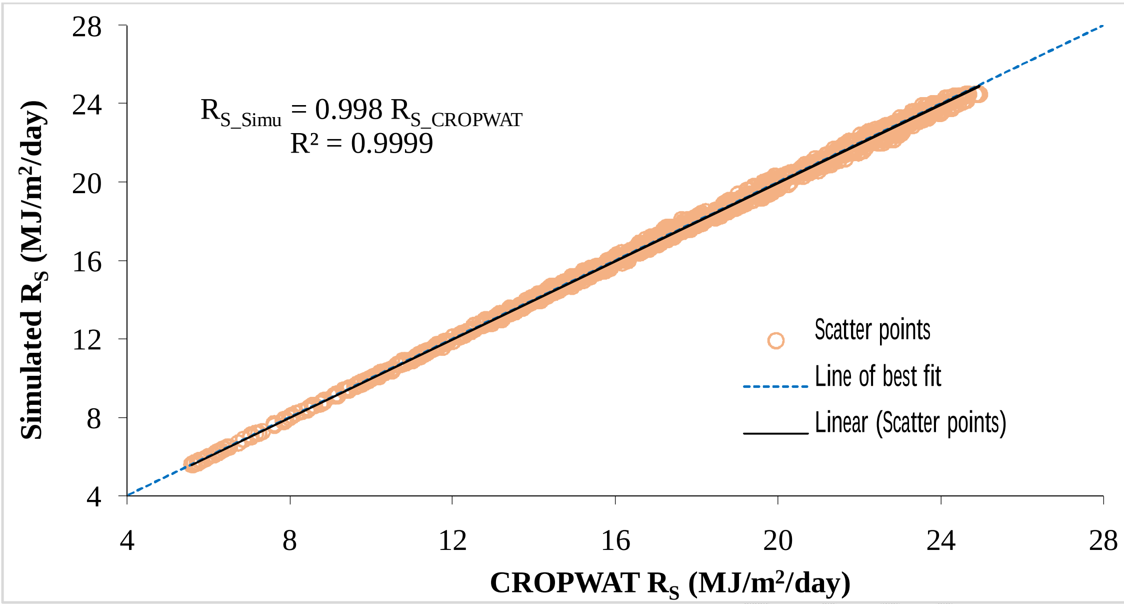

Fig. 2: Scatter plot between simulated and CROPWAT determined daily solar radiation during the years from 2020 to 2022 over the study area.

The scatter plot between simulated and CROPWAT determined daily solar radiation was plotted and shown in Fig. 2. The extremely high value of correlation (R2 of 0.9999 □ 1.0) between them was observed during the analysis of the results. The slope of linear trend line fitted between simulated and CROPWAT determined daily solar radiation was noted to be 0.998 which is near 1.0 show that it is in very close agreement of line of best fit drawn on slope of 1:1 (Fig. 2).

The errors between simulated and CROPWAT determined daily solar radiation was quantified in terms of MAE, MBE, and RMSE, and linear association between them was determined in terms of d, NSC, and PCC during the year 2020-21 over the study area and plotted in Table 2. The lesser values of MAE, MBE, and RMSE were found to be 0.138 MJ/m2/day, -0.024 MJ/m2/day, and 0.182 MJ/m2/day, respectively, whereas very high values of d, NSC, and PCC of 1.0, 0.999, 0.998, respectively were seen during the error analysis (Table 2).

Table 2: Error statistics between simulated and CROPWAT estimated solar radiation during the years from 2020 to 2022 over the region.

MAE ($MJ/m^2/day$)	MBE ($MJ/m^2/day$)	RMSE ($MJ/m^2/day$)	d	NSC	PCC

0.138	-0.024	0.182	1.000	0.999	0.998

4. DISCUSSION

Results and thereby its analysis reveals the high degree of similarity between simulated and CROPWAT determined daily solar radiation computed during the year 2020-21 over the study area.Very high values of Willmot index of agreement (1.0), Nash-Sutcliffe efficiency (0.999), and Pearson correlation coefficient (0.998)between simulated and CROPWAT determined daily solar radiation ensured the perfect agreement between them. Low values of mean absolute error (0.138), mean bias error (-0.024), and root mean square error (0.182)between them showed the very good agreement between simulated and CROPWAT determined daily solar radiation during the year 2020-21 in the region.

5. CONCLUSION

Results revealed the very good simulation of daily solar radiation during the year 2020-21 over the study area.Low values of mean absolute error, mean bias error, and root mean square erroralong with very high values of Willmot index of agreement, Nash-Sutcliffe efficiency, and Pearson correlation coefficientbetween simulated and CROPWAT determined daily solar radiation ensured the perfect agreement between them over the region. The minimum (January) solar radiation reaching over the region were observed around 5.71 MJ/m^2/dayduring winter season with a normal value of 13.50 MJ/m^2/day, while the maximum (June) value of 24.5 MJ/m^2/day was observed during the summer season with a normal value of 24.13 MJ/m^2/day over the region.

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